Climate Change Management

Walter Leal Filho · Franziska Mannke
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Dinesh Surroop *Editors*

Climate-Smart Technologies

Integrating Renewable Energy and Energy Efficiency in Mitigation and Adaptation Responses

Springer

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Prepared as part of the project "Small Developing Island Renewable Energy Knowledge and Technology Transfer Network" (DIREKT), funded by the ACP Science and Technology Programme, an EU programme for cooperation between the European Union and the ACP region.

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ISSN 1610-2010 ISSN 1610-2002 (electronic)
ISBN 978-3-642-37752-5 ISBN 978-3-642-37753-2 (eBook)
DOI 10.1007/978-3-642-37753-2
Springer Heidelberg New York Dordrecht London

Library of Congress Control Number: 2013936955

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

Climate change is regarded as having the potential to derail the good efforts that countries have undertaken for decades to overcome poverty and boost growth. Moreover, in countries with the possibility to seize renewable energy sources, overall socio-economic development is impaired if a large share of the gross domestic product is spent on imported fuels.

Climate-smart technologies such as the use of renewable energy is, for example, of great relevance for the socio-economic development of countries in the Africa–Caribbean–Pacific (ACP) region, especially in Small Island Developing States (SIDS), as to date these vulnerable islands heavily depend on (imported) fossil fuels to meet their energy needs.

Apart from the environmental benefits and the fact that it concretely contributes to mitigate climate change, the local generation and use of renewable energy can offer many benefits for improving economic development (e.g., a wide range of local job opportunities, from high-skill to low-skill, and from high-tech to agriculture) as well as foster investments and reduce energy imports. Moreover, introducing non-fossil energy provision may foster the often low adaptive capacity of the local population to withstand the future challenges of climate change, to which SIDS are particularly vulnerable. Although renewable energy provisions today reach many distant regions, local actors are still lacking expertise and capacity-building is difficult due to limited access to the latest technologies and knowledge, especially in ACP Small Island Developing States.

In order to address the perceived need for a publication which looks at both, climate-smart technologies and the integration of renewable energy and energy efficiency in mitigation and adaptation responses, this book has been produced.

This reference book is based on a set of truly international contributions, provided from two main events. The first is the "International Conference on Technology Transfer and Renewable Energy 2012" held in Mauritius on 21–22 June 2012. The second source is the fifth online climate conference (CLIMATE 2012), held on 5–9 November 2012. Both initiatives were undertaken as part of the project "Small Developing Island Renewable Energy Knowledge and Technology Transfer Network" (DIREKT), funded by the ACP Science and Technology Programme, an EU programme for cooperation between the European Union and the ACP region. DIREKT partners are the Hamburg University of Applied

Sciences (Germany), the University of Mauritius (Mauritius), the University of the West Indies (Barbados and Trinidad and Tobago), and the University of the South Pacific (Fiji).

This book is divided into three main parts. Part I (Climate Change Trends and Strategies) focuses on papers handling matters of strategic nature such as political frameworks and policies, paying special attention to social and economic issues. Part II (Renewable Energy Strategies and Methods) contains a set of papers which deal with technical aspects of energy efficiency and renewable energy use on the one hand, and their strategic nature in energy security on the other. Part III (Climate-Smart Energy Technologies) looks at technologies which may assist with climate change mitigation and adaptation on the one hand, but which also deliver multiple benefits on the other, especially in respect of food security and development benefits.

A unique feature of this publication is that it introduces a variety of concrete projects, initiatives, and strategies currently being undertaken and implemented across the ACP region and beyond, showcasing concrete examples of how new technologies as a whole, and renewable energy in particular, can assist island nations in meeting the challenges climate change pose to them.

We hope this book will prove useful to all those interested in the connections between climate change mitigation, adaptation, and technology transfer in small island developing States.

I want to thank all authors for sharing their know-how, the co-editors, as well as Dr. M. Sima, Ms. F. Rivas, and Mrs. J. Babir for their support in producing this book.

Enjoy your reading!

Walter Leal Filho

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Chapter 1
An Overview of Climate-Smart Technologies in the Pacific Region

Pritika Bijay, Veronika Schulte and Shivneel Prasad

Abstract The Pacific Island Countries (PICs) are especially vulnerable to problems associated with climate change (CC), which is considered as one of the greatest risks to the people of the PICs. This poses a threat to the livelihoods, security and welfare of the people in the Pacific. PICs are considered to be one of the lowest contributors of factors contributing to climate change, yet they are the most vulnerable to the impacts of CC. Therefore, it becomes extremely important that PICs develop ways to adapt to and address the impacts of CC with climate intelligent technologies. Renewable energy (RE) has a large potential to displace emissions of greenhouse gases resulting from the burning of fossil fuels, and thereby to mitigate climate change. This paper gives an overview of climate intelligent technologies in the Pacific, and it goes into detail with some concrete examples. Although it is believed climate intelligent technologies cannot solve all the climate problems of PICs, it can help them to achieve a certain level of economic and social development that will be very beneficial for the Pacific. The present paper is based on the experiences gained by the "Small Developing Island Renewable Energy Knowledge and Technology Transfer Network (DIREKT)", which is a cooperation scheme involving universities from Germany, Fiji, Mauritius, Barbados, and Trinidad and Tobago. The aim of this project is to

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_1,

strengthen science and technology capacity in the field of RE of a sample of African, Caribbean and Pacific (ACP) small island developing states, by means of technology transfer, information exchange and networking. The project is funded by the ACP Science and Technology Programme, an EU programme for cooperation between the European Union and the ACP region.

Keywords Pacific island countries · Climate change · Climate intelligent technologies · Renewable energy

Short Introduction

Climate change (CC) has been identified as one of the greatest challenges faced by any nation, including the Pacific Island Countries (PICs). Threats associated with CC have lead to many nations looking for ways to reduce their impact. Although PICs are considered one the lowest contributors of CC, they are currently heavily reliant on fossil fuels to meet their energy demand (IPCC 2007 and Prasad 2009). Together with this, the diverse geographical nature of the PICs makes it difficult and expensive to transport fuel and other basic necessities (SPC 2011).

To increase their energy security, and at the same time lower their greenhouse gas (GHG) emissions, the PICS are increasing the share of Renewable Energy (RE) in their energy mix. Furthermore, for PICs with not many RE resources, energy efficiency (EE) measures are a solution. Both of these become synonymous with a reduction in GHG emissions, and an important tool for CC mitigation.

Climate Change and the Pacific Island Countries

Despite their diverse physical and socioeconomic features, the PICs share many common issues, with one major issue being how to face the challenges of CC. PICs face devastating and urgent consequences from sea level rise, to more frequent and stronger storms, to the changing distribution of disease vectors. The PICs account for less than 0.1 % of global GHG emissions, due primarily to their relatively small population, limited industrial activity, and underdeveloped energy services (ADB 2010), yet the consequences of CC are obviously inconsistent with their contributions to GHG emissions globally.

CC poses a threat to the livelihoods, security and welfare of the people of the Pacific. The Pacific Island Forum Leaders have stated that if the issue of CC is not immediately and successfully addressed, its impacts will result in severe damage, undermine security and undo progress towards the achievement of national priorities and the Millennium Development Goals (MDGs) in the Pacific. Many countries worldwide are developing and implementing initiatives in order to limit and mitigate GHGs' concentration in the Earth's atmosphere. Concerns for sustainable development, with emphasis on mitigating CC, have lead to concentration on RE and EE. RE sources are not only abundantly available resources, but also provide energy without the emission of GHGs. Similarly, the use of more energy efficient appliances also lowers the emissions of GHGs. Therefore, RE and EE play an important role as tool for CC mitigation.

RE plays an important role in providing energy in a sustainable manner, such as from resources occurring naturally in the environment, and can be replenished in a short period of time. Some examples of RE include, solar, wind, hydro, geothermal, biomass, ocean and hybrid power. On the other hand, EE refers to using less energy to achieve the same task. An example of EE would include using energy-saver lamps (compact fluorescent lamp) instead of incandescent lamps.

CC results from activities such as the burning of fossil fuels, deforestation, industrial activities and any other activities which results in the release of GHGs into the atmosphere. The World Bank warns (WB 2000) that the impacts of CC in PICs are likely to result in a decline in ground water quantity and quality, reductions in agricultural output, significant health impacts (such as increased diarrhoea, dengue fever and fish poisoning), extensive damage due to storm surges and lowered fish production. According to a report prepared by Wade et al. (2005), the Federated States of Micronesia (FSM), Kiribati, the Marshall Islands, Tokelau and Tuvalu are among the countries predicted to endure the greatest impact of CC—including the disappearance of some islands in the worst-case scenario.

Therefore, if PICs are to lower their GHG emissions, adopting RE and EE measures is one option. In a worldwide context, emissions from the PICs are remarkably low, but, on a per-capita basis, many of the PICs are significant emitters (Wade et al. 2005). Hence, as the World Bank (WB 2000) has stated, the future well-being of the Pacific Island people is dependent on choosing a development path that decreases the islands' vulnerability to climate events and maintains the quality of the social and physical environment.

Current and Future Energy Scenarios in the Pacific

The PICs are heavily reliant on fossil fuels to meet their energy demands, even though great potential exists for them in the form of RE (Jafar 2000; Marconnet 2007). Currently, more than 90 % of the PICs' energy demand sare met by the use of fossil fuels alone, with the lowest energy security of a month to be found in the Cook Islands (Oberender 2010). Diversifying their energy needs is the only way for the PICs to improve their energy security at the same time as lowering their carbon footprint. Approximately 25 % of fossil fuel imports in the PICS are used for power generation, with the other 75 % used for transportation (air, water and land) (Gielen 2012). PICs are starting to realise the true potential of RE to meet their energy demands, with Fiji and Samoa leading the way (Marconnet 2007).

In 2009, 99 % of the Cook Islands' energy demands were met by the use of fossil fuels alone, consisting of 12.7 million litres of diesel (7.2 million litres for electricity generation alone), 4.2 million litres of petrol and 9.7 L of kerosene. A minority of 0.03 % of energy demand was met by renewable, a PV and grid connected wind system (40 kW) on Mangaia plus some Solar Home Systems (SHS) on Pukapuka (SPC 2012a).

Nauru's energy demands in 2009 were mostly met by fossil fuels, accounting for a massive 99.95 %. The imported petroleum mix consisted of 11.7 million litres of diesel and 2.2 million litres of petrol. In addition to that, 9.45 t of liquid petroleum gas (LPG) were imported for household cooking, while there was a minute use of biomass. In 2009, 17 GWh of electricity were generated in Nauru, of which only 0.3 % (accounting for only 0.05 % of total energy demand) was accounted for by renewables; this was supplied by a 40 kW grid connected PV system at Nauru College (SPC 2012b).

Similar to Nauru and the Cooks, Niue's energy demands in 2009 were mostly met by the use of fossil fuels (estimated at 99 %) (SPC 2012d). Of this 99 %, 1.2 million litres was diesel (60 % used for electricity generation), 532,000 L was petrol and 25.8 t was LPG. Prior to 2008, cooking and water heating accounted for the majority of electricity consumption, which was greatly reduced by the introduction of solar hot water systems and LPG stoves, an initiative of the REP-5 Programme. Approximately 0.3 % of Niue's energy consumption is met by renewables. The renewable portion of energy production is mainly met by three grid connected systems (52.5 kW) installed as an initiative of REP-5 Programme.

Approximately 91 % of Fiji's energy demand is being met by a net import of 259 million litres of diesel, 58 million litres of petrol, 191 million litres of kerosene and 16 kt of LPG. The transport sector accounts for the most major use of fossil fuel imports, accounting for approximately 70 % of the energy demand (SPC 2012c). The electricity sector mostly met its energy demands using hydro, which accounted for approximately 55 % of electricity generation in 2011, with a contribution of 1 % by wind and 4 % by independent power generators respectively (FEA 2012). The rest was met by diesel, which accounts for the 30 % of total energy demands. Unfortunately, only 72 % have access to grid connected electricity, while the rest are provided power by the Public Works Department and Fiji Department of Energy's rural electrification units. This is achieved by the installation of diesel and microhydro in-grid systems, and SHS.

In Kiribati, petroleum products met approximately 75 % of energy demands, with 25 % being met by biomass and an insignificant amount, of less than 1 %, being met by solar (Mala 2008). Similarly, the Federated States of Micronesia (FSM) meet their energy demands with approximately 85 % petroleum, 14 % solar and less than 1 % solar (Wade et al. 2005). Energy demands in Samoa consisted of 70 % for transport, 20 % for power and the remaining 10 % in the commercial, agriculture, forestry and fishery, and residential sectors. In 2009, this electricity generation consisted of 58 % diesel, 41 % hydro, 1 % biofuel and about 0.01 % solar (Energy Unit 2010). Tonga meets 75 % of energy demands with fossil fuels, with the significant amount of 25 % from biomass and off-grid solar.

Before the opening of the grid connected PV system in Tonga, almost 100 % of Tonga's electricity generation was from fossil fuels alone (TERM 2010). Data for rest of the countries are limited; however, reports compiled as part of the Pacific Islands Renewable Energy Project in 2004 indicate that PICs are heavily reliant on fossil fuels to meet their energy demands (Wade et al. 2005).

PICs mostly utilise RE for electricity generation and, as such, to move towards a more energy secure future. Targets have been set to increase RE contribution to electricity generation in the near future (Table 1.1). Targets range from a low of 20 % to a maximum of 100 % to be met by the PICs by 2020.

Renewable Energy Technologies in the Pacific

RE technologies, such as solar, wind or hydropower, have the potential to reduce emissions. Most of the PICs possess RE resources in abundance as seen in Table 1.2.

The main RE sources of interest to the Pacific are solar water heating, solar PV, hydro, wind, biomass, and biofuel (Syngellakis 2012). Other sources that are also possible are biogas (not proven in PICs), geothermal (remote and very capital intensive) and hybrid. Wave and ocean energy could also be possible in some of the countries, although they are currently at the experimental stages of development.

Table 1.1 Current and projected targets for RE electricity generation by PICs (*Source* Gielen 2012)

Countries, territories and associated sates	RE electricity generation (% of Total)	RE targets % of Total	years
Cook Islands	<1	50	2015
		100	2020
Fiji	75	90	2015
FSM		Urban 10 and Rural 50	2020
Kiribati	<1	10	ND
Marshall Islands	1	20	2020
Nauru	< 1	50	2015
Niue	3	100	2020
Palau	3	20	2020
PNG	46	No target set	
Samoa	42	+20	2030
Solomon Islands		50	2015
Tokelau	1	100	2012
Tonga	<1	50	2012
Tuvalu	25	100	2020
Vanuatu	19	25	2012

Table 1.2 Resource potential in the PICs (Johnston 1995)

Country	Solar	Wind	Biomass	Hydro	Geothermal	OTEC	Wave
Cook Islands	✓✓✓	✓✓	✓✓			✓✓	✓
Fiji	✓✓	✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓	✓✓
FSM	✓✓	✓	✓✓	✓✓	✓✓	?	?
Kiribati	✓✓✓	unlikely	✓			✓✓	?
Marshall Islands	✓✓✓	✓	✓			✓✓	?
Nauru	✓✓✓	unlikely	✓			✓✓	?
Niue	✓✓✓	✓✓	✓			?	?
Palau	✓✓✓	✓	✓✓			?	?
PNG	✓✓	✓✓	✓✓✓	✓✓✓	✓✓✓	?	?
Samoa	✓✓	✓✓	✓✓	✓✓	✓✓	?	?
Solomon Islands	✓✓	✓✓	✓✓✓	✓✓✓	✓	?	?
Tonga	✓✓✓	✓✓	✓			?	✓✓
Tuvalu	✓✓	unlikely	✓✓			?	?
Vanuatu	✓✓	✓✓	✓✓✓	✓✓✓	✓✓✓	?	?

Hydro

Hydropower is an RE source, where the power is derived from water sources. This technology has the best conversion efficiency of all energy sources, while also being a proven, mature, predictable, as well as typically price-competitive, technology (Kumar et al. 2011). In the PICs, hydropower has also proved to be one of the best sources of energy, especially in the high islands. Hydropower is the main source of electricity generation in Fiji, while in French Polynesia, New Caledonia, Papua New Guinea (PNG), Samoa, the Solomon Islands and Vanuatu, it is the second largest source (Marconnet 2007). Details of some of the hydropower schemes are provided below, and have been adapted from Wade et al. (2005).

- PNG's power utility commissioned 162 MW of hydro at eleven locations between 1957 and 1989. A 63 MW system was installed in Port Moresby, 87 MW in Ramu in the highlands and 12 MW in New Britain. Altogether, there is about 220 MW of installed capacity. The government also commissioned three micro-hydro systems between 1988 and 1992 with a capacity of 300, 60, and 100 kW.
- The Fiji Electricity Authority (FEA) commissioned an 80 MW hydro system in the interior of Viti Levu in 1983 and a 0.8 MW scheme at Wainikeu in Vanua Levu in 1992. Between 1930 and 1999, seven small hydropower stations (3–100 kW) were built. A 3 MW hydropower scheme also exists in Nagado in

Viti Levu and a 40 MW at Nadarivatu is expected to be commissioned by end of 2012 (FEA 2012).

- In Samoa, between 1959 and 1992, eight hydro systems have been built at five locations in Upolu, with a total capacity of 12.2 MW. All of these are run-of-river systems, except the largest system (Taelefaga with two 2 MW turbines).
- In the Solomon Islands a 185 kW scheme was built at Buala on Santa Isabel in 1996, which provides electricity to a hospital, a school, a store, fish storage and houses. In 1983 and 1994 two small (10–12 kW) microhydro schemes were constructed in Kolombangara in the Solomon Islands, at Iriri and Vavanga villages respectively, through an Australian development organisation, APACE. A 75 kW microhydro Pelton turbine was installed in 1976 serving a church mission and health centre at Atolifi on Malaita. Currently, there are also operational hydro systems at Manawai (50 kW), Bulelavata (29 kW) and 25 kW system at Raeao (JICA 2009).
- Vanuatu's only experience with hydropower has been the Sarakata system, consisting of two 300 kW turbines which have been used for baseload at Espiritu Santo island and produced on average about 4.5 GWh per year since early 1995.

There is also an existing 2.06 MW hydro facility, though limited to 1.8 MW due to intake restrictions, at Pohnpei in FSM (Wade et al. 2005). There is some potential for hydro in other PICs, although it is limited.

Wind

Wind power is the fastest growing RE technology globally, accounting for 40 % of new RE capacity last year (REN21 2012).Generation from wind is currently negligible due to the low installed capacity in the PICs; however, with proper assessment of wind potential and ability to harness the resource, more potential could be realised in the PICs (Singh 2012a). Electricity generation from wind is the basic conversion of the wind's kinetic energy into electrical energy using wind turbines. Wind resource assessments are currently being undertaken by governments and research organisations in the PICs. Out of all the countries in the PICs only the Cook Islands, Fiji, Vanuatu, New Caledonia, French Polynesia, Hawaii and PNG utilise wind for electricity generation (Marconnet 2007; Andrieu and Pesnel 2006).

Fiji's first wind farm in Butoni, as seen in Fig. 1.1, was commissioned in 2007, with an installed capacity of 10 MW. At the end of 2011 the Butoni wind farm had generated approximately 26.3 GWh of electricity, generating 4.98 GWh in 2011, accounting for fuel savings of approximately FJD 2.13 million (FEA 2012). With a predicted generation capacity of 50 GWh annually, seven wind farms are spread over four locations in Vanuatu, accounting for an installed capacity of more than 25 MW (Andrieu and Pesnel 2006). Approximately 80 kW of wind have been

Fig. 1.1 Butoni wind farm in Fiji

installed in PNG; however, in 2010 they were only used for trial purposes (Tai 2010). The Cook Islands have also had their first experience with wind generation, installing two 20 kW wind turbines; however, they failed due to mechanical failures (Zieroth 2006). A Danish study carried out indicated viability of wind with wind speeds ranging from 6–7.5 m s^{-1} at a hub height of 30 m; however, greater emphasis needs to be placed on operation and maintenance to make it work (SPC 2012a).

Viability of wind power at lower latitudes around the PICs is non-existent, with potential increasing for countries at higher latitudes (Wade et al. 2005), making smaller wind systems better for power generation, however, data need to be compiled properly to obtain the true potential of installed wind power in the PICs.

Solar

Solar energy is the main source of energy from which all other renewables are derived. The PICs' location, in regards to the equator, makes it possible to use solar energy in the form of solar thermal or for electricity generation via use of photovoltaic (PV) panels (Jafar 2000; Woodruff 2007).

Solar thermal is mostly used to heat water in the PICs and most of the technology is imported from abroad, with Fiji, Tonga and PNG having domestic small scale manufacturing (Wade et al. 2005). Due to the easy nature of installation and use, the uses of solar thermal installations are diverse, though they are mostly used in homes and hotels, or wherever hot water is required in large amounts, which would offset the installation costs (Miller et al. 2012).

On the power generation side, PV was a bit slow to develop in the PICs due to the initial high costs of installations. However, with costs going down and the rise in the prices of fossil fuels, some of the PICs have turned to PV for power generation, either using large grid-connected systems or small home systems (SHS).

SHS was the first to be initiated in the PICs, since grid power was unavailable to most of the islands. Several thousand homes have been provided with access to electricity for their basic needs using SHS since 1995 (Wade et al. 2005).

Kirbati had the most successful SHS scheme, with a total of more than 2000 SHSs installed (Akura 2004). There are various PV initiatives, as well as installed systems, around the PICs (www.sprep.org). These include the 500 plus SHSs in Tonga, with a total of 42 already installed, with a capacity of 160 W. In Tuvalu, two grid connected systems were in operation, 46 kW in Motufoua and 40 kW in Fongafale, which were able to save around 6,143 L of fuel. Also highlighted, was that schools and homes in the Solomons and Kiribati were using PV (SHS systems plus grid standalone) systems to meet their basic energy needs, such as lighting and water pumping, with more being installed in the second quarter of the year (www.sprep.org).

In Vanuatu, SHS systems have been funded by the Japan International Cooperation Agency (JICA), ranging from small systems of 40–100 W with battery storage of 70–100 Ah, enough to provide electricity need for 8 or 15 W lights respectively (Chow 2010). Chow (2010) also stated that there were many rural community institutions in Vanuatu that had standalone solar power systems ranging from 80 to 400 W, with the majority of the systems below 300 W.

The Electric Power Corporation in Samoa successfully installed a self-sufficient 13 kW PV power system on Aplomia Island, demonstrating the environmentally friendly standalone PV system (www.epc.ws). In Fiji, two grid connected systems have come online, the first in 2011, a 12 kW pilot project in Lautoka (Nanjangud 2012). The second is a 45 kW system, as seen in Fig. 1.2, commissioned in February 2012, constructed at the University of the South Pacific's lower campus. The systems have a dual purpose: to generate clean energy, and at the same time to serve as training ground for aspiring graduates.

Tonga has the PICs' largest grid connected PV system at a rated peak power of 1.3 MW, commissioned in July 2012. The system is predicted to meet at least 4 % of Tonga's energy demands at the same time avoiding CO_2 emissions of up to 2,000 t per year.

As part of the REP-5 programme, the FSM, Nauru, Niue, Palau and the Marshall Islands, have directly benefited by having grid connected and standalone PV systems installed at various sites to provide electricity to schools, hospitals and

Fig. 1.2 45 kW grid connected PV system in Fiji

airports, whilst at the same time providing smaller systems to homes to cater for their basic energy needs (REP-5 2010).

Tokelau is about to implement grid connected PV in September 2012 on three of its atolls Fakaofo, Nukunonu and Atafu. The system will boost Tokelau's RE capacity from almost nil to around 90 %, reducing their dependency on fossil fuels, as well as saving 12,000 t of CO_2 emissions over its lifetime (Pacnews 2012).

Geothermal

Geothermal resources consist of the thermal energy from the Earth's interior, stored in both rocks and trapped steam or liquid water (Arvizu et al. 2011). This energy can be used to generate electrical energy in a thermal power plant or in other domestic and agro-industrial applications requiring heat, as well as in CHP applications. PNG, Fiji, Samoa and Vanuatu have known geothermal resources, while the Solomon Islands probably also have geothermal resources. The only known operating geothermal plant in the Pacific is in PNG. Lihir Gold Mine in the West New Britain Province is powered with a 53 MW geothermal plant (JICA 2009).

Biomass

Traditional biomass has been in use in the PICs since ancient times and is still being used as fuel wood for cooking, heating and electricity generation, accounting for nearly half of energy consumption in the PICs (Jafar 2000). There are a few plants around the Pacific that use biomass for purposes of electricity generation and transportation. Biomass for power generation has been utilised in Fiji, PNG, the Solomon Islands and Samoa (Wade et al. 2005, and www.sprep.org). Fiji has around 16 MW of electricity generation capacity from bagasse by the Fiji Sugar Corporation during the sugar harvesting season. Tropik Woods Fiji also provides electricity by using wood chips as fuel to run steam generators. Biomass accounted for the largest RE contribution towards Samoa's energy production in 2010. Biomass accounted for 41.11 kt of oil out of the 44.74 kt of oil of RE consumption (Government of Samoa 2012). RE contribution in Vanuatu is mainly by biomass; however, potential for power generation by wood chips in saw mills does not appear to be promising, with most of the waste product from them being used as firewood or compost (Johnston and Vos 2004). Kiribati's main RE contributor is also biomass which accounted for 25 % of energy demands in 2005 (Mala 2008).

Biofuels are derived from biomass and can be used for electricity generation or transportation. Singh (2012b) and Woodruff (2007) highlighted that coconut oil and ethanol could be used to replace fossil fuel imports in Fiji. Experience with biofuels has been limited in the PICS. However, in the past decade, interest in using biofuels has been increasing with rural electrification projects showing the viability of using coconut oil as a fuel substitute for diesel (Woodruff 2007). Biofuels show potential in replacing fossil fuels in the transport sector, as well as in electricity generation.

Energy Efficiency

EE measures improve the use of natural resources and fossil fuels, thus reducing emissions and easing pressure on land resources. EE projects are being implemented by a wide variety of project proponents in the public, industrial and commercial sectors. Certain activities in the Pacific have been carried out to demonstrate EE.

The REP-5 (2010) programme, implemented by the Pacific Islands Forum Secretariat (PIFS) and funded from the 9th European Development Fund (EDF9) focuses on RE and demand-side EE activities. Through this project Nauru, Niue, the Republic of the Marshall Islands, the Federated States of Micronesia and Palau through were involved in conducting some EE activities. Amongst these activities included, conducting energy audits, distribution of compact fluorescent lamps, installation of lockboxes on thermostats and purchasing energy efficient materials for a building. Apart from this, EE awareness campaigns have been conducted, and, in some PICs, EE has been included in the National Energy Policy document. Some PICs, such as Fiji, are also ensuring that energy efficient white goods are being imported by following Minimum Energy Performance Standards and Labelling. Currently, refrigerators with star ratings are being brought into the country, and the Fiji Government is also developing this scheme for other appliances. PICs that do not have the necessary RE resources are still able to reduce their GHG emissions through EE measures.

Climate Change Mitigation Initiatives

CC mitigation efforts in the Pacific are being directed at reducing fossil fuel use, developing RE, improving EE and reducing GHG emissions. According to the International Energy Agency's (IEA) "BLUE" scenario, end-use efficiency accounts for 36–44 % of all reductions, and renewables account for 21 % (46 % of the electricity mix in 2,050) (United Nations 2010). This scenario is applicable globally, including in the Pacific, although it is one of the lowest contributors of climate change. Nevertheless, PICs are the most vulnerable to the impacts of climate change.

RE and EE have potential to reduce GHG emissions, and thus help PICs meet their commitments under the Kyoto Protocol and mitigate the effects of climate change. Reduction in the use of carbon based energy sources and reduced energy consumption in transport, construction, at home and at work will help prevent GHG concentrations in the atmosphere from reaching a dangerous level. Table 1.3 shows the potential GHG savings (ktons CO_2) for each RE resource in each PIC.

Currently, the Cook Islands, Fiji, Kiribati, Nauru, Niue, Papua New Guinea, Samoa, the Solomon Islands, Tonga, Tuvalu and Vanuatu are able to implement appropriate mitigation measures through RE activities under the Pacific Islands Greenhouse Gas Abatement through RE Project (PIGGAREP), extended to include Clean Development Mechanism (CDM) initiatives and EE as funds become available. The national assessments that were carried out under Wade et al. (2005) have identified Nauru, Niue, Palau, Samoa and Tuvalu as suitable for grid applications. Fiji, FSM, Kiribati, the Marshall Islands, PNG, the Solomon Islands and Vanuatu have shown large opportunities for both grid and off-grid applications. Tonga has potential for both on-grid and off-grid RE technology applications for rural electrification.

In order to mitigate GHG significantly, use of RE and efficient use of energy are absolutely necessary. For the Pacific, mitigating CC by using RE resources is possible, given the plentiful supply of some of these inexhaustible resources, like sunlight, wind, waves and the ocean etc. Similarly, incorporating EE measures can also help to mitigate climate change.

Table 1.3 GHG savings (kilo t of CO_2) for each RE resource in each PICs (*Source* Wade et al. 2005)

Country	Years	Geothermal	Hydro	Bio-diesel	Ethanol	Other biomass	Solar PV	Wind
Cook Islands	2013	0	0	2.6	0	0	2.1	6.3
Fiji	2010	43	818	4	27	17	1	19
FSM	2012	0	14.2	2.3	0	0	0.3	0
Kiribati	2013	0	0	20.8	0	0	3.7	
Marshall Islands	2013	0	0	7.6	0	0	0.4	0
Nauru	2013	0	0	0	0	0	2.8	0
Niue	2012	0	0	0	0	0	0.64	
Palau	2013	0	0	0	0	0	12	0
PNG	2011	333	691	113	430	Very small	9	10
Samoa	2013	12.8	40.2	27	0	0.3	2.5	1.1
Solomon Islands	2012	Low	31	75	0	2	3	1
Tokelau	2013	0	0	0.15				0
Tonga	2010	0	0	27	0	0	1.4	2.8
Tuvalu	2013	0	0	0.8				0
Vanuatu	2013	17	14	75.6	0	1	2	1

Conclusions

Despite being the lowest contributors of GHG, the PICs are the most vulnerable to CC. Thus, with the need to reduce emissions, the PICs need to play their part in either going green by implementing RE into their energy mix or becoming more energy efficient. The current energy scenario in the PICs indicates that they are heavily dependent on fossil fuels to meet their energy demand.

Thus, the PICs are making an effort, with the help of donor countries and other organisations, to incorporate RE into their energy mix. Some of the PICs are already showing great potential in incorporating RE into the generation of electricity. Hydro has shown great potential, with some of the PICs having it as the largest or second largest contributor to their electricity generation. Solar and wind have also shown great potential in terms of new RE in PICs, and solar is already growing steadily, with most countries having grid connected systems as well as SHSs installed to meet their electricity demands. Biomass has been widely utilised to meet energy demands, but mostly in the area of cooking or heating. Very little biomass has been used for power generation. Biofuels are also emerging to replace fossil fuels in the transport sector, as well as in power generation. A single geothermal power plant in PNG and well surveyed resources indicate good potential from geothermal, however, this needs to be further researched.

Apart from RE, EE has also helped in reducing GHG and the use of fossil fuels in the PICs. This has been achieved by trading less efficient appliances for efficient ones.

All of the above indicate that the use of RE and EE is essential, and has been practiced to mitigate GHG emissions. Previous and upcoming experience in the PICs show great potential for the PICs to mitigate CC by using RE or EE, or both at the same time, to reduce or meet their energy demands.

Combined with their experience and the lowering prices of RE technology, the PICs have set the target of being 100 % fossil free in electricity generation. The dramatic rise in fossil fuel prices, which has highlighted the low energy security of the PICs due to their geographical nature, resulted in looking at alternative energy sources to increase their security, this being energy derived from RE sources.

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Chapter 2
Climate Change Mitigation in Developing Countries Using ICT as an Enabling Tool

Abel Niyibizi and Alexander Komakech

Abstract ICT is envisaged to be an important tool in the communication of climate change mitigation technologies, which are necessarily of low carbon footprint in order to reduce GHG emissions. This paper, based on literature, illustrates how new and emerging ICTs will be applied in developing countries to mitigate impacts of climate change. It highlights some smart applications, like the smart grid, mobile phone, ICT-enabled technologies for energy efficiency and management, ICT-enabled smart technologies for transportation, land use change and forestry emissions mitigation, smart motors for enhancing carbon footprint reduction in manufacturing and smart buildings technologies. Detailed review and analysis of emerging economies, notably China and Brazil, were used to identify and recommend appropriate ICT-enabled climate change mitigation technologies. It concludes that while ICTs with low carbon footprints are potentially capable of mitigating impacts of climate change, there are existing constraints that these countries must overcome, including capacity building and ICT-embedded carbon-offset project financing. It is recommended that collaboration among policymakers, academia, research and business be enhanced, and capacity building could go a long way towards the realisation of this.

Keywords GHG emission reduction · Smart transportation · Smart buildings · LUCF · Optimisation · Capacity building · Mitigation technologies

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_2,

Short Introduction

This paper illustrates the importance of computer-based applications towards offsetting climate change impacts by explaining how these technologies can be used to reduce emissions of carbon dioxide into the atmosphere, thereby contributing to the reduction of greenhouse gases in the atmosphere. It explains how modern technologies that work with the use of a computer can reduce emissions in buildings, land, transport, manufacturing, farming and forestry, among others. It gives the basis for the use of computer technologies in the least developed countries and identifies the problems that need to be overcome for successful use of these technologies.

Background

Climate change mitigation is almost entirely centred around the application of technologies and processes that reduce the carbon footprint of these technologies and processes, thereby reducing greenhouse gas (GHG) emissions into the environment. Low-carbon technologies that apply information and communication technologies (ICTs) are envisaged to contribute towards climate change mitigation in developing countries where emissions have been steadily exacerbated due to their quest to race ahead in industrial and urban development. These countries also depend on agriculture as a major economic activity, especially for people living in the rural settings. They still use high carbon footprint technologies in energy applications and transport, and it is in these countries that high-carbon fossil fuels are still used intensively.

Agriculture has the potential to degrade the environment through land reclamation from forests and wetlands. GHG emissions from land use change and forestry degradation (LUCF) are still significant in developing countries, and so are emissions from energy systems, transportation, industrial motors, buildings and manufacturing, among others. These countries' contibutions towards GFHG emissions has steadily converged with thoseof developed countries, as the latter have painstakingly deployed technologies to offset GHG emissions. In light of the existing global reality of climate change and its aggravated impact, there is a need to reverse the trend of GHG emissions in developing countries, and ICTs have been proved to provide such opportunities.

This paper, based on a comprehensive review and analysis of existing literature, aims at disseminating some of the world's smart ICTs that, if properly implemented, will contribute significantly towards climate change mitigation. It underlines the fundamental ICT applications on per sector and highlights some of the constraints likely to be faced by developing countries during project implementation.

Materials and Methods

Comprehensive literature on ICT application to climate change mitigation was reviewed and then analysed in light of its applicability to developing countries where potential ICT deployment could be used for low-carbon growth and development. The areas with opportunity for ICT-enabled climate change mitigation were identified on the basis of the carbon footprints of developing countries. Of particular consideration were the key development needs of developing countries, as well as the existing challenges facing these countries. The paper also focuses on critical development issues by evaluating how ICT-enabled climate change mitigation can be applied to poverty alleviation through industrial development and the development of pro-poor solutions such as microgrids for poor remote communities. The paper elaborates on mitigation technologies by drawing lessons from emerging economies such as China, India and Brazil. This is expected to stimulate developing countries to reinvigorate their development strategies based on low-carbon development technologies by using success stories from the advancing emerging economies which in the near-past were not much different from typical developing countries in terms of economic and industrial development and technologies. It is envisaged that ICT-enabled climate change mitigation technologies will protect the climate while promoting economic growth and development.

Climate Change Challenges for Developing Countries

Developing countries have been lately found to be experiencing rapid growth andindustrialisation, thereby becoming major sources of greenhouse gas (GHG) emissions on a global scale (Roeth and Wockek 2011). GHG emissions from developing countries are increasing, while those from developed countries are decreasing—there is some convergence between the two types of economy, as the emissions from the former have hit the 50 % mark. The major sources are fossil fuels in energy consumption and the transportation sector. This has been exacerbated by the rapid rate of development, including accelerated industrialisation, of the developing countries. Although GHG emissions per capita in the least developed countries (LDCs) are comparatively low, they are also increasing due to rapid economic development; however, these countries still remain minor contributors to global climate change with only about 0.5 % of cumulative GHG emissions between 1995 and 2008 (UN-OHRLLS 2010). The majority of LDCs have emissions of less than 2 tCO_2e per capita, with Rwanda, for instance, exhibiting per capita emissions of only 0.3 tCO_2e, while Cambodia had 1.6 tCO_2e in 2008 (World Resources Institute 2009).

The main challenges facing developing countries as regards climate change mitigation is the low potential for financing projects focused on a low carbon footprint. The other challenge is that developing countries have contributed virtually insignificantly towards global climate change, and may thus find no reason to to put effort and funding into mitigation technologies in the first place. While ICT has been found to be an enabler of climate change mitigation and development, with the carbon offset by these technologies being much higher that of the technologies themselves, thereby making them highly feasible mitigators, there is still inadequate capacity to finance and develop infrastructure for ICTs in developing countries.

Developing Countries' ICT-Enabled Climate Change Mitigation: Opportunities for Development

The main focus of this paper in this aspect is to illustrate the potential of ICTs to help move towards a more sustainable low-carbon community, thereby mitigating environmental impacts and climate change using solutions that measure, monitor, manage and enable more efficient use of resources and energy. Very high potential for the realisation of this goal has been cited in infrastructure and systems for dematerialisation, transport substitution, energy efficiency and smarter lifestyles [see e.g. Roeth and Wockek (2011)].

ICT is envisaged to tackle climate change, and subsequent solutions are expected to create enabling environments for strategic development sectors, notably transport, construction, power and industry, for greater efficiency. However, measures should be taken to keep the carbon footprint of the ICT sector below that of the potential for ICT-enabled emission reduction, thereby realising positive costbenefits.

ICT has been predicted to have the potential to reduce emissions by 7.8 $GtCO_2e$ by 2020, from an assumed total of 51.9 $GtCO_2e$ under a business-as-usual (BAU) scenario, which is much larger than the ICT sector's carbon footprint (Roeth and Wockek 2011). This assertion justifies the potential of ICTs in climate change mitigation in developing countries if the barriers to their adoption could be broken.

ICT-enabled mitigation measures include:

- Dematerialisation: by replacing physical goods and processes with 'virtual' alternatives such as videoconferencing instead of travelling for meetings and conferences, electronic mailing, e-commerce and e-procurement.
- Machine-to-Machine (M2M) communications to enable a large share of GHG emissionsto be saved using process optimisation technologies like smart grids, smart logistics, smart buildings and smart motor systems (Roeth and Wockek 2011; Vodafone and Accenture 2009).
- Systemic impacts or behavioural effects, such as better consumption patterns that contribute to GHG emission reductions as a result of ICT applications.

Prospective ICT-Enabled Climate Change Mitigation Technologies for Developing Countries

Transportation

It has been estimated that the application of ICT-driven transportation has the potential to achieve total global GHG emission reductions of up to 1.52 $GtCO_2e$ (Roeth and Wockek 2011). ICT software systems can be designed to optimise the transportation system,there by saving large amounts of energy. Specific software solutions for intervention in the rapid urbanisation and congestion problems of urban areas in LDCs include internodal shifts, ecodriving, inventory reduction and software for the design and implementation of electronic vehicles. The last intervention suggests the application of electrical energy in transportation, while reverting from fossil fuel use thereby reducing the carbon footprint of the transportation sector. Other applications of electrical energy include systems integration in road traffic through the use of smart charging systems and vehicle-to-grid systems, vehicle navigation assistance using ICTs, electronic billing systems and electronic payment systems, as well as computerised fleet monitoring systems and mobility services (Roeth and Wockek 2011).

The electronic vehicle (EV) is of particular potential as an ICT-enabled climate change mitigation innovation technology that uses sophisticated software for managing information and electricity flow between the car, the end-user, battery manufacturers, electricity distribution agencies, grid operators and government regulatory authorities. Implementation of this will necessitate the amendment of industrial and transport policies, with the objective of regulating electronic vehicle development and manufacturing [see, e.g. AltTransport (2010)].

Smart Buildings

ICT is expected to help improve the efficiency of building design, construction and operation for existing and new buildings. ICT-enabled solutions in this sector should focus on energy intensity and surface area, through operations monitoring and optimisation throughout the building's lifecycle from design through to construction, use and decommissioning, while applications in building design optimisation can be implemented through energy modelling software. Emphasis here should also be on the greening of the whole building lifecycle using green architecture and energy efficiency.

Developing countries can apply building management systems, metering technology, environmental sensors, light-control systems, energy auditing/optimisation, software services, data loggers, and building optimisation software.

With the increasing shift from rural to urban settlement, there is a need for smart city solutions, including combined Geographical Information Systems (GIS) and Global Positioning Systems (GPS) solutions, for the development of a robust operation and maintenance plan for facility management, as well as optical fibre cable networks, and telecommunications infrastructure to promote e-governance applications, such as utility services management, facility management, security enablement, on-demand services, telemedicine, e-traffic management and online communities, including social networking and video services like teleconferencing.

These may, however, require a centralised information and communication hub (Lewis 2009; LCL 2009; UKCEED, not dated).

Decarbonisation of Energy Supply and Use

The world's energy needs are expected to grow by about 45 % from 2006 to 2030, largely in developing countries, which are still using carbon-intensive fossil fuels, and this necessitates new and smart measures for decarbonising energy supply and use. ICTs can be applied in energy generation applications, such as smart grids, that enable monitoring of power consumption and use over the electricity grid, thereby enhancing energy efficiency during distribution and use, with the possibility of increasing the use of renewable and non-GHG-emitting sources of energy.

ICT applications in energy and power transmission and distribution include remote sensing to monitor and measure energy use, remote grid element management and computerised energy accounting. These technologies are expected to enhance the monitoring of energy use across the grid and the tracing of energy loss hotspots. End-use ICT-enabled technologies will accelerate the transition to low-carbon communities using smart meters to regulate consumer patterns. Decentralised energy distribution is expected to enable renewable energies, such as solar micro-hydro sources, to be integrated into the grid for fast response to local power surges and shortages, thereby enhancing energy management.

Smart Micro-Grids for Remote Areas

The UN (2010) asserts that developing countries will need to expand access to reliable and modern energy services to reduce poverty and improve the health of citizens while increasing productivity, enhancing competitiveness and promoting economic growth. That developing countries experience energy poverty, leading to health-related consequences and deterrence of economic development and inefficient combustion of solid fuels in inadequately ventilated buildings,in turn leading to indoor air pollution, are critical issues of concern to the UN [see UN (2010)]. Insufficient power supply in developing countries like Uganda has led to the emergence of novel terminologies in the energy sector, including 'loadshedding', and this has significantly limited opportunities for productive income-generating activities, especially in the rural communities.

Strategies for accelerating access to power in remote areas include extension of the national grid, microgrid access and off-grid access using, for example, decentralised renewable energies like solar energy systems for households. Microgrids—which are small power systems that include self-contained generation, transmission, distribution, sensors, storage and energy management software with seamless synchronised connection to a utility power system—have been suggested as possible alternatives to the high energy poverty in the developing countries (Hertzog 2010) and they can also operate independently of the utility power system. In remote areas, this operates in a sort of island mode and contributes significantly to a secure energy supply at a reduced cost, and can also integrate renewable and less carbon-intensive energy sources available locally. ICT can be used to balance between generation and demand, and to optimise transmission and distribution of distributed energy generation and storage (Roeth and Wockek 2011). This will also enable integration of large amounts of fluctuating and decentralised renewable energy sources. ICTs can be used to communicate and disseminate the technologies through outreach programmes to encourage energy efficient behaviour, such as use of electricity meters.

Export-Manufacturing Emissions

Low-carbon development paths are the shared responsibility of developed and developing countries, though the former have contributed almost entirely to the GHG emissions that have caused global climate change and its adverse impacts. There is, need to develop and transfer low-carbon technologies from advanced to developing economies in order to reduce international trade-related emissions and support those in developing countries to catch up on the road to development (Roeth and Wockek 2011). ICT-enabled climate change mitigation technologies would still include optimisation of logistics and transportation systems, electrical vehicles, monitoring and operations management, fuel efficiency management, improved design of industrial and transport facilities, flexible home delivery services, M2M technologies and electronic commerce to improve operational efficiency, including onboard telematics, loading monitoring devices and tracking systems.

Land Use Change and Forestry Emissions

Land use change and forestry (LUCF) emissions, including deforestation, logging and intensive cultivation of cropland soils are the second largestglobal anthropogenic sources of GHG emissions, estimated at 15–20 % (Roeth and Wockek

2011). Deforestation, which is the largest driver of LUCF emissions, converts forests into agricultural land in developing countries, and this makes developing countries vulnerable to forest degradation, which contributes 30 % of all their GHG emissions (Roeth and Wockek 2011). The largest emitters, as cited in the existing literature, include Indonesia, Brazil, Malaysia, Myanmar and the Democratic Republic of Congo (DRC), in that order.

Box 1: Wetland Reclamation in Uganda

In the quest for accelerated urbanisation and industrial growth, Uganda has embarked upon the reclamation of wetlands. While wetland reclamation has not been cited as a major contributor to climate change, it is implicitly evident that it contributes to the destabilisation of the water cycle, and this impacts on the energy cycle (carbon footprint) due to the close nexus of water and energy and their closely intertwined impact on climate change.

Source: Adopted from National Environmental Management Authority (NEMA) 2011

The largest and most immediate carbon stock impact in the short-term can be realised by any mitigation measures that reduce or prevent deforestation (IPCC 2007). Thus, reducing emissions by 50 % in the next century has been anticipated to help prevent 500 billion tonnes of carbon from being released into the atmosphere per year (ITU 2010).

ICT-enabled mitigation in LUCF includes systems for monitoring land use change and deforestation, thereby enhancing data collection on forest conditions and remote sensing applications by taking images through clouds at night to monitor deforestation and illegal logging, as well as forest loss from road construction, agriculture and animal grazing (Roeth and Wockek 2011). ICT makes ground data collection more efficient and cost-effective, while remote sensing applications to LUCF are expected to enhance forest monitoring and resource management (SPIDER not dated), thereby overcoming the existing challenges of understaffing in forestry management in developing countries. Remote sensing data, however, need be complemented by ground data and geolocation information to ensure accuracy.

Smart phones can be used to facilitate data collection and timely processing and dissemination globally, as well as storage in a database or server for better land use planning and more informed land use decision making (Roeth and Wockek 2011).

ICTs will also enhance capacity building by increasing public awareness of critical environmental issues, as well as enhancing opportunities for staff development, stakeholder involvement and collaboration between the public and private sectors. It also creates opportunities for fast-tracking the mainstreaming of climate change mitigation and adaptation into education and policy enforcement, thereby empowering communities and increasing support for conservation.

ICT-enabled mitigation technologies for forestry management include software for forest monitoring using Radio Frequency Identification (RFID) labels, which in turn are readable by hand-held computer devices with data capture software to record information on each tree and transfer it to a central server via the Internet or a mobile phone connection.Users can also record GIS-referenced information using touch-screen hand-held computers with databases of icon images instead of text, thereby enabling people with low literacy levels to interpret the data. ICT can also be applied to verify sourcing from sustainable legal sources of timber using supply chain software for tackling illegal logging and addressing deforestation-related GHG emissions (Youngman not dated).

Smart Motor Systems

Motor systems are key drivers of rapidly increasing energy demand in developing countries' manufacturing systems and constitute over 50 % of total industry electricity consumption in many cases (Roeth and Wockek 2011). They are, thus, energy inefficient and there is a need for ICT-enabled solutions for offsetting the proliferating carbon footprint of manufacturing systems in developing countries due to increased use of industrial motors.

Smart applications for enhancing motor efficiency include variable speed drivers (VSD) for controlling the frequency of electrical power supply to the motor, thereby adjusting angular speed to the required output and saving up to 25–30 % energy (Roeth and Wockek 2011). Other measures for enhancing motor efficiency include intelligent motor controllers (IMC) for monitoring the motor's load conditions and adjusting voltage input accordingly to extend motor lifespan and reduce the number of motors associated with GHG emission in manufacturing, though with a minor efficiency gain of less than 10 %.

Industrial motors are thus key elements in the design and implementation of energy efficiency programmes in manufacturing and the application of ICT for controlling their frequency and load conditions will enhance climate change mitigation, while improving the operational efficiency and profitability of manufacturing.

Constraints on the Implementation of ICT-Enabled Climate Change Mitigation Technologies in Developing Countries

In light of the prevailing circumstances in developing countries, such as poverty and inadequate access to project financing, some of the constraints that are likely to inhibit these countries from implementing ICT solutions in climate change mitigation are:

- diversity of the carbon footprint in the developing countries due to their diverse economic activities that range from land use for agriculture to manufacturing, with the latter often prompting reliance on unclean energies with high carbon footprints, like coal and fossil fuels. This accentuates the need for the decarbonisation of the energy supply. Since developing countries are resource-constrained, there is likely to be much laxity towards smart technology adoption, and this exacerbates GHG emissions in these countries.
- inadequate capacity of the various stakeholders along the technology uptake pathways slows promotion of ICT-enabled climate change mitigation technologies. There is frequently a lack of or low awareness and appreciation of technological developments and their potential for more carbon-and energy-efficient solutions. ICT adoption is expected to be rather slow due to insufficient knowledge on climate change mitigation applications.
- inadequate capital due to the conservative banking sector operating a system devoid of the importance of environmental conservation and climate change to economic development. This is exacerbated by the highly sector-specific venture capital and private equity sources (Carbon Trust 2008).
- highly uncertain cost of new technologies, with less or no proven commercial viability, for large scale investment in smart technologies such as smart grids and smart cities (Vodafone and Accenture 2009).
- limited or uncertain suitability of ICTs to local conditions, which often limits technology compatibility across countries or organisations. This calls for stronger linkages along the technology-uptake pathways and between the technology and telecommunications providers and affected industries in order to develop common operating standards (Vodafone and Accenture 2009).
- lack of incentives in LDCs to encourage investment in ICTs for climate change mitigation and adaptation. This has not been helped by the stringent conditions of the clean development mechanism of the UNFCC, which would otherwise encourage developing countries to invest in carbon offset projects.
- inadequate capacity to harness the potential synergies offered by the quadruple helix of linkages between and among the academia, research, policy and the private sector/non-government actors towards addressing the issues of low-carbon innovation challenges in a coordinated manner.
- the rebound effect: efficiency gains are potentially offset by a change in consumption patterns triggered by the very same technology. For instance, lower energy costs resulting from efficiency gains may lead to increased energy consumption, while e-commerce may lead to long distance delivery (increasing the carbon footprint of the consumption of delivered products) and teleworking could lead to increased household energy use and demand for electronic appliances like routers and printers.This may subsequently lead to the problem of leakage, whereby emission reductions from one locality may lead to increased emissions in another, thereby contravening the principle of additionality, which is a major requirement in carbon offset projects.

The ‘paperless’ office may not necessarily lead to the energy saving patterns promised by dematerialisation.

Summary and Conclusions

Energy savings may not result from the technology itself, but from how it is deployed and used—according to the rebound effect. Energy and ICT policies will play a crucial role in encouraging desired behaviour, thus mitigating anthropogenic impactson climate change. Technology transfer and financing schemes for carbon offset projects covered under UNFCCC could also be extended to incorporate the broader deployment of ICTs in developing countries. This will necessitate capacity building in project design and development (PDD), energy efficiency management and the promotion of voluntary carbon marketing prior to upgrading to CDM certifications. These will fasttrack the adoption of carbon offset projects, including those on a small scale. Developing countries could also take the voluntary carbon market path to benefit from carbon offset markets, while fast tracking opportunities for sustainable development. This is partly because CDM has more costly and more bureaucratic and time-consuming procedures, which tend to favour developed countries and seem to be infeasible for LDCs. Moreover, CDM does not incorporate conditions for sustainable development and benefit sharing, and, consequently, rural settings in LDCs are bound not to benefit from CDM. They thus need to start with voluntary carbon offset projects such as Reducing Emissions from Deforestation and Forest Degradation with sustainability and socio-economic development benefits (REDD+). This will enhance the ability and willingness of low-income, rural communities in LDCs to fast track climate mitigation projects, while harnessing the accompanying benefits.

New and alternative mechanisms to drive inclusive low-carbon growth, which utilise ICT opportunities, shall first be prototyped, before large scale uptake of the technologies. This will enhance implementation of viable projects and offset the possibility of project failure.

Recommendations

- Benchmarking could accelerate low-carbon ICT-enabled climate change mitigation technology uptake and multiplication in LDCs using lessons learned from China and other emerging economies. LDs thus need to identify appropriate technology uptake pathways that will enable the accelerated design and development of ICT-enabled carbon offset projects that will meet their investment capacity and optimise the benefits of emissions reductions, while promoting sustainable socio-economic development, especially in poor rural communities.

- There is a need to expand local lending capabilities and financial access through local commercial banks and microfinance institutions (MFIs) to accelerate the uptake of ICT-enabled carbon offset projects. These projects should be centred around energy efficiency and the application of renewable energies as substitutes for solid energy options such as biomass. The process may be very involved, as this also demands capacity building for the banking sector to create an awareness and appreciation of the socio-economic benefits of carbon offset projects.
- Small and Medium Enterprises (SMEs) in LDCs should be enabled to access ICT-enabled carbon-offset project funding. This would call for comprehensive capacity building as a prerequisite to access the funding. LDCs particularly need to take into consideration the specific development needs of these countries, while focusing on ICT-enabled low-carbon development pathways. This will translate into context-specific technology transfer, with strategies that enhance public–private partnerships for accelerated uptake and upscaling. This would be accentuated by the existing envisaged benefits oftechnology transfer to these SMEs. Once these ICT-enabled technologies are identified and proven feasible, then collaboration with financial institutions could follow to motivate the SMEs to undertake these innovative projects.
- There is a need for reducing GHG emission and providing incentives for offseting ambitious targets throughout the entire economic production value chain grid areas. This would also call for the engagement of a number of participants in a quadruple helix pattern namely policy (governments), research and academic institutions, the business sector and development agencies or non-government actors like NGOs. Research and academic institutions need to take a lead in the quest for novel ICTs that could promote climate change mitigation, and these could be incubated to tangible solutions or products through the business and non-government actor trajectory (private sector), while governments should provide conducive environments and incentives to the private sector to undertake technology incubation, through, for example, subsidies and joint investments in ICTs. Government should also help to set an agenda that focuses on carbon-intensive sectors that are crucial for economic development in developing countries, such as manufacturing, energy, transport, agriculture and forestry. It should be emphasised that technology transfer should be encouraged from local, rather than from industrialised, countries and this will necessitate the building of innovative capacity within the LDCs.
- Developing countries need to mainstream low-carbon development into industrial, energy, construction and transportation projects. This will also be achieved through enhanced capacity for innovation in ICT-enabled carbon offset projects. Once this capacity is realised, governments should set the ICT development agenda, focusing on carbon offset production and development, while prioritising thematic areas specific to the different sectors. The national planning authorities would then take and prioritise development projects that include measures for carbon offset for immediate funding. Meanwhile, policymakers

should develop carbon offset standards, or adopt existing ones from the best ones already in use in industry, for regulation, verification and certification.

- There is a need for to engage in policy advocacy to promote regulatory and policy reforms for better investment opportunities in ICT-enabled carbon offset projects. This would also be possible through the deployment of the quadruple helix highlighted above. Capacity building for non-government actors should be enhanced to enable them to act as 'watchdogs' for compliance with climate-proofed development ICTs for sustainable development.
- Since agriculture forms the main economic activity for the majority of the population of LDCs, who mainly live in rural settings, and since few studies have been conducted in ICT-enabled GHG emission reductions in the agricultural sector, there is a need for further research to explore ICT solutions in specific high-carbon sectors in LDCs. LDCs are also beset by low levels of smart energies, while they are dominated by traditional biomass as the major source of energy, with high GHG emissions and environmental degradation. In addition, electricity grids in LDCs often have poorly planned distribution networks, overloaded system components and a lack of reactive power support and regulation services, while the efficiency of metering and bill collection is low. LDCs will thus need to benchmark best practices from fast developing economies like China for energy efficiency improvement and lowcarbon development.

Finally, the business sector's capacity should be enhanced to promote a reduction in the carbon footprint of the ICT sector, and help comprehend the lifecycle impact of ICTs in developing countries. Incentives for participation in research and development ICT projects that prioritise GHG emissions reductions should be provided to private organisations once they attain adequate capacity for innovation in climate-proof ICTs.

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Chapter 3
Climate Regulation: Implications for Trade Competitiveness in Caribbean States

Michelle Scobie

Abstract The right to development and the fairness in the application of the burden to mitigate greenhouse gas emissions, especially as they relate to Small Island Developing States (SIDS) are discussed in this paper. It poses some questions, such as: what are the implications of international trends relating to trade and carbon emissions reduction schemes for Caribbean SIDS' competitiveness from the perspective of environmental justice and the principles of common but differentiated responsibilities? While there have been several studies on SIDS' vulnerability to climate change, they focus mostly on the effect of climatic events, especially natural disasters and sea level rise, on island states, and consequent adaptation efforts and challenges. This paper draws attention to one way in which the global fight for a green economy works to the detriment of Caribbean SIDS. Climate regulation in the areas of maritime and air transport make long hauls more expensive and reduce the trade competitiveness of Caribbean SIDS. Both in the case of regulation of international transport, and in the case of carbon border taxes being applied to imports, the special vulnerabilities of SIDS have not led to special treatment for these countries. This paper argues that this aspect of climate change regulation requires specific attention at the international and domestic level. The trade and environment discourse must consider the special development challenges and vulnerabilities of SIDS if the principles of justice, fairness and common but differentiated responsibilities are to be observed.

Keywords Caribbean SIDS · Climate change · Trade competitiveness · Carbon border taxes · Maritime and aviation emission schemes · Principle of common but differentiated responsibility

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_3,

Short Introduction

In general, this paper examines the negative economic effects of global climate change regulation on vulnerable Caribbean Small Island Developing States (SIDS), discussing questions, such as: what are the implications of international trends relating to trade and carbon emissions reduction schemes for Caribbean SIDS' competitiveness? Additionally, this paper argues that this aspect of climate change regulation requires specific attention at the international and domestic level.

Introduction

This paper examines the negative economic effects of global climate change regulation on vulnerable Caribbean Small Island Developing States (SIDS). The effort to reduce carbon emissions though helpful in lowering the environmental vulnerability of SIDS, has had an unwanted effect on their economic competitiveness. The international aviation and maritime transport sectors' emission reduction schemes increase international transport costs, which will make exports from remote SIDS less competitive in global trade. The legality of carbon related border tax measures has not yet been decided by the WTO. If applied, however, to SIDS' exports, they reduce their ability to compete in an already difficult international market. State and private certification schemes related to carbon emissions, direct the environmentally sensitive consumer away from products and services shipped from remotely located SIDS.

The complexity of SIDS' vulnerability is well documented by Briguglio and others (Briguglio et al. 2010; Kisanga et al. 2006). A vulnerability index for SIDS was proposed in 1990 by Malta at a United Nations Conference on Trade and Development (UNCTAD) meeting of government experts from SIDS and donors. The 1994 SIDS Global Conference, held in Barbados, and its outcome document—the Barbados Program of Action (BPoA) for the Sustainable Development of Small Island Developing States—encouraged the development of indices that, "integrate ecological fragility and economic vulnerability" (Para. 113 of the BPoA).SIDS' economic vulnerability indices measure greater remoteness and higher transport costs, export concentration and instability of exports, dependence on basic imports, unstable agricultural production, high levels of economic openness, limited global share of manufacturing and service industries, and low resilience.SIDS' environmental vulnerability indices include the high levels of pressure facing their environmental space, the limited intrinsic resilience to these pressures and the ecological integrity of these SIDS. SIDS' economies and infrastructure are debilitated by natural disasters, such as tropical cyclones and hurricanes, typical of large ocean–atmosphere interactions.

Climate change has exacerbated the intensity and frequency of these events. Climate change is also the cause of warming ocean surfaces and increases in heavy rainfall, which negatively impact agriculture. Ocean warming and acidification is responsible for coral reef bleaching, loss in mangrove forests due to sea-level rise and saltwater intrusion reducing freshwater lenses (UNFCCC 2007b). St. Bernard and others have identified indicators of social vulnerability: health, education and resource allocation. These relate to how exposed and resilient the society is to internal or external pressures, be they environmental impacts, economic loss, etc. (Bernard 2003). Another vulnerability index for SIDS is one that combines the UNDP human development index rank of these SIDS with their debt: service ratio, GDP per capita and public expenditure on health and adult literacy (Pelling and Uitto 2001).These studies show that the probability of natural hazard, political economy and the size of the islands are important variables in determining the vulnerability of SIDS. To sum up, SIDS' smallness and lack of economies of scale, minimal export product diversification, remoteness, high international transportation costs and weak public administration, are endemic and persistent challenges that make the new challenges to international competitiveness resultant from climate change regulation almost unbearable. Figure 3.1 shows the GNI per capita of Caribbean States compared with that of North America.

Caribbean States share the characteristics of environmental, social and economic vulnerability of other SIDS, and among SIDS, Caribbean Island states are particularly sensitive to the climatic effects of greenhouse gas emissions (Nurse and Sem 2001).Extreme climate events challenge their sustainability and their sovereignty, and weaken their capacity to chart a path for future development (Intergovernmental Panel on Climate Change 2012). Although most Caribbean Islands are too small to be identified specifically on global climate change models, most regional projections include the following: sea level rise; increased rain intensity and more frequent and severe flooding and higher surface, air and sea temperatures. These economies are mostly based upon natural endowments

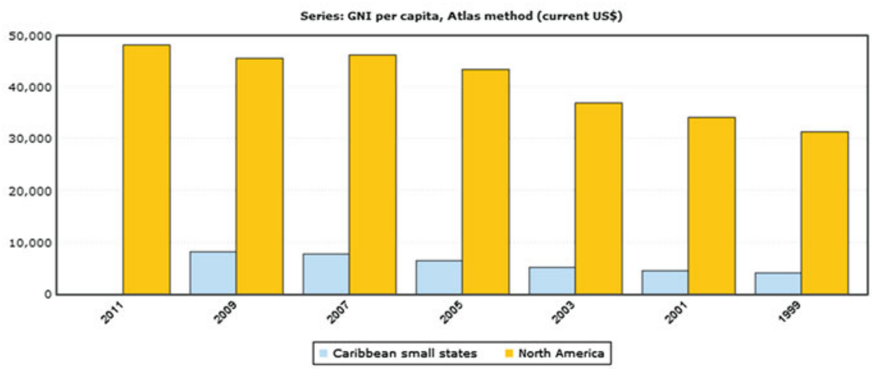

Fig. 3.1 GNI per capita of Caribbean states (*Source* World Bank, World Development Indicators)

(forestry, fishing, tourism, mining, agriculture) 300,000 people (of the region's 39 million inhabitants), for example, are employed directly in the fishing industry (Agard et al. 2007).

Tourism is the main foreign exchange earner in many states. For the year 2011, the World Travel and Tourism Council (WTTC) has ranked the Caribbean region first in travel and tourism's total contribution to GDP (14.7 %), to capital investment (11.56 %) and to exports (16.69 % of total Exports). The Caribbean is ranked third in travel and tourism's contribution to employment (12.6 %). In the Bahamas, 70 % of the jobs in the tourism sector depend on the country's natural endowments (UNEP 2008). A 2008 study estimates the cost of hurricane damage, loss of tourist-generated revenue and infrastructure damage due to sea level rise to be as high as US$22 billion or 10.3 % of the GDP of the Caribbean by 2050 (Ramon Bueno 2008, p. 3). In Barbados, for example, 70 % of hotels are within 250 m of the high water mark (UNFCCC 2007b) and are under threat from a rise in sea level.

Caribbean SIDS, inherently vulnerable, face new threats to their environmental and economic sustainability from climate change. The following sections of this piece will focus on less-studied aspects of climate change problems for SIDS' competitiveness. First, the literature on adaptation to climate change focuses heavily on the environmental impacts of climate change, and not enough of the economic impacts of climate regulation on SIDS' trade competitiveness. Secondly, the impact of new regulations in international transport is considered. Here too, the debate between trade and environment scarcely factors in the peculiar vulnerabilities of SIDS, as they are bound to comply with these regulations to the detriment of their economic competitiveness. Thirdly, the growth of non-state certification schemes is examined. SIDS will find their market space further reduced by the growing volume of sensitive consumers who shy away from goods and services of which the carbon footprint is greater because of the distance to the importing states. Finally, this piece examines these realities from the perspective of environmental justice. Generally this concept posits that the vulnerable (present and future generations) should not be made to pay the penalties for damages caused to the environment by others. Alternatively the vulnerable should enjoy the benefits of the environment as much as those better placed to harvest environmental goods. The justice debate, however, is often lacking in considerations of climate regulation and trade where SIDS are concerned.

Adaptation to Climate Change

What does adaptation mean for Caribbean SIDS? Adaptation costs are the cost of development projects to restore welfare to levels predating climate change in areas such as infrastructure, coastal zones, water supply and flood management, agriculture, fisheries, human health, forestry and ecosystem services and extreme climatic events. The costs of adaptation for the Caribbean have been estimated to be approximately US$21.5 billion per year between 2010 and 2050—or about 10 % of the present Caribbean economy (The World Bank 2010, p. 4). Another study divides adaptation and mitigation measures for the Caribbean SIDS into areas such as improved infrastructure, public education to foster behavioural change in recreational and food choices, policy change, relocation, loss prevention, distribution or absorption and research and monitoring (Nurse 2007).

Funding mechanisms for adaptation include the Global Environmental Facility, the Special Climate Change Fund, the Least Developed Countries Fund and an Adaptation Fund (funded via a 2 % adaptation levy on Clean Development Mechanism projects).All support adaptation projects and finance efforts to reduce emissions, to facilitate technology transfer, to assist countries highly dependent on income from fossil fuels to diversify out of those sectors, and to build capacity in climate change adaptation (UNFCCC 2007a). Future financing mechanism proposals include extending the CDM adaptation levy, introducing an adaptation levy on bunker fuels, funding through carbon taxes and raising revenues from auctioning through emission trading schemes (Hægstad Flåm and Skjærseth 2009). Generally, vigilance on the part of recipients is needed to ensure that this adaptation financing is not counted as part of the aid already pledged (Srinivasan 2006).

These measures extend the burden of reducing carbon emissions to SIDS, in spite of the UNFCCC principles of common but differentiated responsibility, and adaptation funding does not cover this. The following sections discuss three sources of loss of competitiveness: maritime transport, aviation transport, carbon border taxes and ecolabelling schemes.

Trade Competitiveness Eroded by International Shipping and Aviation

The Caribbean is part of the Trans-Pacific Trade Route which includes China and North America, and both imports and exports are influenced by changes in the international shipping regime.

90 % of world trade is transported by sea and 8 % (accounting for 40 % value) by air. International shipping amounted to 2.7 % of man-made emissions according to a 2009 International Maritime Organisation (IMO) greenhouse gas emissions (GHG) study (Buhaug et al. 2009). CO_2 emissions from shipping increased twofold between 1994 and 2007, and left unmitigated may expand by 150 % over the next decades (Buhaug et al. 2009). Aviation (the means by which most Caribbean SIDS receive visitors) accounts for 1.9 % of carbon emissions and is the most emissions-intensive transport sector per passenger-kilometre: dollar spent or for time travelled (ICTSD 2010, p. 1).

The international transport sector, not part of the Kyoto Protocol, has faced increasing international pressure to reduce emissions. There is no established coordination mechanism between the Secretariats for the Kyoto Protocol and the

International Maritime Organisation; the two have historically operated independently of each other (Hackmann 2012). However within the Environmental Protection Committee (MEPC) of the IMO, the process of making the shipping industry greener has advanced substantially.

In July 2011, the IMO adopted amendments to MARPOL Annex VI to strengthen efforts against pollution. The amendments—to apply to ships of every nationality from 2013—were to the "regulations for the prevention of air pollution from ships" and a new chapter on "regulations on energy efficiency for ships". The Energy Efficiency Design Index (EEDI) is mandatory for all new ships and the Ship Energy Efficiency Management Plan (SEEMP) will be mandatory for all ships.[Resolution MEPC 203 (62)]. It is estimated that by 2020 these measures will have achieved between 10 and 17 % reduction in greenhouse gas emissions, and by 2030 emissions will fall between 19 and 26 %. The EEDI and the SEEMP have the potential to reduce CO_2 emissions by up to 180 million tonnes annually by 2020 and 390 million tonnes by 2030 (International Maritime Organisation 2011, p. 12).

These measures are the first such reduction regime for an entire economic sector. The IMO's Environmental Protection Committee is also considering Market Based Measures (MBM). Developing countries are, however, wary of creating a precedent of establishing global emission reductions in an economic sector that is not founded on the principle of common, but of differentiated responsibilities [UNFCCC Article 4.1 (c)]. India registered strong opposition to such measures at the IMO's Environmental Protection Committee meeting in March 2012 (International Maritime Organisation 2012), and it is debatable whether the IMO and International Civil Aviation Organisation (ICAO) are the correct forums to address emissions, since at these institutions, the underlying principle for the application of measures is equal treatment of parties—something already internationally recognised as not correctly applicable to carbon reduction commitments and developing states (ICTSD 2010, p. 37). The International Union for Conservation of Nature's (IUCN) (2010) proposal (a threshold of 4,000 gross tonnes or greater for MBM) to the IMO's Marine Environment Protection Committee was an attempt to apply the common but differentiated responsibilities principle, and protect SIDS who face high transport costs for their imports (IUCN 2010). This may not be sufficient for most Caribbean SIDS engaged in tourism, as this figure is far below the average for cruise ships (100,000–225,000 gross tonnes) from some Caribbean ports(Royal Caribbean 2010).

Jamaica, at the March 2010 60th Session of the Marine Environment Protection Committee, supported a uniform emissions charge for all vessels, based on fuel consumed per voyage, independent of design operations or energy source, on the grounds that this measure was easier to administer and would avoid the leakages associated with quality control mechanisms. Jamaica also suggested that funds raised be used for mitigation and adaptation measures for the benefit of SIDS (International Maritime Organisation 2010). This position is understandable given the limited administrative resources facing SIDS at their ports. There is a danger, however, that such funds never reach these states. Brazil and the Republic of

Korea, for example, were opposed to proposals that funds be administered through the UNFCCC's funding mechanisms or through those of other international organisations precisely on such grounds (International Maritime Organisation 2010), para. 5.31).As it stands, it seems that the Jamaican proposal would need to find a way to ensure the effectiveness of such returns.

In air transport, emissions trading and technology standards are the main measures for GHG emissions reduction. Both will increase the cost of air transport. There is no global aviation emissions trading scheme or international aviation tax. The EU Emissions Trading System (ETS), operational since 2008, was extended to aviation as of January 2012 and is to date the only multi-state aviation emissions trading initiative. The ETS applies to airlines operating in the EU regardless of the country of origin (Chiavari et al. 2008). Airlines will be required to pay for emissions that exceed annual emission levels. For the first year, 85 % of aviation allowances will be allocated free of charge. The BASIC countries (Brazil, South Africa, India and China) expressed "firm opposition" to the EU's inclusion of international aviation in the ETS in their Joint Statement at the end of the 10th BASIC ministerial meeting of February 2012. They considered that it violates international law and the UNFCCC because of the unilateral nature of the action, even in the face of strong international opposition. The ministers also expressed concern about similar proposals in the area of shipping (BASIC 2012).

The EU ETS makes long hall tourism in the Caribbean less competitive and will reduce tourist arrivals as tourists will choose destinations closer to home for their holidays. Initial estimates by the European Commission place the cost of the scheme as anywhere between €2 and €12 per ticket (depending on the price at which carbon is trading).It is difficult for most SIDS to measure the possible future impact of each of these MBM in shipping and aviation. Consultations with shipping and tourism agencies in the Caribbean reveal that the economic impact of these formulae on trade are not yet the subject of market research in the region. Preliminary data shows, however, that price-sensitive travel destinations could face a reduction in tourism between 2.4 and 7 % (Bartels 2012). Barbados in particular could face a loss up to 1–2 % of its GDP as a result of a fall in tourist arrivals. (Pentelow and Scott 2011).

Though not specifically related to GHG emissions, the sensitivity of the economies of Caribbean SIDS to variations in the cost of air transport was patent in the most recent United Kingdom increase in air passenger tax. The UK Air Passenger Duty is not a carbon tax, but did negatively affect Caribbean SIDS' tourist arrivals. In 2008 the Department of Transport reported that under the condition at the time, aviation would cover climate change costs with an excess of about £0.1 billion, and emphasised that the charge was not only to capture the environmental cost of aviation (Department for Transport, UK 2008). In 2012 the UK increased Air Passenger Duty, which had been doubled just 5 years before. This took place amid strong international opposition and concern from Caribbean SIDS. Some commercial airlines dubbed this a tax on tourism (Thomas 2012), it has been criticised as being especially harsh on Britain's families (many with roots and links to ex-colonial Caribbean countries) travelling abroad, and is considered

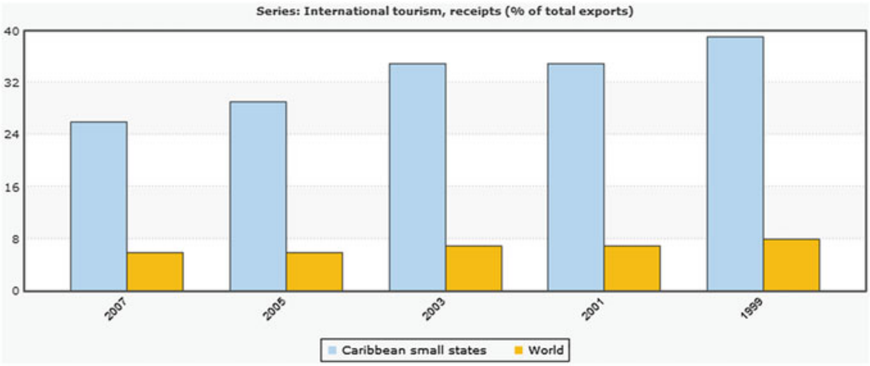

Fig. 3.2 Degree of dependence on tourism receipts compared to the global average (*Source* World Bank, World Development Indicators)

as partly responsible for the fall in tourist arrivals (Sinclair 2012). There was a decline of 5.5 % in tourist arrivals in the first quarter of 2012, as compared with the same period in 2011. In 2011, figures from the Eastern Caribbean Central Bank registered a decline of 20.7 % in UK arrivals between 2008 and 2011. A decline of 12 % in hotel revenue per available room was registered between 2008 and 2012. Thus, although there is no present data to reflect the impact of the EU ETS, given these trends, it is reasonable to assume that a similar reduction in tourist arrivals may result from this scheme. Figure 3.2 shows the high degree of dependence on tourism income compared to the global average.

Efficiency-enhancing measures for ships and aircraft as well as market-based measures (emission trading or fuel levies, for example,) in this sector will reduce competitiveness for remotely located SIDS, which will face higher transport costs for both exports and imports. Price elasticity of demand in the maritime sector is low. Under the high end scenario for the Copenhagen Summit, a US$30 carbon price will increase freight costs by 5–6 % (Faber et al. 2010). For SIDS this may be as much as USD 1.5–3.0 billion per annum or between 0.45 and 0.89 % of GDP as compared to 0.02–0.04 % for Annex 1 countries (Faber et al. 2010). The impact of increased transport charges will also be greater where market shares are smaller, and where there are higher price elasticities. Caribbean SIDS also tend to import lower-value bulk goods, and thus may bear a higher proportion of the costs of a fuel levy (International Monetary Fund 2010). SIDS will thus pay a larger share of the mitigation burden (ICTSD 2010; Wang 2010). Where the importers of services, goods or commodities are sensitive to transport costs, some sources of supply will become uneconomic, and, in some cases, may lead to a substitution of consumption away from imports to domestically or regionally produced substitutes. This does not auger well for exports of Caribbean primary products and for the tourism sector.

Climate change reduces the competitiveness and attractiveness of tourism in Caribbean SIDS on two counts. Firstly, its negative impact upon the environment makes the region less attractive (more extreme weather events, loss of coral reefs due to bleaching and ocean warming and acidification, rising sea levels and erosion of beaches and loss of coastal infrastructure, etc.). In addition, emerging carbon regimes will make long trips less economically attractive to visitors and increase the cost of their imports (Simpson et al. 2008).

What are the policy implications of this for Caribbean SIDS? SIDS would do well to prepare for reduced national income from tourism and for less competitive exports to distant markets. At the international level, SIDS should bring development challenges and competitiveness concerns to the trade and climate-change discourse. The disconnect avoids questions of intra-generational equity that will be treated in greater detail later.

The international debate on financing climate change has not given specific attention to financing the loss of trade competitiveness. The November 2010 Report of the Secretary General's High-level Advisory Group on Climate Change Financing (AGF) was made against the backdrop of the debates within the IMO and the ICAO on reducing carbon emissions from international transport. The AGF proposed three climate financing mechanisms to address the underpricing of environmental externalities of carbon emissions and to finance climate change action in developing countries: an emissions trading scheme; a fuel levy on international fuels in the maritime and aviation sectors; and an aviation ticket tax (UN High-Level Advisory Group on Climate Change Financing 2010). The AGF proposed that such measures be equally applied to operators of all nationalities in keeping with IMO/ICAO principles of flag neutrality and non-discrimination (which conflicts with the UNFCC common but differentiated responsibility principle, however).

Should not financing adaptation to climate change for SIDS compensate for loss of economic competitiveness? One option open to Caribbean States is to support measures that provide a rebate for carbon costs embedded into goods and services, subject to fuel levies or other market-based carbon-reducing mechanisms, for international transport and resist further attempts to apply schemes that do not accord with environmental justice and CBDR principles.

Unilateral Carbon Taxes

The threat to SIDS' trade competitiveness does not come only from the increased cost of international transport. Border-adjustment measures for emission reductions are a further challenge. The United States' Senate rejected the Kyoto Protocol to the UN Framework Convention on Climate Change in large part for competitiveness reasons (Pauwelyn 2012). The US did not want to saddle itself with its international prescriptions regarding emissions control, and, by refusing to join the Kyoto Protocol, signalled that its position on climate change will be governed by economics and the need to protect its economy's competitive edge. The debate, ongoing since the turn of this century in the US, is how to both implement a domestic programme to curb greenhouse gas emissions, while not reducing the competitiveness of energy-intensive industries (such as chemical, steel, iron, pulp, cement, paper and aluminium) which compete on the US market with producers not subject to similar national emissions schemes. Several options were proposed to ensure that US firms remain competitive, even with a domestic emissions regime. They include excluding trade-exposed firms from the emissions regulations, compensating firms through free emission allowances, giving incentives for emissions reduction, applying border tax adjustment measures (BTA) on imports from countries with weaker or no emission control regulations or requiring imports from these countries to show that emissions allowances were purchased (Pew Centre on Global Climate Change 2008).

The WTO recognises the nexus between trade and environment. The Preamble, the General Agreement on Tariffs and Trade (GATT) 1994 Articles XX (b) and (g), the Agreement on Technical Barriers to Trade and the Agreement on Sanitary and Phytosanitary Measures provide countries with the flexibility to adopt trade measures to protect the environment. Such measures must respect the most favoured nation (MFN) and the national treatment (NT) principles of the WTO (GATT Art. I and III) or may be branded a unilateral restriction on trade. The legality of BTA measures has been heavily debated by international lawyers (Pauwelyn 2012; Bordoff 2008), and the issue is still to be tested by rulings at the WTO Panel. Also to be tested by the WTO, is whether developing countries, which are not historically responsible for climate problems, be exempted from the MFN rule in the application of these taxes (Pauwelyn 2012, p. 50). Additionally, is this a right, or is it a possibility, at the pleasure and leisure of the state imposing the measure? For developing states, it would be alarming if it were the latter. BTAs applied indiscriminately to imports from developing states appear to run afoul of the principle of common but differentiated responsibilities of the UN Framework Convention on Climate Change (UNFCCC Art. 3.1) and the WTO Enabling Clause. Developing states have not historically contributed to the climate change problem and, for reasons of justice, should be afforded different treatment in the application of these measures. The danger for Caribbean SIDS is that BTA measures may be introduced unilaterally and states are not legally obligated to discriminate in favour of developing states under international trade law. It is difficult to see how the principle of common but differentiated responsibilities would be applied in this future.

Ecolabelling

Voluntary or mandatory government, private industry or NGO-driven ecolabelling is another threat to the competitiveness of exports from Caribbean SIDS.

Ecolabels signify to how environmentally friendly a product or service is, regarding the economy of use of renewable resources such as water and energy, as well as its impact upon biodiversity, climate change, its reusability, its ethical and social neutral or positive effects, etc. (Art. 6—Regulation (EC) 66/2010). The USDA has an organic label for agricultural products, the Forestry Stewardship Council has a label for environmentally sustainable lumber, and there are several others, such as the Energy Star label for energy appliances and Green Globe 21 for tourism (Buckley 2002). In the EU, ecolabels are given to products originating from within and outside the EU, and ecolabelling based on the environmental impact of a product over its life cycle is administered by the Community, together with the relevant bodies of each Member State and the EU Ecolabelling Board.

Although some labels are discredited or may lose credibility for lack of scientific rigour and transparency in their application (Lavallée and Plouffe 2004; Font 2002), generally, ecolabels serve to inform consumers of the environmental impact of goods, allow them to differentiate between similar products (Crespi and Marette 2005) and enable the consumer to be more equipped to make environmentally friendly decisions. Consumer sensitivity depends upon the type of product, the target market and the available alternatives (Charnovitz 2010; Vranes 2011; Joshi 2004; Appleton 1997; Gulbrandsen 2006) as well as the type of label.

NGO and transnational private-sector labelling schemes (Melser and Robertson 2005) are not subject to the WTO rules for state-driven certification schemes. The latter must satisfy the non-discriminatory most favoured nation and national treatment principles (Charnovitz 2003). Ecolabels must also be applied to similar or “like products” as defined by WTO jurisprudence and the Working Party on Border Tax Adjustments (i.e. products in a close competitive relationship) (Vranes 2011, p. 421).

As consumer sensitivity to carbon emissions increases, and as ecolabels become more common and monitor and report on emissions produced in the manufacture, delivery and use of goods and services, they will challenge Caribbean SIDS’ trade competitiveness. Products and services from remote SIDS necessarily carry a heavy carbon footprint because of aviation or maritime-transport emissions. What does this mean for Caribbean SIDS? The trade policy implications are that Caribbean states should look to closer markets in North and South American, rather than to Europe, to ply their products and services.

Environmental Justice

Will SIDS’ economies survive as the world goes green? It is a paradox: Caribbean SIDS need a greener world for environmental survival, yet climate-change regulation jeopardises their economic survival.

SIDS contribute less than 1 % of greenhouse gas emissions (Placeholder 1) and sixteen of the world’s fifty-one SIDS are in the Caribbean. SIDS’ acute vulnerability to climate change gives them the moral authority to be active stakeholders in the shaping of the trade–environment regime (Barnett and Adger 2000), for they suffer the effects of a climate-change problem for which they do not share historic responsibility. Principles of environmental justice, as applied to SIDS, have not

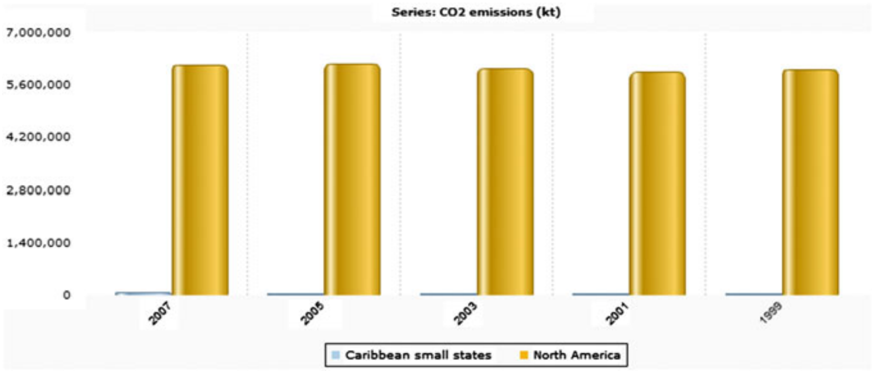

Fig. 3.3 CO_2 emissions from Caribbean small states compared with North America (*Source* World Bank, World Development Indicators)

been present in the global discourse on trade and emission-reduction schemes for aviation, shipping, border tax adjustments, nor for environmentally friendly certification schemes. Furthermore, the mechanisms that create these schemes often involve SIDS peripherally, if at all. Figure 3.3 shows the emissions from Caribbean Small States compared with its neighbouring region in North America. In 2007 the Caribbean's emissions were 60,487 (kt) compared to North America's 6,126,226.

These principles are, however, part of the climate-change and sustainable-development discourse. The international community is committing itself to promote higher standards of living and adequate economic and social conditions for all (Article 55 of the UN Charter).Principle 6 of the Rio Declaration on Environment and Development affirms that,

> the special situation and needs of developing countries, particularly the least developed and those most environmentally vulnerable, shall be given special priority.

Rio Principle 7 recognises the principle of common but differentiated responsibility (UNEP 1992). The UNFCC recognises the need to protect developing states from the adverse effects of climate change, and their differing responsibilities in mitigation efforts (Articles 2–4). The Kyoto Protocol Article 3.14 also requires parties to take steps to reduce the adverse effects of climate change on vulnerable developing and least-developed states—which the Alliance of Small Island States (AOSIS), for example, interprets to include capacity building for adaptation (Barnett and Dessai 2002).

These principles and concepts, however, do not seem to go as far as to protect vulnerable SIDS from the adverse effects of trade measures to address climate change that are not contrary to international trade law—i.e. that are not "arbitrary or unjustifiable discrimination or a disguised restriction on international trade" under the WTO (General Agreement on Tariffs and Trade Art. 5). This is a gap in the conceptualisation of the climate change regime, especially for SIDS. Neither does adaptation funding build economic rights (such rights as the right to work, protection against unemployment and the right to a standard of living that ensures health and well-being) into its design and implementation, in so far as these rights are jeopardised by loss of trade competitiveness (United Nations 1948). Studies thus far on climate change and Caribbean economies tend to focus on how to harness natural endowments and to reduce carbon emissions (UNDP, UWI, Government of Barbados 2012). Further research is needed on the impact of carbon reduction schemes on trade for Caribbean SIDS.

As discussed above, the region perceives the UK APD as an unjust tax that militates against SIDS' competitiveness. The communiqué issued at the close of the meeting of the Caribbean Community Council for Foreign and Community Relations in May 2012 stated that:

> Ministers engaged in intense discussion regarding the deleterious effects that the discriminatory implementation by the UK of its Air Passenger Duty (APD) is having on the Region's economies. They denounced in strong terms the negative impact that the tax continues to have on the region's revenue sources, observing that the tax was distorting trade and compromising the Region's efforts towards sustainable development.

Caribbean SIDS' economic survival depends on their ability to transition to a global green economy. In justice, however, those responsible for the climate change problem should help SIDS in this transition—or at least exempt SIDS from some of the burdens of this transition. The "just transition" concept was adopted in 2010 by the International Trade Union Confederation in its approach to the challenges labour faces with climate change (Rosemberg 2010). Made popular by Kohler, it posits that jobs and the environment are not irreconcilable concepts (Kohler 1996), and that vulnerable sectors should not suffer the impacts of the economy becoming greener (International Trade Union Confederation 2012). Including this concept in the global discourse on environmental justice and SIDS can assist in the conceptualisation of policies of intergenerational equity in the trade–environment discourse.

Conclusion

Trade liberalisation challenges sustainable development and the protection of the environment (Cavanagh 2002). Carbon taxes, new technical specifications on ships and aircraft to reduce emissions, environmentally friendly certification schemes, fuel levies, etc. help solve the problem of putting a price on environmental externalities in the global production and trade processes. However, they also raise justice and equity issues relating to the environment and trade, both at the international and the domestic level. Developing SIDS, who do not share historic responsibility for carbon emissions, are being forced to assume the cost of mitigation through these measures.

Applying principles of environmental justice to this analysis would suggest that SIDS should not bear equal burdens of paying for carbon, which would reduce trade competitiveness. It is up to SIDS to draw attention to the principles of sustainable development and of common but differentiated responsibility as the climate regime develops in the area of trade. Studies that quantify the economic impact of measures such as carbon border taxes, carbon restrictions on maritime and aviation transport and green certification schemes on products and services are needed. At the IMO's EPC this lack of data limits SIDS' ability to engage in debates on the effects of proposed measures. It is also in the interest of SIDS to support certification watchdogs to ensure that certification agencies deal transparently and fairly in the markets in which they have an interest.

The preliminary findings on the effects of the EU ETS and the case of the UK APD (though the latter is not specifically a carbon emissions reduction measure), show that SIDS are being squeezed out of the traditional tourism markets upon which they depend for economic survival. At the domestic level, the poor face the greatest burden as international transport pushes up the costs of imports. Development, intergenerational equity and distributive justice should factor into decisions on trade in a carbon-sensitive world.

The missing element in funding adaptation to climate change is in assisting SIDS towards economic diversification of their economies to include goods and services that have a small carbon footprint for manufacture, delivery to market and product lifecycle, and are less vulnerable to climate change (Gueye et al. 2010). Resource limitations in several Caribbean States make coordination between the environment, development and trade departments of government very challenging, and is perhaps responsible for the silence on the environmental and development issues related to trade in areas outside of travel for tourism.

Like China at the WTO and the IMO, the principled stance of SIDS on trade and the environment should be that CBDR should be applied to all market measures to reduce climate change—to thus avoid a loss in competitiveness. This would mean excluding their exports and imports from such regimes. The alternative—that finance raised from such measures should, in part, be directed towards economic adaptation efforts in SIDS—is harder to administer, and the conditionalities to access the funds often prove challenging. Financing in this case may be by direct compensation, or compensation based on import and export volumes. The difficulty in operationalising green funds—as is evident in REDD+ and other environmental funds—should, however, be a call to caution for SIDS to support such policies.

Is this a losing battle? Perhaps, but it throws light on another important way that SIDS are highly vulnerable to the (indirect and economic) effects of climate change.

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Chapter 4
Climate Change Issues on the Pacific Islands: An Overview

Tony Weir and Dan Orcherton

Abstract This paper sets a context for the theme of KLIMA 2012 by outlining the key issues of climate change as it affects the Pacific Islands. The paper describes projected biophysical impacts and the social issues they raise for Pacific Islanders. These issues are particularly acute for the low-lying atoll countries, whose continued existence is threatened by sea level rise. Most Pacific Island countries have populations concentrated in coastal areas, and have few financial or technical resources—all of which factors make them particularly vulnerable to climate change. Although Pacific Island countries are all striving to decrease their use of fossil fuels, including by greater use of renewable energy to save import costs, the intent is also to set an example to the large industrialised countries and to influence them to reduce their greenhouse gas emissions, which are causing climate change. However, as global GHG emissions continue to rise, adaptation to climate change is essential for the sustainable development of the Pacific Islands.

Keywords Pacific islands · Climate change · Impacts · Adaptation · Forced migration · Sustainable development · Sealevel rise

Short Introduction

This paper is aimed at readers who are familiar with climate change in general, but not so familiar with the Pacific Islands. The paper describes projected biophysical impacts and the social issues they raise for Pacific Islanders. These issues are

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_4,

particularly acute for the low-lying atoll countries, whose continued existence is threatened by sea level rise. Most, if not all, Pacific Island countries have populations concentrated in coastal areas, and have few financial or technical resources—all of which factors make them particularly vulnerable to climate change.

The Pacific Islands Context

The 15 independent Small Island Developing States (SIDS) of the Pacific, often referred to as Pacific Island Countries (PICs), comprise many islands scattered across a very large area of ocean (Fig. 4.1). For example, Kiribati comprises some 50 islands, with about 3,000 km between the most western of its islands and the most eastern. Fiji has over 300 islands, though two are much larger and more heavily populated the rest. All the Pacific SIDS are small in land area and population (except for Papua New Guinea); in most cases the label on a map is far bigger than the island(s) to which it refers! Papua New Guinea (PNG) is the only PIC with a population exceeding 1 million; Tuvalu, Nauru, the Cook Islands, Palau, and the Marshall Islands all have populations of less than 50,000 (SPC 2012a).

The geographical fragmentation of the Pacific Island countries, their remoteness and their small size are fundamental constraints on their economic development.

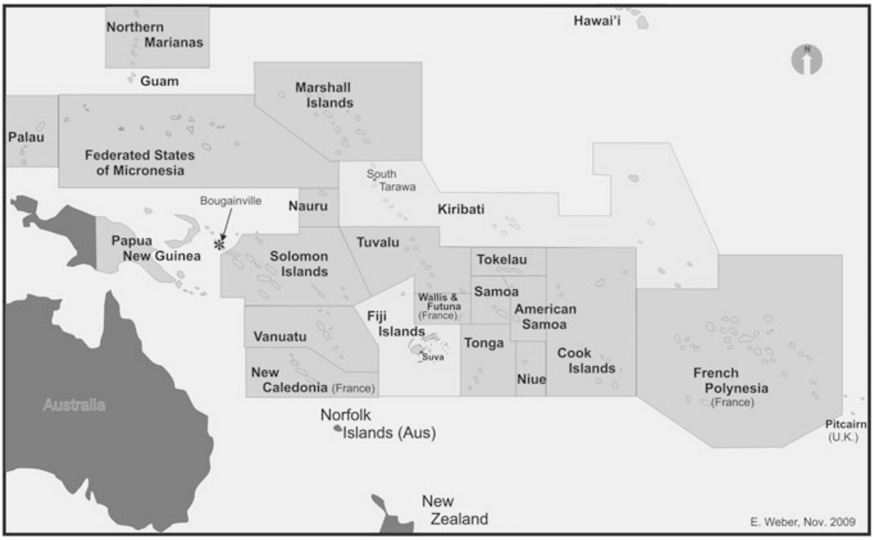

Fig. 4.1 Map of the Pacific showing the Pacific SIDS and some neighbouring countries. Note that New Caledonia, French Polynesia and Wallis and Futuna are French overseas territories and do not count as SIDS; the same is true of Tokelau (a territory of New Zealand) and Guam, the Northern Marianas and American Samoa (territories of USA) (map *courtesy* of E. Weber)

Most Pacific Island countries are heavily dependent on their marine resources, although some have relatively fertile agricultural land and tourist potential. Overseas aid and remittances by islanders working abroad make major contributions to the GDPs of several PICs (Rao et al. 2008).

Literature

Each of the Pacific SIDS has produced a first National Communication under the UN Framework Convention on Climate Change. These documents set out the basic geography of the country concerned, its vulnerability to climate change and measures it has taken or would like to take to reduce that vulnerability. All are publicly available on the convention website http://unfccc.int. These are the most comprehensive reports specifically on the Pacific that are widely available, but most of them were compiled before 2000, and there have been many developments since then, in both science and action (or non-action!) The present paper outlines some of these developments.

The Intergovernmental Panel on Climate Change (IPCC) was set up by the United Nations to provide authoritative scientific and technical background information on climate change. Its three working groups respectively cover physical science, impacts and adaptation, and mitigation. Its comprehensive Fourth Assessment Report was published in 2007 and is the basis of much of this paper, particularly the next two sections.

Greenhouse Gases and Climate Change

'Climate change' refers to trends or other systematic changes in either the average state of the climate, or in its variability (including extreme events), with these changes persisting for an extended period, typically decades or longer.

IPCC Working Group 1 reviewed observations that clearly show climate change over the past century, and particularly over recent decades. In particular, the Global Mean Surface Temperature (GMST), i.e. the annual average of temperatures measured by meteorological stations around the world, has increased by about 0.7 °C in the past 50 years. The IPCC unequivocally attribute this change to the corresponding increase in the tonnage of greenhouse gases in the atmosphere, particularly CO_2 emitted from the burning of fossil fuels (IPCC 2007a).

Future annual GHG emissions into the atmosphere are highly dependent on various future factors including economic growth, population growth, the associated demand for energy, energy resources and the future costs and performance of energy supply and end use technologies. Unfortunately, it is not possible to know today with any certainty how these different key forces might evolve decades in the future. Therefore, The IPCC developed a range of scenarios covering factors such as those listed, from which scientists can project a range of possible emissions, concentrations, and hence a range of possible changes in the climate.

Using these scenarios in global climate models, the IPCC projected that the global average temperature will rise over this century by between 1.1 and 6.4 °C over the 1980–1999 average (IPCC 2007a). This range of uncertainty also allows for uncertainty about the responsiveness of the climate to a given increase in the stock of GHGs in the atmosphere.

Biophysical Impacts of Climate Change

It is clear from the summary by IPCC Working Group 2 on the impacts of climate change, that a rise in GMST of a modest-sounding 4 or 5 °C would have consequences for ecosystems, water supply, food, coasts and health that would be unacceptable—indeed dangerous—to a large proportion of the world's population (IPCC 2007b).

In that authoritative review, the IPCC concluded that "small islands, whether located in the Tropics or higher latitudes, have characteristics which make them especially vulnerable to the effects of climate change, sea level rise and extreme events".

The left column of Table 4.1 lists the points made in the IPCC's Summary for Policymakers about the impacts of climate change on small island countries in general. In the right column of the same Table, we highlight the extent to which these impacts would affect life for Pacific Islanders.

These impacts could be even worse if the climate system passes certain 'tipping points' where abrupt changes occur, such as irreversible melting of the Greenland ice shelf, or the bulk release of methane from permafrost regions. Though the precise increase in GMST required for these tipping points is still uncertain, it is likely that some such potentially catastrophic changes could occur following increases in GMST of 4 °C or more (Schellnhuber et al. 2006; Smith et al. 2009).

Worryingly, increases in GMST of this magnitude are within the range of IPCC projections and could occur if global fossil fuel use continues to increase without constraint.

Coral reef ecosystems in the Pacific Islands will suffer major impacts from climate change. A prolonged temperature rise of only 2 °C takes many coral species outside their range of tolerance, which is likely to lead to death and weakening of many coral reefs in the Pacific Islands (See Fig. 4.2a). These temperature effects are worsened by the increase in CO_2 in the atmosphere that caused them, because more CO_2 then dissolves in the ocean, making it more acidic and thereby chemically attacking the reef structure (Hoegh-Guldberg et al. 2007; Hoegh-Guldberg 2011).Given the importance of these reefs as protection from storms, as sources of food and as attractions for tourists, these ecological impacts have grave consequences for Pacific Island people dependent on fisheries and coastal reef ecosystems for their livelihoods.

Table 4.1 Impacts of climate change on small island countries

General impact according to PCCI (2007b)[a]	Specific effect on Pacific Islands
Deterioration in coastal conditions, for example through erosion of beaches and coral bleaching, is expected to affect local resources, e.g. fisheries, and to reduce the value of these destinations for tourism	• *Fish* make up most of the protein input for many islanders • *Tourism* (based on the attractiveness of beaches which might erode and corals which could be killed by climate change) is the economic mainstay of several Pacific Island countries
Sea-level rise is expected to exacerbate inundation, storm surge, erosion and other coastal hazards, thus threatening vital infrastructure, settlements and facilities that support the livelihood of island communities	• *Inundation* by salt water, if frequent enough, makes land incapable of growing crops • In all Pacific Island countries,(except Papua New Guinea), most people live in *coastal* towns and villages, the very places most vulnerable to inundation and erosion because of sea level rise • *Cyclones* (very strong storms), the most frequent 'natural disasters' in the PICs, are expected to become more severe as ocean temperatures increase
Climate change is projected by the mid-century to reduce water resources in many small islands, e.g. in the Caribbean and Pacific, to the point where they become insufficient to meet demand during low rainfall periods	• The 2011–2012 drought in Tuvalu, induced by a strong la Niña season, indicates the drastic social impact that reduced water resources can have in the Pacific • High population growth in some islands (e.g.: South Tarawa, Kiribati and Funafuti, Tuvalu), increases the demand for fresh water and thereby significantly reduces the fresh-water lens. Replenishment of the lens on atolls is primarily rain-fed

[a] *Quoted from* p. 15 of IPCC (2007b). See Mimura et al. (2007) for fuller version

Another consequence of global warming for the Pacific Islands is an increase in the severity of tropical cyclones, because cyclones are driven by evaporation from regions of warm sea water. So, the warmer the ocean, the more likely it is to generate a severe cyclone. Given the economic and social damage caused by severe cyclones like of a and Val (Samoa in 1990–1991) Kina (Fiji in 1993), and Zoe (Solomon Islands in 2002), this is another worrying prospect for Pacific Islanders (See Fig. 4.2b). Flooding of flat land near rivers (much of which, but not all, is due to cyclones) is also likely to get worse.

These effects on reefs and cyclones are almost certain to occur, no matter what action is taken, as they require only a relatively small increase in GMST.

Another key impact for many Pacific Islands comes from the rise in sea level, which is associated with global warming because sea water expands when it gets warmer. A pertinent example of its damaging effects occurred in February 2006, when the highest tide of the year, coupled with a rise in mean sea level of only ~10 cm since 1970, allowed sea water to inundate many parts of the low-lying atolls of Tuvalu and Kiribati. This ruined some 60 % of vegetable-growing pits

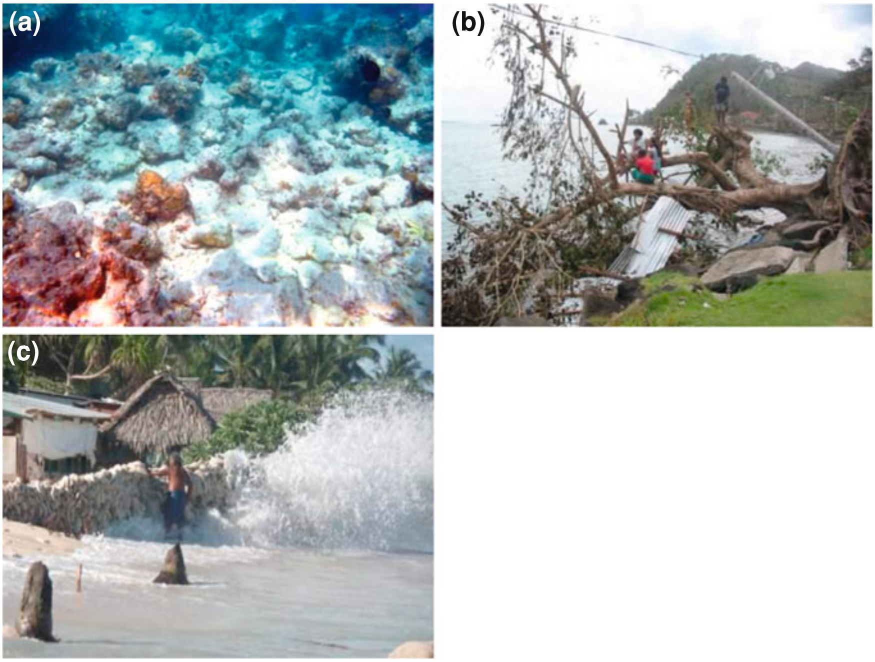

Fig. 4.2 Some biophysical impacts of climate events, that will become worse with climate change. **a** Bleaching of coral reefs (*photo* taken at Moofushi in the Maldives by Bruno de Giusti, reproduced from Wikimedia under the creative commons license). **b** Damage caused by tropical cyclones—in this case Cyclone Heta in American Samoa, 2004 (NOAA photo). **c** An atoll being inundated with salt water during a storm, despite the best efforts of the man repairing a sea wall (*photo* taken at Temwaiku, South Tarawa in October 2009 by NTNK video, reproduced with permission)

and many of the wells used to tap into the groundwater ('fresh water lens'), which constitutes the main traditional supply of fresh water. Such inundation is most likely when storm-driven waves add to a high tide (see Fig. 4.2c).

We note that many Pacific Islands are already undergoing social, economic and environmental stresses, which will become unsustainable unless something is done to lessen them. These stresses include population growth (especially in urban areas), pollution (both of land and sea), pressure on land (especially forests), food insecurity, lack of paid employment, and non-communicable diseases such as diabetes (aggravated by poor diet and urban lifestyle) (ESCAP 2010). Climate change is not the main cause of any of these stresses, but it is likely to make many of them worse, and thus make 'sustainable development' even harder to achieve than it is already.

International Treaties and Negotiations

The threat of world-wide consequences of greenhouse-induced climate change, documented in the IPCC's First Assessment Report of 1990, prompted the United Nations to begin a series of negotiations aimed at an international agreement to limit such damage. These international negotiations on climate change have so far led to the United Nations *Framework Convention on Climate Change* (FCCC) of 1992 and the *Kyoto Protocol* of 1997.

The key provisions of these treaties urge all countries to take action to limit their emissions of GHGs into the atmosphere (*mitigation*) and to help each other to adapt to such climate change as does occur. In principle, these provisions place stronger obligations on the richer, more industrialised countries, which are responsible for most of the world's GHG emissions, and have the financial resources to take actions to adapt themselves and also to assist the poorer countries, who do not have such resources, such as the Small Island Developing States.

International negotiations on climate change continue each year, with the Association of Small Island States (AOSIS, which includes all Pacific SIDS) pushing strongly for a strengthening of the existing treaties and seeking a new treaty with even stronger provisions. However, these efforts have had little success as yet. It is fair to say that those countries most responsible for climate change have failed for the past 20 years to assume the responsibility to prevent dangerous climate change.

Mitigation Issues

In the PICs, all fossil fuel is imported. In the smaller island states, fuel imports account for around 30 % of GDP, and in the larger PICS around 7–15 % of GDP (SPC 2012b). Consequently Pacific Island countries are striving to decrease their use of fossil fuels, including by greater use of renewable energy. Doing so will also reduce their emissions of CO_2. However, as the PICs account for less than 0.3 % of global CO_2 emissions, direct action by the PICs will have negligible effect on the mitigation of climate change. China, the USA and the EU between them account for over 60 % of global emissions; therefore, all of them must substantially reduce their emissions if dangerous climate change is to be avoided (WRI 2010).

Therefore actions by the SIDS are intended to set an example to the large industrialised countries. In the international treaty negotiations and other forums, the SIDS can then ask: "if we can reduce our emissions, why can't you do so too?"

Adaptation Issues

Adaptation refers to "a process by which strategies to moderate and cope with the consequences of climate change, including variability, are developed and implemented" (Lim et al. 2004).

The IPCC Synthesis Report (IPCC 2007c) (Sect. 5) concludes that:

> Adaptation is necessary in the short and longer term to address impacts resulting from the warming that would occur even for the lowest stabilisation scenarios assessed. There are barriers, limits and costs, but these are not fully understood. Unmitigated climate change would, in the long term, be likely to exceed the capacity of natural, managed and human systems to adapt. The time at which such limits could be reached will vary between sectors and regions.

In the Pacific Islands, communities (i.e. villages) are the main place where action will need to take place, but many communities are ignorant of the bigger picture and options for adaptation (although they are aware of coastal erosion and other impacts taking place). To date, government outreach on this has been limited to a few pilot projects, many of them helped by NGOs, although their resources are limited. Much more is needed.

Fortunately, financial aid for adaptation has increased considerably since the failed treaty negotiations at Copenhagen in 2009, as many rich countries are keen to show the small island countries that they are doing *something* to help, even if they have been unwilling to adequately reduce their own GHG emissions.

Pacific Islands are already strongly impacted by extreme climatic events such as cyclones, floods and droughts, to which the people have developed traditional coping mechanisms, some of which are illustrated in Fig. 4.3. For example, food security is enhanced by growing a diversity of crops, some of which cope better with drought while others cope better with a prolonged wet spell (Fig. 4.3a). Some traditional crops can be preserved for months by careful storage (e.g. the yams in Fig. 4.3b) or fermentation (as used to be done with breadfruit). Traditionally, houses were built of bush materials (e.g. Fig. 4.3c), which meant that, although they were easily destroyed by cyclones, they could be rebuilt quickly without assistance from outside the village. However, changing lifestyles, urbanisation, and increased populations, have made some traditional mechanisms less easy to apply than in past centuries. Modern houses, for example (e.g. Fig. 4.3d), require cash and time to build or rebuild. However, if carefully constructed, they are harder to destroy in the first place. Almost all villages in the non-atoll (or high) islands are located by streams, which makes them vulnerable to flooding after heavy rain, especially if the "stream" is a major river, as for Bureau in Fiji. However houses, in that village are built on stilts, giving protection against all but the worst floods (Fig. 4.3d). Another widespread modern adaptation measure is rainwater tanks, capturing water off the corrugated iron roofs of modern houses, which give some buffer against the occasional seasonal droughts which occur in some parts of the Pacific (Fig. 4.3e).

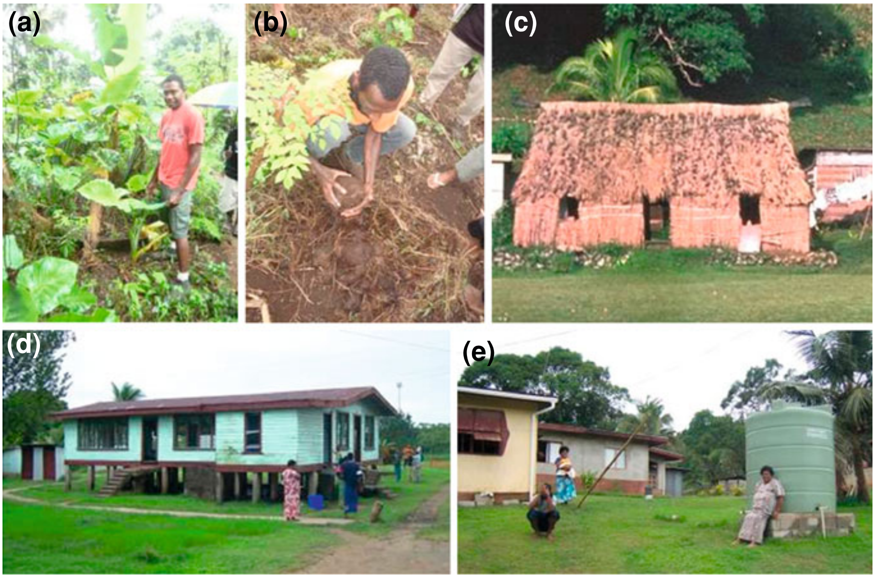

Fig. 4.3 Some adaptations to current climate extremes. **a** Food garden with a diversity of crops, (Teouma, Efate, Vanuatu). Crops in this garden include taro (2 varieties), yams (2 varieties), ‘island cabbage’ (*Bele*, several varieties) and bananas. **b** Traditional method for preserving yams (*Ipomoea batatas*) by burying them (Teouma, Efate, Vanuatu). **c** Traditional house of bush materials, easily rebuilt after a disaster (Moturiki, Fiji, 1977). **d** House on stilts in a flood-prone place (Buretu, Rewa Delta, Fiji). **e** Water storage in a drought-prone place (Bavu village, Western District, Fiji). See text for further discussion

Many of the physical effects of climate change will affect Pacific Island populations, mainly by making the existing climate extremes either more intense or more frequent, or both. Adapting to these effects of climate change will require similar techniques to those used now for climate extremes, but a more concerted effort. It will be like the step up from playing club football to playing in the World Cup: it’s the same basic idea but your opponents are stronger and faster!

There is a strong need, therefore, to identify, develop and disseminate community-based adaptation strategies that are suitable for use on diverse Pacific Islands, sharing similar climate change related issues. Such strategies need to be sustainable environmentally, economically and (above all) socially and culturally (Limalevu et al. 2010).

Sea Level Rise and Atolls

One physical effect of climate change, which is without precedent in the Pacific in the past few centuries, is the slow, but steady and insidious, rise in sea level, and the saltwater incursion it brings to coastal and low-lying land. Sea level rises with global warming for two reasons: (a) sea water expands with increasing temperature, and (b) ice that was on land melts into the sea. The 2007 report by the Intergovernmental Panel on Climate Change projects that sea levels may rise by 60 cm by the end of this century (IPCC 2007a). Yet the IPCC acknowledge that this is an underestimate, because it excludes future rapid dynamic changes in Arctic ice flow from Greenland and similar, but larger-scale, changes in Antarctica. More recent research, taking account of the fact that these ice flows are accelerating, suggests that the sea level may rise by 120–200 cm by 2,100, thereby swamping many coral atolls, in which most land is less than 2 m above mean sea level (Allison et al. 2009).

But an atoll will become uninhabitable long before it is totally submerged, because salt water incursion will pollute its fresh water supply, which is held underground, in a 'lens' floating on top of the salt water in the porous coral rock (see Fig. 4.4a). Salt water incursion from below is aggravated by extra high tides (king tides) and storm surges, which bring in salt water from above as it washes over the land (see Figs. 4.2c and 4.4c). This is already happening to many atolls in the Pacific, with the Carteret Islands of PNG and Funafuti (Tuvalu) being well-publicised cases. Currently, this occurs only every 2–3 years in Tuvalu. Observations and modelling suggest that the lens takes about 2 months to recover to fresh water, in the absence of further salt water influx (Terry and Falkland 2010; Terry and Chui 2012; O'Brien "personal communication").

Therefore, it is reasonable to infer that if sea level rises to the stage that saltwater inundation occurs every few months instead of every few years, then the lens will remain salty and the island will become effectively uninhabitable, with little fresh water available and crops unable to grow (Fig. 4.4). At current rates of sea-level rise this could occur within the next 30 years or so (i.e., as early as 2040).

Several PICs consist almost entirely of atolls, notably Kiribati, Tuvalu and the Marshall Islands. Because of these impacts of sea-level rise, all or most of the tens of thousands of inhabitants of these countries will probably have to migrate to other countries, either legally or illegally, by about 2040 (Weir and Virani 2011).

Social and Cultural Issues Raised by Climate Change Impacts, Adaptation and Mitigation

Large-scale forced emigration as a result of sea-level rise would obviously have a huge social and cultural impact on the countries concerned. Some analysts regard such large-scale forced migration as an extreme adaptation to climate change (Nunn 2009), while others argue it should be classified as an *impact* on the small islands and compensated accordingly by the countries whose emissions caused the problem (Barnett and Campbell 2010). Some PIC governments, notably Kiribati under President Tong, squarely face this issue and try to lessen its impact, on both the sending and receiving countries, by seeking much-increased legal migration to

Fig. 4.4 Vulnerability of atolls to sea level rise. **a** A well in Kiribati, drawing fresh water from the underground water lens. **b** The staple root crop (swamp taro, *pulaka*) is traditionally grown on atolls in pits tapping into the underground water lens. But this pit in Tuvalu has been made unproductive by salt in the water lens (*photo* R Thaman). **c** Salt water flooding surrounds a *mwaneaba* (meeting house) in Kiribati in October 2009 (*photo* taken at Tebikenikora Village, South Tarawa by NTNK Video, reproduced with permission)

nearby metropolitan countries, most likely through gradual labour migration (Nadkarni 2008; Tong 2011).

Food availability and people's access to food are among the first things to be affected following natural disasters. It therefore seems obvious that any significant change in climate on a global scale will impact local agriculture, and therefore affect the world's food supply (FAO 2008). In a changing climate regime, the need to strengthen food security is, therefore, paramount.

Human *health* is likewise expected to be affected by climate change, with increased heat stress, changes in the availability of clean water and the spread of vector-borne diseases such as malaria (e.g. *Anopheles* mosquitoes are migrating inland and to upland, cooler areas of Papua New Guinea).

Poorer countries are expected to bear a disproportionate burden from climate change, because of their inability to make the necessary adjustments without help. Thus, climate change raises issues of *equity* between countries. However, climate change also raises issues of equity *within* a country—that is, unequal access to economic and technical resources, such as between rural and urban areas, between rich and poor, between men and women, and between villages favoured with an adaptation pilot project and those without.

A key component of dealing with climate change in the Pacific is the active involvement of rural communities (villages).Success is only possible with *communities* who recognise their need and are seeking help. Participation of the whole community in planning and implementation is vital (Limalevu et al. 2010). This often requires special efforts to ensure that women and youth are consulted, and that their knowledge and skills are appropriately used.

Pacific people have a strong social and cultural attachment to their land, which is recognised in many countries by continued traditional ownership structures. Land and *culture* are intertwined, so that being forced to relocate to someone else's land or (even more so) to another country, is seen as a threat to the continued identity and culture of a people (Crocombe 2008). That is why President Tong of Kiribati frequently refers to climate change as a 'moral challenge to the world' (Tong 2011). Due to these moral and social justice aspects, churches can play a key role—not least because of their wide reach to communities. The Pacific Conference of Churches is actively working on this front.

In general, cultural capacity (norms and values) is modified or changed due to gradual shifts in climate, which eventually influences individual awareness and behaviour. A major study by the American Psychological Association's taskforce on psychology and global climate change (APA 2009) highlighted these issues that recur in the literature. Certainly, risk perception is often mediated by cultural values and beliefs (Christie et al. 2010).Therefore, it is likely that the culture of many PICs, which are already changing due to the interaction between traditional village-based societies and the modern economy, have been (or will be) affected by the impacts of climate change.

Conclusion: Challenges for the Pacific Islands

The biophysical impacts on the Pacific Islands of scenarios where global emissions of CO_2 continue to increase are frightening and would have huge social impacts, especially as they may include the forced relocation of many Pacific communities. Adaptation measures that cope with current climate extremes can also help alleviate many of the impacts of climate change, but only if much stronger international action is taken so that climate change is held within manageable limits. The technologies to enable this are largely available now, but the political will and economic and institutional structures are not.

Therefore, we agree with the conclusion of Nunn (2009), that the implementation of appropriate adaptation measures in the Pacific Islands requires 'a sea change in thinking' and in particular for Pacific governments to:

- take ownership of the climate change issue as it applies to their countries;
- ensure that viable and appropriate long-range plans are followed;
- ensure that climate change awareness is mainstreamed within the knowledge pools of these countries;

- ensure that community-level decision makers are given the knowledge and the right tools to make informed decisions about environmental management in a world where the climate is changing at an unprecedented rate.

Although Pacific Island leaders have spoken for years about the dangers of climate change, we are now beginning to see a range of on-the-ground adaptation actions, though many of these still depend on external funding, such as through the EU-ACP Global Climate Change Alliance. However, such actions will ultimately be in vain unless China, the USA, the EU and other large industrialised countries respond to the moral challenge of climate change by substantially reducing their emissions of greenhouse gases.

In short, for the Pacific Islands, climate change should not be treated as a matter of science shaped by computer modelers from outside, but as a vital social and cultural issue affecting almost every aspect of our future development, which raises many challenges for all our institutions and communities (Barnett and Campbell 2010).Many of these challenges stem from the remoteness (geographic isolation), and relative size (smallness) of the islands, especially in terms of financial resources and skills base. Some stem from culture, and recent changes in it arising from interaction between traditional village-based societies and the modern economy, particularly a tendency away from the self-help of centuries past to a dependence on overseas aid and from living with gradual shifts in climate on top of climate extremes.

Acknowledgments This paper draws heavily on material we have used for teaching at the University of the South Pacific, and on various presentations over the years, particularly one given to the Pacific Youth Festival in 2009. It is abridged from a chapter prepared for a forthcoming book on the Social Impacts of Climate Change in the Pacific Islands, to be published by the USP and UNESCO. We thank students and festival participants and an anonymous referee of KLIMA 2012 for their helpful feedback. We also thank those who have given us permission to use their photographs, notably NTNK Video of Kiribati.

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Chapter 5
A Framework for Technology Cooperation for the Successful Deployment of Renewable Energy Technologies in Pacific Island Countries and Territories

Emanuele Taibi

Abstract Local market conditions should be taken into account for successful technology deployment. The organisational framework should favour the consolidation of technology transfer through the establishment of appropriate mechanisms for capacity retention and private-sector involvement (i.e. public–private partnerships with independent power producers, renewable energy service companies, etc.). Ultimately, local capacity for maintaining and operating the technologies to be transferred is key. Every country or region has different priorities and reasons for desiring an increased deployment of renewable energy technologies: the EU has a focus on climate change mitigation, the US has a focus on energy security, and sub-Saharan African countries generally have the objective of energy access. Small Island Developing States in the Pacific have a clear focus on energy security at the regional level, while many of them also have an unfinished agenda for energy access. Technology transfer and cooperation efforts in the region must address the barriers to the deployment of renewable energy technologies to ensure long-lasting provision of energy access and durable improvement of energy security. Pacific energy ministers endorsed the Framework for Action on Energy Security in the Pacific (FAESP) and its associated implementation plan (IPESP) in April 2011. At the global level, the UN General Assembly has declared 2012 the "International Year of Sustainable Energy for All". This paper analyses the requirements for renewable energy technologies in Pacific Island Countries and Territories, the role of such technologies in the context of the FAESP and IPESP and their possible contribution to increased energy access, and identifies the main barriers to their deployment. Once common barriers have been identified, specific

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_5,

actions to address them will be highlighted in a framework setting out guidelines for policy development and identifying technology transfer needs, barriers to successful technology deployment and funding opportunities.

Keywords Small island developing states · Renewable energy · Technology transfer · Technology cooperation · Energy policy

Short Introduction

Larger countries in the Pacific region have hydropower plants for renewable energy (RE) production, and almost all regions aim to make more use of solar energy to reduce their dependency on diesel fuel. In order to succeed in ensuring both energy access and energy security, it is important to take into account local market conditions, funding possibilities, local capacity for maintenance and operating the technologies. All that should be combined into a well-organised system.

This study analyses what kind of RE technologies are needed in Pacific Island Countries (PIC), how they can help to produce the energy, what problems may occur and what should be done to avoid them.

Introduction

The Pacific contains some of the smallest and most remote countries in the world. Lack of scale and challenging logistics have led to an energy sector almost entirely dependent on diesel fuel for power generation.

Larger countries in the region, which have hydropower resources, largely benefit from the use of this reliable, affordable and environmentally friendly renewable energy source (Bazilian 2009; Bazilian et al. 2010; IPCC 2010). As a matter of fact, the Pacific Island Countries with the lowest price of electricity are the ones with the highest share of renewable energy in the mix, almost entirely produced by hydro power plants (Table 5.1).

In most of the region, there is an increasing focus on solar photovoltaic as a way to reduce dependency on diesel fuel for power generation. Although there is at least one donor-funded solar PV system in each country (in many countries there are dozens of them), the resulting share in the electricity mix is, if not negligible, generally below 1 %, as can be noticed in the Table 5.1.

A similar reduction in diesel consumption can be easily achieved with basic energy-efficiency measures on the supply side, which are usually much cheaper (KEMA 2010), but also less visible.

At the regional level, Pacific energy ministers endorsed the Framework for Action on Energy Security in the Pacific (FAESP), and its associated implementation plan (IPESP), in April 2011. These documents represent the guiding regional framework on energy matters in the Pacific.

Table 5.1 Residential and commercial electricity rates for selected PICs and the share of renewable energy

	Average residential electricity tariffs(US cents/kWh)	Average commercial electricity tariffs (US cents/kWh)	Renewable energy share in electricity (%)
Fiji	*16.1*	*23.8*	*50*
Samoa	*35.3*	*42.3*	*43*
RMI	38.8	44.8	0.22
Palau	41.3	46	0
FSM	42.6	46	0.45
Cook Islands	48.5	54.9	0
Niue	49.7	48.5	2.6
Tonga	50	50	0
Solomon Islands	50.5	55.5	0
Vanuatu	72.1	50	–
Tuvalu	83	94.3	2.1

The only two countries with relevant hydropower generation are in italic

As the name suggests, the main focus is on energy security. The driving force behind the preparation of this framework is the need to reduce the region's high vulnerability to rising and volatile oil prices.

The suggested means to reduce this vulnerability are:

- mainstreaming energy security into national planning and budgetary processes;
- improving energy efficiency and conservation;
- adopting financially viable renewable energy sources;
- where appropriate, taking regional and subregional approaches to petroleum procurement.

Technology Cooperation on Renewable Energy in the Pacific

The FAESP emphasises that technological solutions need to be "cost-effective, technically proven and appropriate", while acknowledging the importance of capacity building for ensuring proper maintenance and use of these energy technologies. Most importantly, it clearly states that each country should invest in its human capital for energy, "to gain the skills needed for the planning, management and implementation of national energy plans".

Lack of capacity at the national level is often the limiting factor in the identification of the most cost-effective solutions, whether for improving energy security; developing realistic, yet ambitious, energy plans or, often, for accessing additional sources of funding for the energy sector. Numerous facilities exist, both from bilateral and multilateral donors, which could provide a good boost to the removal of barriers to the deployment of renewable energy in the Pacific (Gualberti and Taibi 2011). Far too often, these facilities are too complex for national institutional actors to access, and many smaller Pacific Island Countries are unable to submit acceptable proposals. Yet these grants could be expected to be sufficient to achieve ambitious renewable energy targets on their own. However, while grants are useful for technology demonstration and for building the capacity of local actors in specific renewable energy technologies, significant deployment requires larger investments. Lack of fiscal surplus prevents direct investments from government, while the expensive diesel fuel baseline makes an excellent case for an economically viable loan, available from multiple commercial development banks; these banks usually provide particularly favourable conditions and associated, free technical assistance. However, some Pacific Island Countries have reached the threshold at which they cease to be eligible for further loans from development banks; in these cases, the focus should be on how to mitigate the risk and reduce the interest rates applied by commercial banks, which usually consider the Pacific a high risk region for lending. Grant funding can, for instance, be used to mitigate the risk and reduce the interest rate on commercial loans.

The other way to scale up the deployment of renewable energy in the Pacific would be to increase private-sector participation. At present, in many cases, private sector involvement is often limited to small companies that provide technical services to grant-funded projects. Although important, this is not sufficient to scale up the deployment of renewable energy in the region. There is an urgent need to address the "orgware", creating a level playing field for investors to bring Foreign Direct Investments (FDI) into the Pacific Island Countries.

Capable policymakers are needed to create a stable policy framework for Independent Power Producers (IPPs) to invest in renewable energy deployment in the Pacific region. The baseline is a very high cost of power generation through diesel; however, although the potential for renewable energy technologies to provide more affordable electricity is there, it is often largely unexploited.

According to the definition from IIASA, technology is the sum of hardware, software and orgware. While hardware in our case is simply the equipment that will produce electricity from renewable energy sources, and the software is constituted by the knowledge required to design, operate and maintain these renewable energy systems, orgware is often the overlooked component in technology cooperation projects. Orgware is defined as the set of institutional settings and rules for the generation of technological knowledge and the use of technologies.

This article argues that the main role for technology cooperation on renewable energy in the Pacific should concentrate on orgware to enable the creation of a strong and stable policy framework for the improvement of energy security in the Pacific, through increased deployment of renewable energy technologies.

This deployment should be started by accessing the available grant financing, scaled up through access to soft loans from development banks, and completed by creating conditions for the private sector to invest its own capital in the deployment of renewable energy in the Pacific.

As an integral part of this deployment, national capacity needs to be strengthened in all its dimensions, from policymaking to technical expertise on the technologies. Although this has been addressed in the short term as part of past donor-funded projects, retention of this expertise has always proved difficult. Some potential solutions have been tested in different contexts, but none have yet been proven successful in the Pacific. In the long term, investments in the education sector of each country are needed to create the local energy experts of the future—both policymakers and technicians. As an example, energy experts trained at the University of the South Pacific in Fiji provide a critical mass of expertise for the energy sector of Fiji itself. Through regional organisations, this expertise often reaches out to the rest of the Pacific.

Orgware: The Institutional Framework

Enabling the *creation of knowledge of renewable energy technologies through national or regional training institutions* is the first change that is needed for the long-term sustainability of efforts for a more energy-secure Pacific.

Being able to produce knowledge of technology locally is the first step toward enabling a paradigm shift from assistance-based, adhoc, small renewable energy projects to the self-sustaining, large-scale deployment of renewable energy technologies. Trained policymakers can do better energy planning. Trained designers and technicians can lower the cost of renewable energy projects, allowing for more competitiveness and, ultimately, more energy produced for the same amount of money. This will also radically lower the costs associated with a lack of professional maintenance, which translates into poor efficiency and, ultimately, low reliability of energy supply.

To scale up the deployment of renewable energy after initial support, in the difficult period between first adopting technologies and their full commercialisation, *the private sector must be involved.*

The initial risk is taken by the government—if not with its own money, then through grants and possibly loans to initiate deployment at scale—as it is essential to have a stable and incentivising playing field in place for the private sector to invest in renewable energy. Although the scale in the Pacific might be generally too small for large investors to be interested, the high cost of producing power from diesel generators can alone provide very profitable returns on investments for medium-sized investors. As many power utilities in the Pacific structure their tariff based on a fixed amount per kWh for operational costs, plus a changing amount linked to diesel price, a simple tender process where the winner is the company that bids for the lowest discount on the fuel price would transfer the risk connected with fuel price volatility from the government to the investor.

Another essential component of the institutional framework, which is to be addressed, is the *strengthening of the role of energy offices* in government structures. Very often, energy offices in the Pacific have very few personnel, or are even staffed by one person, sometimes with no educational background in energy. Considering the relevance of energy expenses in the budgets of Pacific Island Countries, an investment must be made to enable national energy offices to undertake a serious energy policy process, and political support must be given to these offices and the policies produced by them. Due to the same constraint on energy experts in the government structures of Pacific Island Countries, there are still many opportunities for grant funding that remain unexplored or untapped. The cost of hiring a person with some energy background, capable of writing grant proposals, would be easily covered by a small fraction of the grants this person would leverage (Fig. 5.1).

In the short term, this would be an increased cost incurred by the government; however, by the end of the first year, the investment will already give returns: even a 1 % saving in the multimillion-dollar yearly energy expenses through a more effective energy office would repay the salaries of the additional staff many times over. By the same token, if the policies put in place by energy offices are not reflected in the national budgeting process, it will not only limit the extent to which the policies can be actually implemented, but will also damage their credibility in view of the private sector and the lending institutions. Without an associated budget commitment, any policy will be unlikely to bring the results it has been designed to achieve.

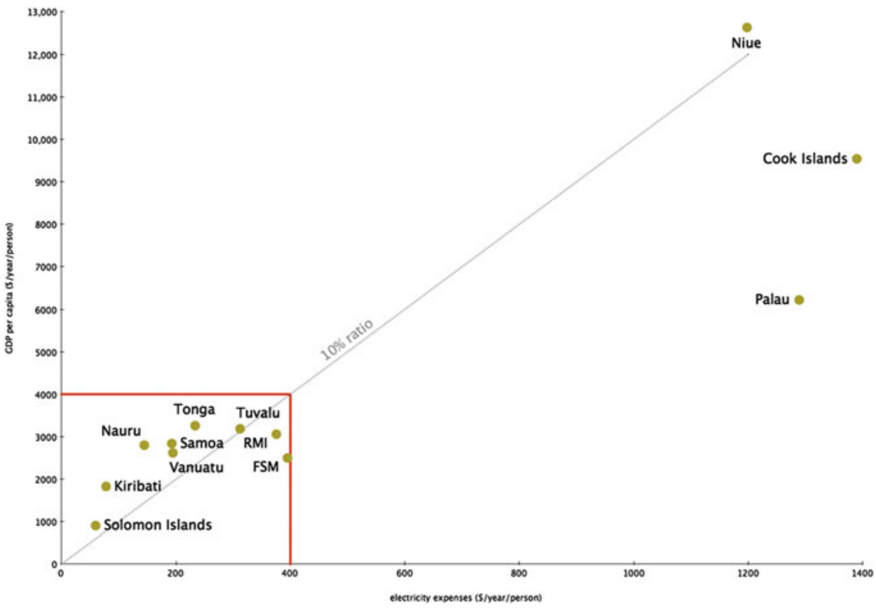

Fig. 5.1 Yearly expenses on electricity compared to GDP in selected Pacific Island countries (per capita values)

Software: Capacity Needs

Having training programmes set up in local training institutions and ensuring energy offices are properly staffed is only the first step. The next question is how to create knowledge through these training institutions, and how to educate policymakers and technicians on renewable energy matters. Technology cooperation efforts should use the existing institutional framework to address the capacity needs of each country. Training the trainers gives longer-lasting results than repeating one-off, adhoc training courses for each technology cooperation project that takes place. The same applies to training policymakers: training courses should build on existing material, in order to gradually increase the knowledge of both the institutions providing training and those directly involved in the energy policy process.

This is the approach taken by the North REP project in the Federated States of Micronesia, where the training components are conveyed through the local college in order to train their trainers and provide the training materials for the incorporation of solar PV into their electrical vocational courses.

The strengthening of policymakers' capacity to produce sound energy policies and regulations needs to be addressed under the software component of technology cooperation. Whilst the orgware essentially has to provide energy offices with sufficient personnel, and ensure that the policies they produce are able to be implemented, the software component should support these offices in the adjustment of the country's body of rules and regulations. As it has been expressed by Pacific Island leaders on recent occasions, there is a need for Independent Power Producers (IPPs) to scale up renewable energy deployment in the Pacific. However, most Pacific Island Countries do not have regulations for IPPs to operate under the existing legal framework, and often the existing law prohibits any entity except the public power utility from producing electricity.

Another important issue that energy offices need to be able to tackle is the transition from an electricity tariff based on a fixed component and a variable component linked to diesel fuel price, to a tariff that incorporates the different cost structure associated with a significant share of renewable energy in the electricity generation mix.

Both these issues have to be addressed under the software component of a technology cooperation framework, in order to establish the necessary conditions for rapid, large-scale deployment of renewable energy technologies in the Pacific.

Hardware: Technology Needs

There has commonly been a problem in the Pacific with operation and maintenance of renewable energy systems. While training reaches out to all the technicians involved in operating and maintaining renewable energy systems, to mitigate this problem in the short term, technology cooperation should choose the hardware and the technology accordingly. The technology which, on paper, provides the lowest cost per unit of electricity produced, or especially which minimises the initial investment cost, is not necessarily the best. Existing local capacity should be taken into account in the design of renewable energy systems, assuming that a poorly operated or non-maintained system will have a lower efficiency and a shorter lifetime. Taking these elements into account would favour technologies that require less maintenance and that are easier to operate. In addition, sometimes more expensive equipment will last longer in the harsh, salty environment of most Pacific Island Countries. Replacing rusted or failed components, especially in remote outer island locations, sometimes requires many months, on some occasions more than a year. To increase the emphasis on "spending more today, to spend less tomorrow", oversizing the components of a renewable energy system is often good practice, especially when storage is involved.

To give a simple example, if you are providing power to a remote rural clinic, one of the great benefits is that you do not have to rely on people to come from the main island to administer vaccinations. However, if you undersize your battery bank, in the case of an unusually long series of very cloudy days the system might run out of power. This is not unlikely, as, on cloudy days, artificial lighting will also be used during daytime, shortening battery life still further. Failing to keep vaccinations cold will make them unusable, defeating the main purpose of electrifying the rural clinic.

In brief, technology cooperation on renewable energy in the Pacific has to carefully address not only the orgware and software components, but also the hardware. Harsh environmental conditions, difficult—sometimes extremely difficult—logistics, and poor capacity to operate and maintain renewable energy systems all require the careful selection of technology, components and design.

Towards a Framework for Technology Cooperation on Renewable Energy in the Pacific

Based on the previous considerations, the following framework is presented to identify goals, actors and concrete actions toward the large-scale deployment of renewable energy in the Pacific, through the concerted cooperative efforts of international, regional and national actors, governments, training institutions and the private sector. For effective technology cooperation, all these actors should be involved and all the conditions must be fulfilled, since overlooking one of the dimensions of technology cooperation might hinder efforts in the other dimensions, and render any result achieved unsustainable in the medium and long term.

	Orgware	Software	Hardware
Goals	Strengthening national and regional policymaking and training institutions in the field of renewable energy Creating an enabling policy framework for private sector involvement in the deployment of renewable energy	Building the capacity of national policymakers on renewable energy planning and regulation Enable national training institutions to deliver quality vocational and graduate training courses in the field of renewable energy Building technical capacity in the private sector and public utilities for supporting the deployment of renewable energy (i.e. on installation and maintenance of RE systems)	Identification of the most appropriate technologies and technical requirements for RE systems on each Pacific Island Deployment of the most appropriate RE technologies on a large scale in the Pacific
Participants	Regional and international organisations, donors, national governments, regional and national training institutions	Regional and international organisations, donors, national governments, regional and national training institutions, private sector, public utilities	Regional and international organisations, donors, development banks, commercial banks, private sector, public utilities
Scope of activities	Creation of vocational and graduate courses in renewable energy in local training institutions Strengthening of the role of national energy offices Creation of policies and regulations for the promotion of renewable energy	Adhoc training courses for policymakers on energy planning Support for policymakers from regional and international organisations in the development of national regulations on renewable energy Train-the-trainers courses at national training institutions, and institutional support for the incorporation of renewable energy topics in their vocational and graduate courses Adhoc training courses for the private sector and public utilities for installation, operation and maintenance of renewable energy technologies	Identification of the most appropriate technical requirements and existing standards of renewable energy technologies in the Pacific context, and of environmental conditions Use of all available funding sources to deploy renewable energy technologies on a large scale in the Pacific

(continued)

(continued)

	Orgware	Software	Hardware
Resources	Bilateral and multilateral donors, government resources, training institutions' resources	Bilateral and multilateral donors, private sector	Bilateral and multilateral donors, concessional loans, commercial loans, public utilities' resources, private-sector equity investment

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Chapter 6
The Vulnerability, Adaptation and Resilience Capabilities of Water Sector Users in Mauritius

Reshma Cunnoosamy

Abstract Mauritius is classified as a water-stressed country. This study aims at evaluating the vulnerability and resiliency levels of water users (domestic, agricultural and commercial/industrial/tourism) in the face of water scarcity, and with existing adaptation and mitigation measures. A specific zone of water supply representing the different users, namely the Northern District Water Supply System, was selected as the case study. A sample size of the target population was determined and a quota-sampling method was used to indicate the quota sample per sector. Mixed-mode surveys were conducted using the same questionnaire. The questionnaire included indicators of vulnerability, adaptation and mitigation, as well as resiliency. A scale of 1–5, 1–2 as lowest rating, 3 as moderate, 4–5 as high was generated depending on the percentage obtained through the indicators. Results were compared between users. Results show that although all sectors are vulnerable to water scarcity, the agricultural and domestic sectors face an increased risk. The sectors with a higher level of vulnerability are also those with a lower level of adaptation. On average, all users show only a basic level of resilience, but these lie within a range of importance. This paper adopts a sector-based approach to investigate the level of vulnerability and resilience of each user of water resources. It provides insightful and specific data for each sector, and proposes a comparison between the different users. Observations by experts in the water sector could provide more integrated water resource management recommendations.

Keywords Mauritius · Water stress · Vulnerability · Adaptation and mitigation · Resilience

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_6,

Short Introduction

Small Island Developing States, like Mauritius, are especially vulnerable to the effects of climate change on resources, particularly freshwater. It has become imperative not only to conduct research pertaining to water resources, but also to take appropriate conservation measures.

This paper seeks to explore to what extent the different users—domestic, agricultural, commercial, tourism and agricultural—of the water resource have the capability to adapt to water scarcity. It also investigates whether users are actually aware of water problems, which means they have to overcome these, and that further adaptation and mitigation practices need to be implemented.

Introduction

The Republic of Mauritius, located in the south-west of the Indian Ocean, east of Madagascar, is categorised as a water-stressed country by the United Nations. It faces significant water issues in the face of increasing pressure on this resource due to rapid urbanisation, and population and economic growth, a predicament intensified by the impacts of climate change.

The chief source of water in Mauritius is rainfall. Despite a rather wet climate (an average annual precipitation of more than 2,041 mm), the topography of Mauritius, the fact that a large fraction of the total amount of rainfall falls during the summer months, and cyclonic events have the consequence of a high level of surface runoff, about 53 %, of which only one third is tapped by reservoirs, lakes and rivers. The high temperatures cause 38 % of the water balance to be lost through evapotranspiration. As such, the remaining just 9 % of rainfall contributes to recharging the aquifers.

A sufficient, safe and dependable supply of water has to be mobilised to meet the various demands of all sectors: agricultural, domestic, industrial and tourism, among others. As such, Mauritius counts 11 man-made reservoirs with a total storage capacity of 90.7 mm^3, the two largest being Mare aux Vacoas and Midlands Dam. Water is also extracted from about 350 river-run offtakes, providing some annual mobilisation of 514 mm^3 of surface water (Proag 2006). Groundwater contributes 145 mm^3 of water on average yearly (Proag 2006).The Ministry of Public Utilities is the core institution responsible for the legal operational framework and management of water resources in Mauritius; authority is delegated to the Water Resources Unit in charge of assessing, managing, developing and conserving water resources. Parastatal bodies; the *Central Water Authority*, the *Irrigation Authority*, the *Waste Water Management Authority* and the *Central Electricity Board* have specific functions in managing the available water.

This study aims to evaluate the degree of vulnerability and resiliency of users of water resources—domestic, agricultural and commercial/industrial/tourism—with existing adaptation and mitigation measures in Mauritius. Along with the use of national data, the Northern region, with its highest number of users and water production among the six supply zones, was selected as the case study for conducting this survey.

Vulnerability to Water Shortage in Mauritius

Diop and Rekacewicz (2003) in their analysis of water scarcity in African countries, place Mauritius in a situation of waterstress; in 1990 1,700–2,500 m^3 of water/people/year (vulnerable category) was available but by 2025 it is projected that this amount will reach 1,000–1,700 m^3 of water/people/year (water-stress category). During recent decades, the island has witnessed an accelerated rate of development in the agricultural, industrial and tourism sectors, as well as a growing population, leading to a rise in the standard of living. This puts more pressure on existing water resources, as demand increases. Water produced by the *CWA* has increased by 20 % over the last 10 years.

Existing supply systems will not be able to sustain such an increase. Although piped water is accessible to around 99 % of the population, there are certain inequalities in distribution, particularly in the east and west of the island and to properties on higher ground (Mauritius Strategy for Implementation—National Assessment Report 2010) (Fig. 6.1).

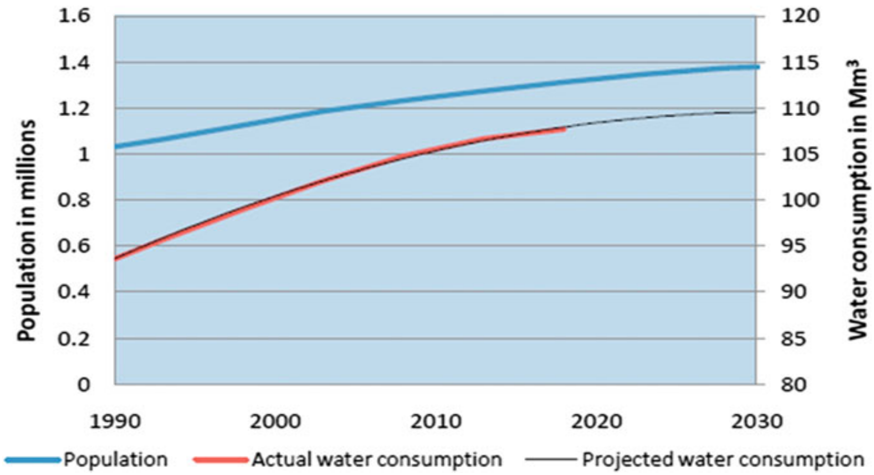

Fig. 6.1 Population and projection of water demands (Digest of Energy and Water Statistics CSO 2009)

Impacts of Climate Change

The impact of climate change on water resources will aggravate the existing situation: intense rain episodes with a high runoff capacity; an increase in droughts; salinity intrusion into coastal aquifers and higher temperatures, increasing the rate of evapotranspiration, will increase vulnerability (Mauritius Strategy for Implementation—National Assessment Report 2010).

The island depends on cyclonic and summer rainfall to replenish reservoirs and aquifers; if these were to fail, a situation of drought would arise. Between 1905 and 2007, there has been a decrease in rainfall and more frequent droughts, as the figure below shows. The temporal distribution of rain has also been modified: the number of rainy days has decreased, but the frequency of heavy rain events has increased, indicating that rainwater-harvesting capacity has to be enhanced (Meteorological Services 2009). The number of days with a daily maximum temperature of above 30 °C is increasing at a rate of 0.6 days per year, while the number of days with a minimum temperature of above 20 °C is increasing at a rate of 1.4 days annually (Meteorological Services 2010 Technical Paper).

Physical factors, like temperature change and the modification of rainfall patterns, distribution and amount, are all closely linked to climate change (Meteorological Services 2009) or topography that favours runoff (Maudarbocus et al. 2001), as well human factors like pollution, increasing pressure on water resources and significant losses through leakage or wastage, make Mauritius vulnerable to water stress (Fig. 6.2).

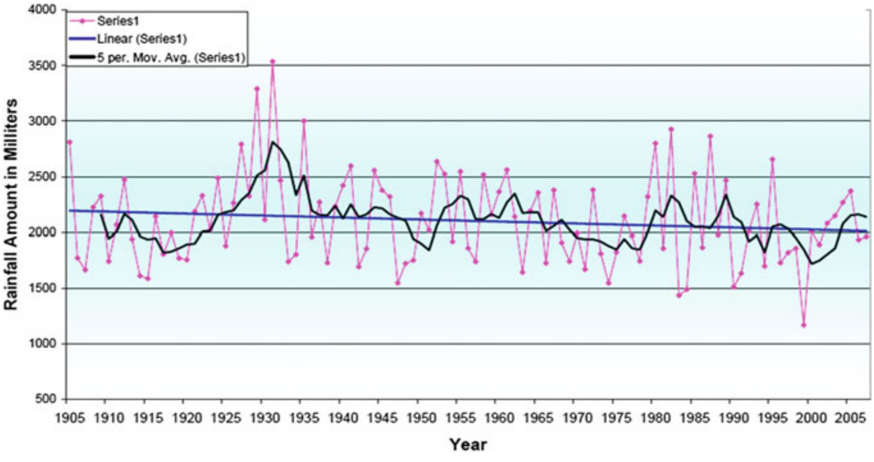

Fig. 6.2 Decreasing trend of mean annual rainfall (Meteorological Services 2009)

Users' Vulnerability Assessment

Waterstress is an indisputable issue in the island state of Mauritius. Among the six supply systems, one for each zone: Port Louis, the North, Upper Mare aux Vacoas, Lower Mare aux Vacoas, the South and the East, the largest system, namely the Northern District Water Supply System, was selected as our case study because it entails the highest percentage of the total population served, has the highest normal water production per day and has almost equal measures of surface water and groundwater utilisation.

A margin of error of 8 % was targeted for this study; as such, the sample size for the target population, considered as infinite, was determined using the following equation:

$$n = \frac{t^2 PQ}{d^2}$$

t represents abscissa of the normal curve that cuts off an area of alpha at the tails. d represents the margin of error. P represents the population proportion. Usually 0.5 is used for P and 0.5 for Q.

Therefore:

$$\begin{aligned} \therefore n &= \frac{1.96^2 \times 0.5 \times 0.5}{0.08^2} \\ &= 150.0625 \approx 150 \end{aligned}$$

The total sample size for conducting the survey was thus set at 150.

The total water requirement (raw and treated water) for 2009/2010 for the North was 133,345 m^3/d (excluding the institutional sector, which benefits from unbilled consumption). That of the domestic sector was 95,460 m^3/d, the agricultural sector 9,220 m^3/d, while, for the commercial/industrial/tourism sector it was 28,665 m^3/d, corresponding respectively to 72, 7 and 21 % of the total water requirement. The total sample size being 150, the quota sample per user, according to the percentage of total water requirements, was established as follows: 108 for domestic users, 11 for agriculture and 31 for commercial/industrial/tourism users.

Survey data was collected during the period of October to December 2011 through the use of questionnaires using mixed-mode surveys as extensively as possible throughout the Northern region. Direct, telephone and post interviews were carried out, and, depending on the literacy level of respondents, this was done using the island's native Creole language. Direct observation was also possible during field interviews. The same questionnaire, with twenty three questions, was used for all users in order to allow data comparison. The first two questions set the context of the survey. The other questions up to number six concerned the problem of water shortage, and to what extent the respondents sensed they were affected. The remaining questions involved the level of adaptation, mitigation and awareness of causes of water scarcity, as well as their capacity for resiliency. Open-ended questions permitted respondents to answer in their own words, and gave an insight into opinions that might not otherwise have been expressed. Closed-ended questions on the other hand, necessitated the respondents to make a choice, or evaluate and rate a variable, as well as gauge their knowledge .

Respondents to the survey were asked to what extent they felt vulnerable to water scarcity. Questions pertaining to water demand, opinion on volume, pressure and frequency of water supplied and water shortage problems were asked. The three indicators for vulnerability show that most users consider themselves to be affected by water stress. A scale of 1–5 was used to evaluate the extent, with 1–2 considered as low, 3 as fairly high, 4 considered as high and 5 as critical. The majority of users from all sectors declared that their demand for water has increased, and only a very small percentage believes that it has decreased. The CWA reports an increase of 20 % of water mobilised over the years 2001–2010, confirming that the trend for water demand is on the increase. Users of the agricultural sector are, for the most part, either moderately satisfied or unsatisfied with the volume, pressure and (minimum) frequency of the water supplied. Domestic users are also moderately satisfied or unsatisfied with frequency. CIT (commercial/industrial/tourism) users are more satisfied or moderately satisfied with the volume, pressure and frequency supplied. More than 50 % of all users believe they face water scarcity, with the highest percentage in the agricultural sector.

Vulnerability indicators—water demand, water supply satisfaction and water shortage problems—demonstrated that, although all sectors are vulnerable, the domestic and agricultural sectors are most likely to endure more hardships, with a fairly high level of vulnerability, estimated at level 3 on a scale of 5 (critical). The CIT sector, with a level of 2.3, was deemed less vulnerable than the other sectors, but it is to be noted that certain disparities do exist within this sector: the most economically well-off touristic and commercial outlets and industries have lesser concerns of water shortage.

Results for the Effectiveness of Adaptation and Mitigation Measures

Another component of the survey included indicators of what extent adaptation and mitigation measures have already been adopted. These comprised alternative water sources, the need for water storage and the sources of the water stored, and have been used to measure the level of adaptation.

Alternative Water Sources

A heavy dependence purely on the CWA was considered as disadvantageous; other reliable means of obtaining water, such as rainwater harvesting, recycling wastewater or desalination, allow users to obtain water even if the CWA does not meet the totality of their demands. It must be noted that none of the respondents from any sector mentioned rain water harvesting as the most significant alternative source of water. 72 % of users of the agricultural sector use water from canals and rivers and 18 % from boreholes. Although the percentage of water available from alternative water sources is high, it does not mitigate the impact of fertilisers and pesticides pollution (leading to eutrophication in the long run) and excessive use of water sources.

29 % of CIT sector users utilise desalinated and recycled water for purposes that do not require potable water, adapting to water shortage, and, at the same time, limiting excessive consumption of treated water, a mitigation measure. However, desalination is costly, energy consuming and the release of brine into seawater can affect marine ecosystems (Mauritius Environmental Outlook Report 2010). This technique is also not available to smaller hotels, industries and commercial outlets.

Only 25 % of domestic users, particularly low-income households, use streams and springs that flow near their locality as alternative water sources. The water is used mainly for cleaning purposes, like washing clothes. Again, the pollution risk exists and, to conserve the quality of this fresh water, particular precautions are needed (Mauritius Strategy for Implementation National Assessment Report 2010).

Water Storage

The need to store water denoted a certain degree of preparedness for water scarcity. It indicates that there has been an investment and a will to remedy immediate water shortages. More than 60 % of users from all sectors store water (more than 80 % for CIT and the domestic sector), mostly in safe and durable tanks. 36 % of users in the agricultural sector, however, do not store water, presumably because a high percentage is obtained water from canals, rivers and boreholes.

Sources of Water Stored

Beyond the need to store water, the sources of the water stored also helps to define the level of adaptation. If the highest percentage of the water stored comes from the CWA, adaptation can be considered to be low. All three sectors depend heavily on the CWA for water storage, at 43 % of users from the agricultural sector, 94 %

in the domestic sector and 80 % in CIT. Rain water harvesting; a simple and effective adaptation measure (Mauritius Environmental Outlook Report, 2010) is only marginally adopted, though a higher percentage of agricultural sector has adopted this measure. Waste water recycling and desalination is available to certain users of the CIT sector for storage.

In comparison to vulnerability, the level of adaptation and mitigation methods that have been adopted per sector has been investigated and ranged on a scale of 1–5 1–2 being a basic level of adaptation, 3 a moderate level and 4–5 high. An average of adaptation and mitigation indicators showed that the domestic sector has an adaptation level of only 2, and the agricultural sector a level of 2.6: a basic level of adaptation. The CIT sector is slightly more prepared for water scarcity with a moderate level of adaptation: 3. It can be reasoned that the level of adaptation and mitigation has to be increased, more urgently for the domestic and agricultural sector, and enhanced for users in the CIT sector (including all users regardless of economic performance). Both more adaptation measures to counter balance effects of water stress and more mitigation measures to limit effects of climate change on rainfall and population pressure must be put in place.

Results for Resilience Capacity

The higher the level of adaptation and mitigation measures, the lower the vulnerability and the higher the resiliency. In addition to indicators, responses to open-ended questions have been considered in evaluating resiliency, as participation of all users is necessary to tackle the problem of water scarcity. These included awareness of causes of water scarcity and solutions proposed, acknowledgement of and attitude towards water wastage, re-use of grey water, water collection awareness and its importance for users, and the level of investment, as well as the willingness, to adopt water collection methods if facilities were to be provided. The same scale was used as for adaptation: 1–2 being a basic level of resilience, 3 a moderate level and 4–5 high.

Awareness of the Causes of Water Scarcity

A resilient population has to first acknowledge its situation of vulnerability, and then identify its spheres of weakness, so as to be more open to adaptation and mitigation, thus increasing resilience. Agricultural users have a sound knowledge of both physical/climatic and human factors that lead to water scarcity; a higher percentage believed in human induced factors, while physical/climatic factors were also mentioned, but to a lesser extent. Yet, the solutions proposed were rather simplistic: government investment for the most part, while some suggested reforestation, and some had no solutions to propose. Although agricultural users are aware of causes of water scarcity, most believe human factors to be responsible and cannot propose far-reaching solutions. This is possibly due to a lower level of education.

About 80 % of domestic users provided more thorough reasons for water scarcity, probably because of a higher level of education (particularly middle and high income households) than agricultural users. Some even believe deviation of streams from reservoirs, pollution and the mindset of users allowing wastage to be causes. More than 60 % of respondents linked physical/climatic factors to water stress. Domestic users also proposed more drastic and extensive solutions, ranging from management issues and tighter laws to sensitisation campaigns, rainwater collection and even privatisation of the water sector. More than a quarter of respondents also advocated environmental protection measures. More mitigation and adaptation measures were proposed by the domestic sector than by the two others.

The CIT sector has the highest percentage of users who believe climatic/physical factors bring about water scarcity. Human-induced factors were mentioned to a lower extent and environmental damage, such as pollution, was not mentioned by larger hotels and industries at all, only smaller touristic and commercial resorts believe so. More than half of respondents proposed better management and more storage facilities, while others believed reforestation, desalination and water recycling would help. At the same time, some disclosed that it was more important to them to carry on their economic activities. Most of the CIT sector users, being the least vulnerable and having more adaptation measures at their disposition, were less keen to propose solutions, although most respondents had a fair level of education. More adaptation measures (like increasing storage or better management policies) than mitigation ones (for instance reforestation or protection of catchment areas) were proposed by most users from all sectors.

Most users in all sectors probably believe that an increase in supply would solve the problem. However, only an integrated approach will increase resiliency (UN World Water Development Report, 2009). Less than 50 % of agricultural respondents believe wastage occurs, as small planters consider there is not sufficient water for use in the first place, and larger plantation owners believe that some abuse can happen, particularly through irrigation methods like the overhead method. Although against wastage, most users merely informed authorities in case of leakages and passively believed not much could be done. This sector was least responsive in proposing means of avoiding wastage; counselling and economic incentives could be proposed to encourage optimised use of water resources (Proag 1995).

Acknowledgement of and Attitude Towards Water Wastage

A little more than 50 % of CIT users acknowledged water wastage through cleaning purposes, lack of appropriate technology and leisure facilities. A higher percentage agreed more should be done to avoid wastage, but most did not feel compelled to do so. However, some did propose water saving technologies. A legal framework and user tax could be established to decrease pollution loads and grants or tax exemptions provided to encourage water saving technologies (Proag, 1995).

Among domestic users, more than 60 % acknowledged that wastage occurs through daily chores, but some also claimed wastage was inevitable and it was their right to do so. A few avoided wastage and would call the authorities in the case of a leakage. Simple water saving measures, rain water collection and education were proposed. Communities could be strengthened to allow water preservation and increase their capacity to become sustainable.

More than 70 % of agricultural users do not recycle water. Water saving techniques could be implemented to reduce consumption if reusing grey water were not possible for most of these users (Mauritius Strategy for Implementation National Assessment Report 2010). The percentage that does not reuse grey water is equally high for domestic users, at more than 70 %, and again, more education and strengthening policies are needed. A higher percentage of CIT users recycle their water compared to other sectors, but this technology should be extended to include as many users as possible.

Level of Investment and Willingness to Adopt Water Collection Methods

Agricultural users have the highest percentage of long-term water supply. CIT users have a combination of short and long term means of water supply, but the long term means are not available to users with lesser economic resources. Domestic users have the least percentage of alternative water sources, and most of those are short term. About 80 % of CIT users, the highest percentage of all sectors, have knowledge of water collection methods and believe it important to invest in those methods. Only 38 % have actually invested in those methods, indicating again, that although none of the users denied its importance, most of them cannot, or will not, invest. More than 50 % of domestic users are aware of water collection methods and more than 70 % agree on their importance, while a few do not agree it is necessary. Less than 10 % have actually invested in water collection, and none of these are users from high-income households, who content themselves with the available supply. More than 50 % of agricultural users are not aware of these methods, and more than 30 % believe it unimportant to do so, or have not thought about it, probably due to a lower level of literacy among users. More than a quarter of users have nonetheless invested in water collection.

The agricultural sector has the highest percentage of users very willing to invest if facilities were to be provided, but more than 20 % are still not willing. More than a quarter also did not know what could be done to lessen vulnerability, and others proposed more storage measures. Yet again, although having the will, users need more advice and incentives on water- collection and saving techniques.

Table 6.1 Respondents' perception of vulnerability, adaptation, mitigation and resilience

Sector	Vulnerability level	Adaptation and mitigation level	Resilience level
Agriculture	3 (Fairly high)	2.6 (Basic)	2.3 (Basic)
Domestic	3 (Fairly high)	2 (Basic)	2.5 (Basic)
CIT	2.3 (Low)	3 (Moderate)	2.8 (Basic)

The CIT sector has only 3 % of users not willing to invest; others are either very willing or willing. More adaptation measures that included all spheres of society and user responsibility were proposed. More than 50 % of domestic respondents were willing to invest and 13 % were not. Most of the users proposed both adaptation and mitigation measures, but believed that the authorities had to apply reforms to the water sector and only then would they cooperate and invest in water collection methods. A few assigned responsibility to the authorities only.

Survey data was entered into the spreadsheet application programme Excel 2007 for statistical analysis. The percentages obtained from these indicators were translated on a scale of 1–5 depending on the percentage obtained from the indicators that assess the critical issues: vulnerability (1–2 was considered as low, 3 as fairly high, 4 considered as high and 5 as critical), adaptation and mitigation (1–2 basic level of adaptation, 3 moderate level and 4–5 is high) and resilience (1–2 basic level of resilience, 3 moderate level and 4–5 high). This methodology was adapted from the *Etude de Vulnérabilité Aux Changements Climatiques,* commissioned by the *IOC* in 2011, to suit the purposes of this study. The scale system aims at facilitating the reading of results and interpretation of findings. For instance, to find the level of vulnerability of the agricultural sector, an average of the level obtained from each vulnerability indicator was calculated, and so on. The table below summarises the study's findings (Table 6.1).

Conclusion

The overall perception of users concerning vulnerability to water scarcity is fairly high within the agricultural and domestic sectors. The CIT sector is comparatively less vulnerable, with disproportions across and within this sector. The domestic and agricultural sectors have only a basic level of adaptation, while the CIT sector is slightly more prepared for water scarcity, with a moderate level of adaptation. The level of adaptation and mitigation has to be increased, more urgently for the domestic and agricultural sectors, and enhanced for users in CIT (including all users, regardless of economic performance). Both more adaptation measures to counter balance effects of water stress and more mitigation measures to limit the effects of climate change on rainfall and population pressure must be put in place.

The results demonstrated are, in order of importance, resilience level for CIT, domestic and agricultural sectors as 2.8, 2.5 and 2.3 respectively. This means that all sectors have only a basic level of resilience, with the CIT sector having the highest level and the agricultural sector the lowest. Much more remains to be done so as to increase water users' resilience and, at the same time, ensure sustainable water management.

The example of the Americas, middle income countries, could be adopted at Small Islands Developing States Level. A series of measures have already been implemented within the framework of the Regional Policy Dialogue, which aims at an integrated approach and participation of all socio-economic actors, as well as the sharing of water-based adaptation experiences. Other countries like China, Colombia and Mexico among others, as well as the state of California, put into practice Integrated Water Resources Management, providing an enabling environment, where stakeholders with different interests team up to plan site-specific adaptation measures.

All water specialists and managers agree that sustainable water management is crucial, but a narrow and sectoral approach prevents unanimous appropriate decisions. In the face of uncontrollable changes, a precise understanding of the water sector; support for investments; the regrouping of institutions; incentives; information and capacity building necessitating the collaboration of the government; institutions responsible for managing water, the private sector and civil society are needed (UN World Water Development Report 2009).

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Chapter 7
Mapping of Organisations Involved in Energy Research Activities in the Pacific Island Region, Their Research Projects, Budgets and Research Gaps

Sheikh Izzal Azid and Anjeela Jokhan

Abstract This study was carried out within the framework of the Pacific Europe Network for Science and Technology (PACE-Net), a project funded by the European Commission (EC). The PACE-Net project seeks to improve regional and bi-regional collaboration and cooperation activities in science and technology (S&T) research within the Pacific and between Europe and the Pacific (ACP—African, Caribbean and Pacific; OCT—Overseas Countries and Territories). Its global aim is to develop networks between Pacific and European stakeholders from research entities, universities, and industries, and including policymakers, programme managers and civil society, in order to facilitate and establish balanced and multidisciplinary partnerships in priority areas of mutually beneficial research. Energy is the theme this study focuses on. Renewable research will be presented in comparison to other research themes in the Pacific. Furthermore, the renewable energy research institutions in the Pacific, their projects and the total cost of their research are discussed. It is seen that only 4 % of total research in the Pacific is on energy, and most collaboration is national. The percentage of energy research projects is compared to Pacific energy goals, and the funding/research/collaboration gap is discussed. The results are further divided into the categories ACP (Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Solomon Islands, Timor-Leste, Tonga, Tuvalu, Samoa and Vanuatu), OCT (French Polynesia, New Caledonia, Pitcairn

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Climate Change Management, DOI: 10.1007/978-3-642-37753-2_7,

Islands, Wallis and Futuna) and regional organisations (University of the South Pacific, Secretariat of Pacific Community, South Pacific, Secretariat of the Pacific Regional Environment Programme) in the Pacific for specific data.

Keywords ACP · OCT · Regional organisations · Research institutions · Pacific goals

Short Introduction

In Pacific Island Countries (PIC), a more active discussion on renewable energy (RE) technologies started in 2004 when the Pacific Islands Energy Policy was established. However, the regional plans are unclear and there are few specialists who really understand how the potential of RE can be properly used. Many regional and local RE research initiatives need to improve their dialogue and cooperation for better planning and implementation of energy research results, as well as proving to the public and politicians that RE technologies do work.

This paper describes the main projects and organisations involved in energy-research activities in PICs, and show the main gaps in cooperation schemes and active participation (e.g. lack of private organisations).

Introduction

This study was carried out within the framework of the Pacific Europe Network for Science and Technology (PACE-Net), a project funded by the European Commission (EC).

The PACE-Net project seeks to improve regional and bi-regional collaboration and cooperation activities in science and technology (S&T) research within the Pacific and between Europe and the Pacific. Its global aim is to develop networks between Pacific and European stakeholders from research entities, universities, and industries, and including policymakers, programme managers and civil society, in order to facilitate and establish balanced and multidisciplinary partnerships in priority areas of mutually beneficial research. To this end, PACE-Net pursues the following three objectives (Description of Work 2010):

- to reinforce existing S&T dialogues and networks and promote regional integration for those networks by seeking to increase cooperation between research organisations and universities in the region;
- to identify S&T international cooperation activities and programmes in the Pacific region by setting up a dialogue that will bring relevant S&T experts and stakeholders from the Pacific and Europe together to establish the priority areas for the EC's funding instrument, the 7th Framework Programme for Research and Technological Development (FP 7), and beyond;

- to strengthen the coordination of S&T cooperation and the complementarities with activities and programmes carried out by other European instruments; in particular, synergies with the European Development Fund (EDF) shall be found (Description of Work 2010).

The Pacific Islands Energy Policy was established in the 2004 Regional Energy Meeting in Papua New Guinea to come up with renewable energy technologies in Pacific Island Countries (Seán 2010). However, the obstacles to renewable energy include weak institutional planning and management structures, a lack of clear renewable-energy development policies, a lack of technical expertise and understanding of the potential of renewable energy, a lack of successful demonstration projects, a lack of public and political confidence in renewable energy technology, and an over-reliance on donor-funded projects (Seán 2010). A large number of regional organisations and local government ministries are the key actors in taking up initiatives, for example USP, SOPAC, SPREP, the Pacific Islands Energy for Sustainable Development (PIESD), the European Union Energy Initiative for Poverty Eradication for Sustainable Development (EUEI), the Renewable Energy and Energy Efficiency Partnership for Asia Pacific (REEEP), the the Global Environment Facility (GEF) and the UNDP (Seán 2010).

Methodology

Various organisations (research institutions, academic organisations, private institutions, development agencies and ministries) in 19 targeted South Pacific Island Countries and Territories (PICTs), as well as in Australia and New Zealand, were contacted for this survey, and in total three questionnaires were designed.

The first questionnaire targeted the South Pacific Island organisations undertaking S&T research for 2008, 2009 and 2010.

This included research institutions, academic institutions, intergovernmental agencies and private companies. The questionnaire was divided into two parts: part 1 contained questions exclusively for the administrative or corporate section of the organisations; and part 2 contained questions specific to the researchers or research teams working in these organisations. These two parts were sent to respondents either as two separate electronic word files or two separate hard-copy documents.

The second questionnaire targeted the New Zealand and Australian organisations undertaking S&T research in and with the South Pacific Island region for the years 2008, 2009 and 2010. Again, this included research organisations, academic institutions, intergovernmental agencies and private companies in Australia and New Zealand undertaking S&T research activities in the South Pacific Island region and/or with the South Pacific Island researchers.

The third questionnaire was designed for South Pacific Islands' government ministries.

Table 7.1 Organisations contacted with Questionnaires 1 and 2

Questionnaire (regardless of the part completed)	Organisations contacted with Questionnaires 1 and 2				
	ACP-based	OCT-based	Regional organisations	Based in Australia and New Zealand	Total
Sent	47	43	6	28	123
Received	19	19	3	9	50
% response rate per region	40.4	44	50	32	40.1
Overall % response rate					

Analysis for Research in the Pacific

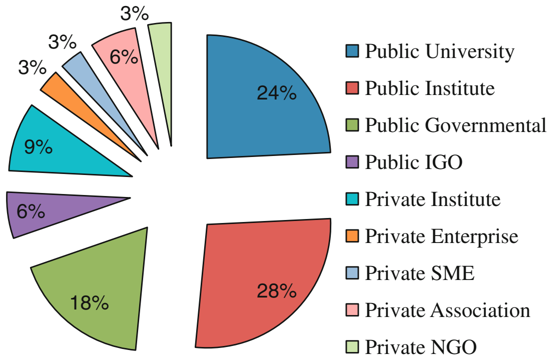
Table 7.1 presents the total number of organisations in the Pacific that were asked to participate in the survey by filling out questionnaires 1 and 2, and the number of organisations that actually participated. The response percentage was 40.1 %.

From these survey responses, the majority of the research in the Pacific Island region appears to be carried out by the public sector (74 %); more precisely, by the public universities (23 %) and research institutions (26 %), followed by governmental departments and ministries (25 %). In the OCT region, the majority of organisations undertaking research activities appear to be public research institutes (60 %), while in the ACP and in Australia and New Zealand these are primarily public education-provider institutions (respectively, 50 and 57 %). The low survey-sending and response rates in these countries do however, mean that this is a partial picture and more research is required (Fig. 7.1).

From the responses, the predominant area in which S&T research is undertaken in and for the Pacific island region appears to be biology and medicine (28 %). Environment, including climate change (24 %), and agriculture and food supply (17 %) are also R&D sectors in which considerable numbers of research teams in the Pacific are working, while a few research teams appear to be working in the areas of industry and industrial technology, and information and communication technology (5 and 6 % respectively), as well as energy (3 %) (Azid et al. 2011a, b).

There are four institutions on the ACP side that have research groups in energy. They are the University of the South Pacific's Faculty of Science Technology and Environment Renewable Energy Group (USP), the Scientific Research Organisation of Samoa (SROS), the Ministry of Natural Resources and Environment, Samoa (MERE), and the Ministry of Environment and Climate Change, Tonga (MECC). The Institute of Research and Development is carrying out a project on renewable energy, but does not have specific research team on energy.

Fig. 7.1 Distribution of types of organisation in the Pacific ACP and OCT group, Australia and New Zealand, as well as regional organisations involved in S&T research for the Pacific Island region



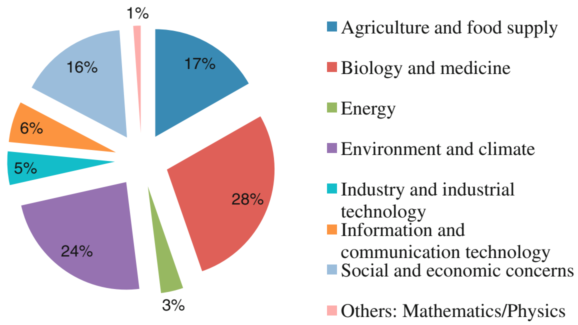
Research Projects in the Pacific

Figure 7.2 shows that the predominant area in which S&T research is undertaken in and for the Pacific Island region is environment, including climate change (39 %). Biology and medicine (25 %), and agriculture and food supply (13 %) are also R&D sectors in which a large proportion of research is undertaken. A few projects address the areas of industry and industrial technology (7 %), social and economic concerns (7 %), energy (4 %) and information and communication technology (3 %). It is worth noting, that the results in Fig. 7.2 correspond to those obtained for the R&D sectors of the research teams in Fig. 7.3 (Azid et al. 2011a).

Energy Projects

A total of 22 projects out of 524 were energy-research projects. Based on the data, the ACP side has the most projects (18), compared to OCT with one research project, and Australia and New Zealand with three projects. Among the renewable energy groups, the University of the South Pacific has the greatest number of projects (73 %), followed by Ministry of Environment and Climate Change, Tonga

Fig. 7.2 Distribution of the research and development sector, in which all respondent research teams undertake S&T research activities



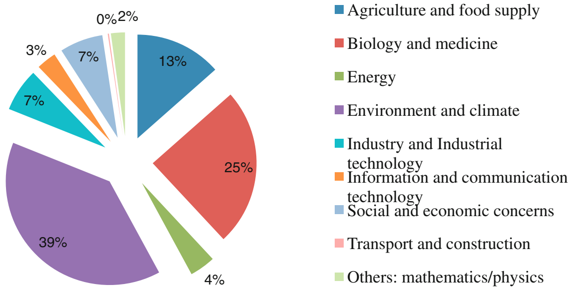


Fig. 7.3 Overall distribution of the research and development sector in research projects

(13 %), the Scientific Research Organisation of Samoa (9 %), and Ministry of Natural Resources and Environment, Samoa.

Table 7.2 demonstrates that the largest proportion of collaboration activities in relation to Pacific island energy research is happening within the region. Surprisingly, despite the geographical proximity of Pacific ACP and OCT, there is no collaboration between these two areas. Similarly, the collaboration between Pacific ACP research institutions and teams in Europe and Asia is minimal. This gap has been identified and there is a need to increase collaborative research activities between the regions.

Nonetheless, the analysis shows the research in Pacific islands' energy projects is funded from several sources, including institutional, private sector, civil sector bilateral and multilateral donors. This shows that stakeholders from different sectors of society more or less support renewable energy research on Pacific islands. Local and regional organisations, European countries, Asian countries and international organisations all fund projects in renewable-energy research. It is also interesting to see that the University of the South Pacific's Faculty of Science Technology and Environment funds 64 % of these projects (Table 7.3).

Major research work is being carried out in wind energy, mostly on blade design, power control of wind hybrid systems and frequency control techniques using "fuzzy logic".

Aside from the concerns associated with biofuels, stakeholder consultations also raised a range of specific needs regarding the energy sector, including the

Table 7.2 Percentage of collaborations with research organisations located in different regions of the world or with regional and international organisations

Respondent research teams based in:	Percentage of collaborations with research organisations located in different regions of the world or with regional and international organisations						
	ACP (%)	OCT	Regional organisations (%)	Australia and New Zealand (%)	Asian countries (%)	Europe (%)	International organisations (%)
USP	25	0	0	6.3	18.8	0	0
SROS	0	0	0	100	0	0	0
MNRE	50	0	50	0	0	0	0
MECC	14.3	0	14.3	0	14.3	28.6	28.6

Table 7.3 Funding agencies with research organisations in different regions of the world, or with regional and international organisations

Respondent research teams based in:	Funding agencies with research organisations in different regions of the world, or with regional and international organisations						
	ACP (%)	OCT (%)	Regional organisations (%)	Australia and New Zealand (%)	Asian countries (%)	Europe (%)	International organisations (%)
USP	88	0	0	0	12	14	0
SROS	50	0	50	0	0	0	0
MNRE	33.3	0	0	0	0	33.3	33.3
MECC	14.3	0	14.3	0	14.3	28.6	28.6
Total							

need for capacity building, on top of direct support for research projects themselves. Some related research projects are: ethanol production from selected cassava varieties, engine performance of coconut oil, and coconut and bioethanol production projects. Less work is being carried out on solar and ocean energy; solar research is mostly on data collection and ocean projects are mostly on turbine design and data collection. Hybrid renewable-energy research, particularly in solar/wind/diesel systems, has seen some success on the Pacific islands due to the high efficiency, reliability and comparatively low cost of these systems (Fig. 7.4).

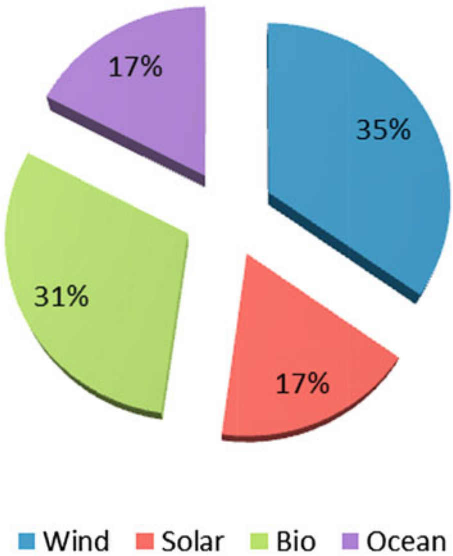


Fig. 7.4 Percentage of renewable energy research projects in the Pacific region

Conclusion

It can be observed that energy research teams work on many projects—four research teams are working on a total of 22 projects. Most of the projects in the Pacific receive public funding. There is a gap for private organisations, such as the respective electric companies of the island countries, to fund some research projects and apply the research data to infrastructure and capacity building. It can also be seen that there is a collaboration gap between the regions, which should be filled in order to boost research, especially since the OCT and ACP sides have similar climatic conditions. Although survey responses are very good on the whole, some institutions engaged in ongoing research did not respond. This means the data presented could change.

Acknowledgments The authors would like to thank the Pacific Europe Network for Science and Technology for funding this project under the 7th Framework network (Grant No. 244514).

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Chapter 8
A Transition Management Approach to Designing Post-Kyoto Climate Policy Architecture: A Framework for Negotiation

Shahryar Mohammadrezaie Omran

Abstract Lessons learnt from the Kyoto Protocol (KP) present the key challenges in designing post-KP architecture in order to bridge the significant gap between the aggregate effect of mitigation pledges by parties in terms of global annual emissions of greenhouse gases by 2020, and aggregate emission pathways consistent with having a likely chance of holding the increase in global average temperature below 2 or 1.5 °C above pre-industrial levels, as set out in the outcome document ofthe Rio+20 conference *The Future We Want*. The 'Transition Management' (TM) approach—employing a multifaceted (multi-actor, multiphase, multi-level, multi-domain, multi-change and multi-pattern) perspective on a new governance (network and self-steering) mode organised horizontally and vertically, within a long-term horizon, through long-term stock monitoring and cyclic knowledge development—inherently presents potential to offer resolutions of the challenges identified. This paper, generating pro and con arguments to post-Kyoto climate policy architecture, conducts an *ex-ante* assessment of the TM approach in order to explore the importance of the approach, and recommends further negotiations, to be participated in by all parties and observer states, to the United Nations Framework Convention on Climate Change (UNFCCC) and its KP to explore the desirability and the feasibility of the TM approach to designing post-Kyoto climate policy architecture. Finally, if the TM approach is desirable to the parties and they recognised the feasibility of applying the approach in the real world context of both Annex I and non-Annex I parties, various elements of the TM framework could further be combined into three interrelated functional levels of global climate governance within UNFCCC and its KP: strategic; tactical and operational levels. However, architecting post-Kyoto climate policy is not a once-and-for-all event. In accordance with the TM principle of social learning, cyclic knowledge development through learning-by-doing and doing-by-learning actions over the

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_8,

second period of the parties' commitment to the KP would lead to validation, invalidation or modification of the TM approach to post-Kyoto climate policy architecture.

Keywords Climate policy · Kyoto protocol · UNFCCC · Post-kyoto architecture · Transition management · Climate negotiation · Climate governance · Climate policy assessment

Short Introduction

Lessons learnt from the Kyoto Protocol (KP) present the key challenges in designing post-KP architecture in order to bridge the significant gap between the aggregate effect of mitigation pledges by parties in terms of global annual emissions of greenhouse gases by 2020, and aggregate emission pathways. This paper, generating pro and con arguments to post-Kyoto climate policy architecture, conducts an *exante* assessment of the "Transition Management" approach to explore the importance of the approach, and recommends further negotiations, to be participated in by all parties and observer states, to the United Nations Framework Convention on Climate Change (UNFCCC).

Introduction

Reaffirming that climate change is one of the greatest challenges of our time, the outcome document of the Rio+20 United Nations Conference on Sustainable Development, *The Future We Want* (UN 2012), reconfirms prior commitments to the United Nations Framework Convention on Climate Change (UNFCCC) to make every effort to accelerate the achievement of the internationally agreed development goals by 2015, including the commitments on the global response to climate change within the Kyoto Protocol (KP).However, expressing profound alarm that emissions of greenhouse gases continue to rise globally (UN 2012), the document has again raised the question of how to design post-Kyoto climate policy architecture.

Lessons learnt from the KP present the key challenges in designing post-KP architecture in order to bridge the significant gap between the aggregate effect of mitigation pledges by parties in terms of global annual emissions of greenhouse gases by 2020, and aggregate emission pathways consistent with having a likely chance of holding the increase in global average temperature below 2 or 1.5 °C above pre-industrial levels, as set out in *The Future We Want* (UN 2012).

This paper generates pro and con arguments to post-Kyoto climate policy architecture, focusing on the inherent potential of the 'Transition Management' (TM) approach to deliver the building blocks of this architecture. Then, an *exante* assessment of the TM approach to designing post-Kyoto climate policy architecture will be described to explore the importance of this approach. It will be recommended that all parties and observer states of the UNFCC and its KP participate in further negotiations, as part of forthcoming meetings of ad hoc working groups, in order to explore the desirability and feasibility of the TM approach in designing post-Kyoto climate policy architecture.

The Transition Management Approach

The term ‘transition’, generally used to describe a process of change from one dynamic equilibrium to another (Kemp and Rotmans 2001; Loorbach 2002), has been pointed out in many publications in the field of sustainability since the late 1990s. Rotmans et al. (2000, 2001b), define a transition as “a gradual, continuous process of change where the structural character of a society (or a complex subsystem of society) is being transformed”. Accordingly, the notion of a multi-stage process applies to transition, describing a transition in four stages or phases (see Fig. 8.1).

In this regard, transitions are transformative change processes, typically nonlinear transformations started by slow change and followed by rapid change (see Fig. 8.2), that lead to a new regime, constituting the basis for further developments in different domains (see Fig. 8.3) that reinforce each other, to be, in turn, followed by another slow change in the stabilisation stage (van der Brugge et al. 2005; van der Brugge and Rotmans 2007; van der Brugge and van Raak 2007; van der Brugge 2009).

Through the multi-stage processes of transitions, Geels and Kemp (2000) identify the interplay between processes at different levels (see Fig. 8.4).

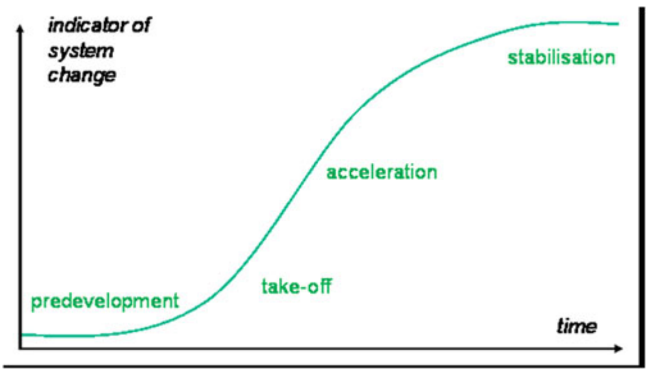


Fig. 8.1 The four phases of a transition (*Source* Rotmans et al. 2001a, 2001b)

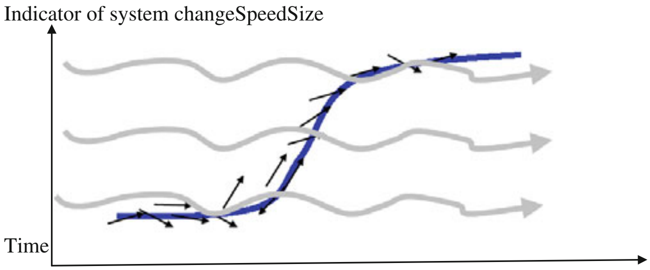


Fig. 8.2 The three dimensions of a systems change: time, speed and size (*Source* Rotmans et al. 2001b)

Fig. 8.3 Transition is the result of development in several domains (*Source* Martens and Rotmans 2005)

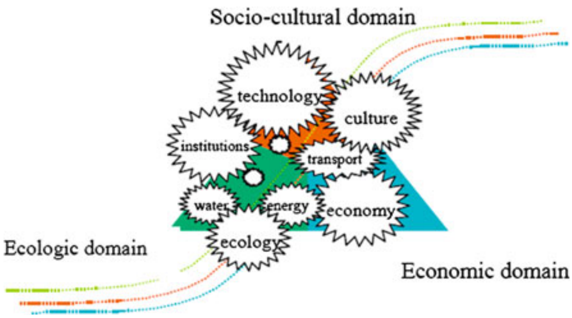
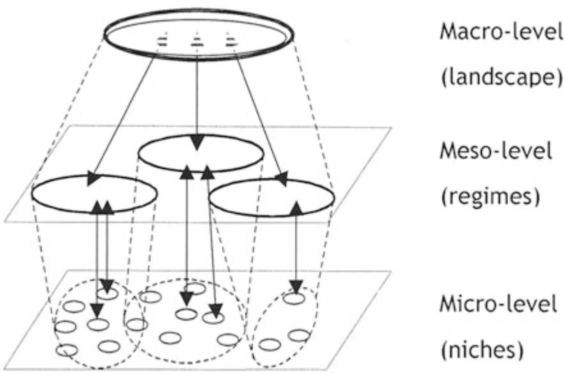


Fig. 8.4 Multi-level interplay through transition process (*Source* Geels and Kemp 2000)



Each transition is unique in terms of content and context (Loorbach and Rotmans 2006). However, Kemp and Rotmans (2004) distinguish two types of transitions:

- *Evolutionary transitions*: in which the outcome is not planned in a significant way; and
- *Goal-oriented* (*teleological*) *transitions*: in which (diffuse) goals or visions of the end state guide public actors and orientthe strategic decisions of private actors (see Fig. 8.5).

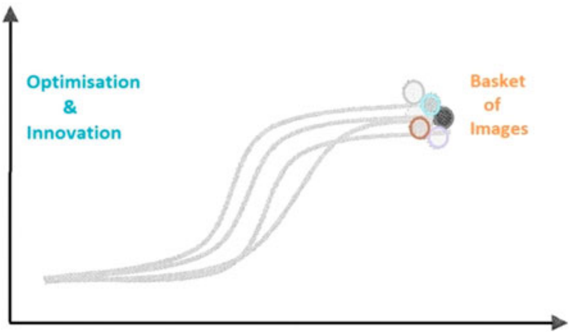


Fig. 8.5 The transition process as a goal-seeking process (*Source* Loorbach and Rotmans 2006)

"A central element in transition approach is reserved for the development and execution of experiments to foster (trial-and-error) learning and thus pave the way towards sustainable transitions" (Van de Kerkhof and Wieczorek 2005) (see Fig. 8.6).

Jan Rotmans, René Kemp and Marjolein van Asselt (2001b), in collaboration with Dutch policymakers, developed the multi-level and multi-phase model of transition management within the project "Transitions and Transition Management" for the Netherlands' Fourth National Environmental Policy Plan (see Fig. 8.7).

Accordingly, the principles of transition management were introduced as below (Rotmans et al. 2001a, 2001b):

- long-term thinking as a framework of consideration for short-term policy (at least 25 years);
- thinking in terms of more than one domain (multi-domain) and different actors (multi-actor) at different scale levels (multi-level);
- focus on learning and a special learning philosophy (learning-by-doing and doing-by-learning);
- trying to bring about system innovation besides system improvement; and
- keeping open a large number of options (wide playing field).

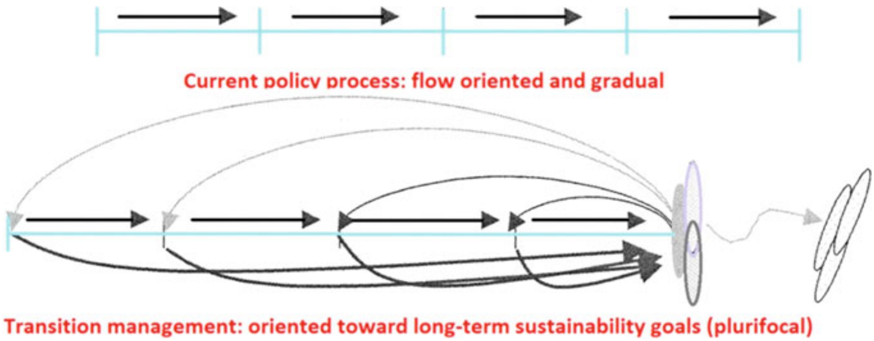


Fig. 8.6 Traditional policy process versus transition management process (*Source* Loorbach and Rotmans 2006)

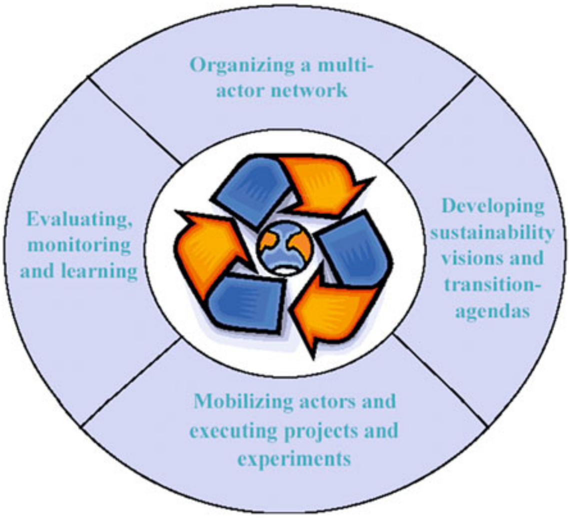


Fig. 8.7 The cyclic, iterative and multi-stage process of transition management (*Source* Loorbach and Rotmans, 2006)

During the last decade, transition studies have met with much enthusiasm in research and practice, contributing to the body of knowledge about transitions, as well as applying the transition model in the real world. Table 8.1, extracted from the most important transition studies conducted over the last decade, illustrates the tenets on which the TM approach is based and the basic steering philosophy underlying each tenet.

Exante Assessment of the TM Approach to Post-Kyoto Climate Policy Architecture

Success of policy instruments is determined by how well they are able to achieve various criteria (Mitchell et al. 2011). As IPCC (2007a) points it out, criteria may be applied to making *exante* choices among climate policy instruments as well as in the *expost* evaluation of the performance of climate policy instruments. To identify a set of criteria for the *exante* assessment of the TM approach to designing post-Kyoto climate policy architecture, a number of literatures have been reviewed.

Crabbé and Leroy (2009) identify the following criteria for environmental policy evaluation:

- *juridical criteria*: control and accountability;
- *economical criteria*: effectiveness and efficiency; and
- *political criteria*: responsiveness and transparency.

Table 8.1 The basic principal on which TM approach is based

Basic principal of TM approach	The basic steering philosophy underlying the principal
Long-term vision	Transitions are societal transformation processes in which society, or a complex subsystem of society, changes in a fundamental way over an extended period (more than one generation, that is 25 years or more). (Rotmans et al. 2000, 2001a, 2001b).
Multi-phase process	Regarding the dynamics of transitions in time, four different phases can be distinguished in the transition process: the pre-development; the take-off; the acceleration and the stabilisation phases (Rotmans 2005).
Multi-level coordination	The transition process happens through three different functional scale levels: the micro-, the meso- and the macro-levels (Geels and Kemp 2000).
Multi-domain approach	A prerequisite for transitions to take place is that several developments in different domains (socio-cultural, economic, technological, institutional, behavioural and ecological) interact in such a way as to positively reinforce each other (Martens and Rotmans 2005).
Multi-actor involvement	The key societal actors, including governmental bodies, NGOs, knowledge institutes and companies, have a role to play in the TM process (Loorbach 2002).
Multi-change perspective	A transition is the result of many changes, and not a deterministic process (Butter et al., 2002), oriented towards both system improvement and system innovation (Loorbach and Rotmans 2006).
Multi-pattern interaction	Different patterns of multi-level interaction can result in a transition, depending on the conditions and mechanisms that exist in a particular societal system, and depending on the way in which landscape, regimes and niches interact over time (De Haan 2010; de Haan and Rotmans 2011).
Trans-disciplinary and cyclic knowledge development	Social learning is a pivotal aspect of the transition process, as the combined outcome of learning-by-doing and doing-by-learning actions (Loorbach and Rotmans 2010).
Portfolio approach	Transition management does not call for specifically defined goals for the long-term, but rather aims to reach a "basket of images, not a societal blueprint" (Kemp and Rotmans 2004).
New governance mode	Network- and self-steering of transition through joint management by all interested parties within a network that do not have a clear hierarchical structure (Rotmans 2005; Loorbach 2007a).
Monitoring long-term stock	A transition is the result of long-term developments in stocks and short-term developments in flows (Rotmans et al. 2001a, 2001b). TM considers that to deal with the complex and persistent problems, for which incremental approaches are not sufficient, emphasis needs to be placed on the stocks (Loorbach 2011).

(continued)

Table 8.1 (continued)

Basic principal of TM approach	The basic steering philosophy underlying the principal
Back- and fore-casting	The setting of short-term and longer-term goals within long-term visions, scenario studies, trend analysis and short-term possibilities (Loorbach and Rotmans 2006).
Anticipation and adaptation	Anticipating future trends and developments is a key element of TM, accompanied by a strategy of adaptation, which means adjusting while the structure of the system is changing (Loorbach et al. 2009; Frantzeskaki 2011).

(*Source* Author)

Mickwitz (2003) makes more distinction between the three groups of the criteria as shown below:

- *general criteria*: relevance, impact, effectiveness, persistence, flexibility and predictability;
- *economic criteria*: effectiveness and efficiency; and
- *criteria linked to the functioning of democracy*: legitimacy, transparency and equity.

In the context of climate policy, Aldy et al. (2003) employ six criteria to evaluate climate change policy proposals: environmental outcome, dynamic efficiency, cost-effectiveness, equity, flexibility in the presence of new information, and incentives for participation and compliance. Baumert and Kete (2002) refer to these criteria as key challenges in designing climate policy architecture.

There are also some criteria of concern for the following technical and institutional requirements of climate policy approaches related to both the negotiation process and the implementation and monitoring of commitments: technical, legal and organisational requirements (Sijm et al. 2007). According to Sijm et al. (2007):

- a first criterion is compatibility with the Kyoto Protocol and UNFCCC. From a legal point of view, and given the importance of continuity in policymaking, it is desirable that a future climate change regime does not require major legal revisions of the UNFCCC and/or the Kyoto Protocol;
- a second criterion is simplicity of the negotiation process. That means regime approaches that are complex in nature, either conceptually due to the need for complex calculations and data requirements or the number of policy variables, complicate international negotiations; and
- a third, related criterion 'ease of implementation' concerns the technical and institutional feasibility of implementation, monitoring and enforcement. Even conceptually simple approaches can pose major implementation problems due to their technical and institutional requirements, particularly in less developed countries.

Bodansky et al. (2004) take a view of the negotiability of climate policy from a political perspective, and take the following considerations that are likely to affect future climate efforts: continuity with the UNFCCC and Kyoto Protocol; economic predictability and compatibility with the Development Goals.

It is inevitable that any policy aimed at climate change mitigation or adaptation will interact with other policies. The extent to which climate change issues are considered and integrated into existing policy fields is therefore a key issue to be tackled in the future (Mickwitz et al. 2009). Furthermore, a comprehensive policy requires coherence between climate-specific policies and general, or sector-specific, policies which should complement each other (Mickwitz et al. 2009). Moreover, climate policy integration and coherence should be viewed in the context of multi-level governance (Mickwitz et al. 2009).

Table 8.2 outlines the criteria selected for the *exante* assessment of the TM approach to post-Kyoto climate policy architecture. Even though Article 3.3 of the UNFCCC stipulates the economic criteria, the following assessment ignores these criteria because they are rather the criteria for *expost* evaluation of the performance of climate policy instruments than for making *exante* choices. Furthermore, economic *exante* evaluation has been found conceptually and practically problematic within this paper, due to need for the application of economic methods to calculate all the effects and all the costs in the same unit—money (Mickwitz 2003).This is beyond the author's xpertise, as well as the scope of this paper. Moreover, using economic criteria requires considerable resources and relates to data availability in practice that has not been provided to the author.

Table 8.3, presenting one-to-one comparison of the elemental building blocks of the TM framework with the key challenges in designing post-KP architecture, explores the inherent potential of the TM approach to offer resolutions for the challenges.

Conclusions and Recommendations

Seeking to develop pro and con arguments to the key challenges in designing post-KP architecture and their resolution(s), this paper is not about the generation of a policy decision. In fact, introducing the inherent potential of the TM approach to deliver the building blocks of climate policy architecture, this paper conducted the first analytical exercise in order to explore the importance of the TM approach in offering solution(s) to the key challenges identified.

However, believing that one-to-one transposition of the building blocks of the TM framework would not necessarily offer the properties of a consistent post-KP climate policy architecture, the second analytical exercise on the TM approach is proposed in order to explore its desirability to all parties and observer states of the UNFCCC and its KP as well as to explore its feasibility in the real world context.

Accordingly, a framework for the negotiation of the TM approach is recommended (see Table 8.4) within which a consistent set of desired properties that construct a normative post-Kyoto framework, as well as of probable (feasible) properties that construct an extrapolative post-Kyoto framework, could be

Table 8.2 The criteria for the *exante* assessment of the TM approach to post-Kyoto climate policy architecture

Criteria	Sub-criteria	Definition
Environmental criteria	Environmental effectiveness	The extent to which intended objectives are met (Mitch et al. 2011). In climate policy context, the ability to effectively control and eventually to reduce GHG emission with the aim of stabilising GHG concentration (Sijm et al. 2007).
Political criteria	Legitimacy	The degree to which the different parties of the UNFCCC and its KP accept the policy approach.
	Equity	Fairness in sharing the costs and benefits of policy instruments (den Elzen et al. 2003a) among the different parties of the UNFCCC and its KP and/or the extent to which all partieshave equal opportunities to take part in and influence the processes used by the administration (Mickwitz 2009)
Technical and institutional criteria	Compatibility with the KP and UNFCCC	How consistent is the climate policy approach with the path to achieving compliance with the UNFCCC and its KP? (Sijm et al. 2007)
	Compatibility with development goals	How consistent is the climate policy approach with national development priorities such as economic growth, etc. (Bodansky et al. 2004)
	Complementarity	How linked are the multiple climate strategies and instruments (Bodansky et al. 2004)
	Simplicity of the negotiation process	How complex is the administrative burden of policy instruments on both the target group and the implementing organisations (Sijm et al. 2007)
	Institutional feasibility	The extent to which the policy instrument is compatible with the capabilities and limitations of the institutions on which implementation and compliance will depend (Bodansky et al. 2004)
	Ease of monitoring	The degree to which the outputs and outcomes of the policy instruments, as well as the processes used in implementation, are observable for outsiders (Mickwitz 2009).In the context of least developed countries, a lack of reliable emission data, statistical capacity and sufficient capacity for verification and enforcement will make monitoring difficult (Baumert et al. 2002, 2005)
	Predictability	How possible it is to foresee the unpredictable variables, such as economic variables, population growth and the rate of technological change, on which implementation of the policy instruments depends (Bodansky et al. 2004).
	Dynamic flexibility	How easily the policy instrument can be adjusted, adapted and corrected in the presence of new information (Siniharju 2009).

(continued)

Table 8.2 (continued)

Criteria	Sub-criteria	Definition
	Integration	The incorporation of the aims of climate change mitigation and adaptation into all stages of policymaking in other policy sectors and a commitment to minimise contradictions between climate policies and other policies (Mickwitz et al. 2009).
	Multi-level governance	The interdependence of governments operating at different levels, while ‘governance’ signals the growing interdependence between governments and non-governmental actors at various territorial levels (Bache and Flinders 2004).

(*Source* author)

Table 8.3 The inherent potential of the TM approach to deliver post-Kyoto climate policy architecture

Potential of the TM approach	The key challenges in designing post-Kyoto climate policy architecture												
	Environmental effectiveness	*Legitimacy*	*Equity*	*Compatibility with the KP and UNFCCC*	*Compatibility withDevelopment Goals*	*Complementarity*	*Simplicity of negotiation process*	*Institutional feasibility*	*Ease of monitoring*	*Predictability*	*Dynamic flexibility*	*Integration*	*Multi-level governance*
Long-term vision				✓									
Multiphase process				✓									
Multi-level coordination				✓	✓		✓					✓	✓
Multi-domain approach					✓							✓	
Multi-actor involvement		✓	✓				✓	✓					
Multi-change perspective	✓				✓						✓	✓	
Multi-pattern interaction								✓			✓		✓
Cyclic knowledge development			✓	✓		✓	✓	✓	✓	✓	✓		
Portfolio approach	✓										✓	✓	
New governance mode		✓	✓				✓	✓	✓				✓
Monitoring long-term stock	✓			✓		✓			✓	✓			
Back- and fore-casting	✓			✓		✓			✓	✓	✓		
Anticipation and adaptation	✓			✓		✓			✓	✓	✓		

(*Source* Author)

explicated in order to tackle the analytical problems of climate change governance based on the TM approach.

The proposed negotiations within the second analytical exercise would therefore be an attempt at further analysis of the TM approach and not a mechanism for making a decision, seeking to generate the strongest possible opposing views on the potential resolution(s) of the key challenges in designing post-Kyoto climate policy architecture. In other words, the negotiations would be less about the

Table 8.4 A framework for the negotiation of the TM approach to designing post-Kyoto climate policy architecture

Objective of negotiation	Dimension of negotiation	Outcome of negotiation
Arguments on designing post-Kyoto climate policy architecture	Importance of TM approach Validity of TM approach	Pro or con arguments to TM approach to designing post-Kyoto climate policy architecture
Consistency of TM approach to designing post-Kyoto climate policy architecture	Desirability of TM approach Feasibility of TM approach	Structuring a set of properties of post-KP climate policy architecture based on the TM approach

(Adapted from: Turoff and Hiltz 1996)

formation of a consensus on an alternative architecture; but rather, more about the presentation of options and supporting evidence for post-Kyoto climate policy architecture by all parties and observer states of the UNFCCC and its KP. Indeed, rather than searching for an alternative architecture or for probabilistic expectations of a TM approach, the further negotiations proposed would try to structure a set of properties of post-KP climate policy architecture, which could be integrated into a normative future—in Sutherland's words: properties based on the criterion of desirability rather than likelihood (Sutherland 2002).

With regard to the assumption underlying this proposal that assumes the TM approach has inherent potential to deliver post-Kyoto climate policy architecture, if the approach was desirable to the parties and they recognised the feasibility of applying the approach in the real world context of both Annex I and non-Annex I parties, various elements of the TM framework could be further combined into three interrelated functional levels of global climate governance within UNFCCC and its KP: strategic, tactical and operational levels (see Fig. 8.8).

Adopted from Loorbach (2007a, 2007b), the following activities are recommended at each functional level of global climate governance within the TM cycle:

- *strategic level*: visioning, strategic discussions, long-term goal formulation;

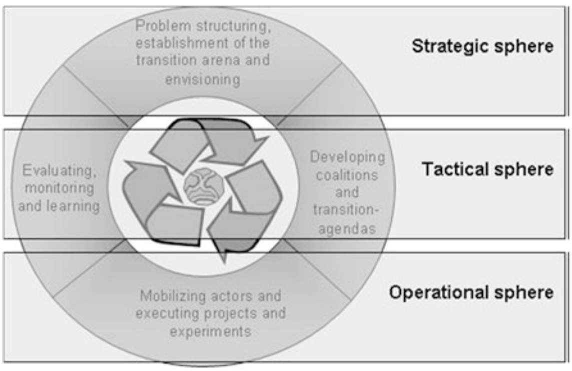


Fig. 8.8 Three interrelated, coordinated functional levels at which the TM cycle should be operationalised to deliver post-Kyoto climate policy architecture (Adapted from: Loorbach and Rotmans, 2006)

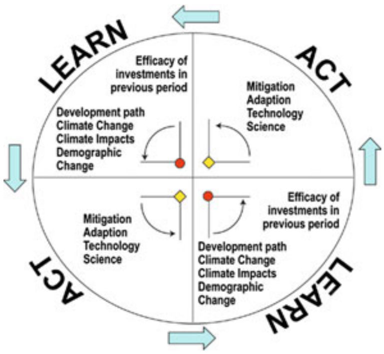


Fig. 8.9 The iterative nature of the climate policy process, where the square nodes represent decisions, the *circles* represent the reduction of uncertainty and the *arrows* indicate the range of decisions and outcomes (Adapted from: IPCC 2007b)

- *tactical level*: processes of agenda-building, negotiating, networking, coalition building; and
- *operational level*: processes of experimenting, implementation.

In the case of the adoption of the TM approach to designing post-Kyoto climate policy architecture, this proposal takes a view of the continuity of negotiations from the post-KP era regarding the iterative nature of climate policy process (see Fig. 8.9) from the perspective of reflexive sustainability governance (Voß and Kemp 2005, 2006; Rotmans and Loorbach 2010).

As architecting climate policy is not a once-and-for-all event, it requires transdisciplinary and cyclic knowledge development through learning-by-doing and doing-by-learning actions in accordance with the TM principle of social learning. Accordingly, the continued negotiations over the second period of the parties' commitment to the KP would generate further pro or con arguments, leading to validation of the TM approach to designing post-Kyoto climate policy architecture (see Table 8.4), through which the lessons learnt from applying the approach in the real world context of both Annex I and non-Annex I parties would validate, invalidate or modify the approach. In any case, the outcome of the continued negotiations could stimulate the development of visions, pathways and experiments, which could be used to design a new architecture, as well as to pave the ground for the reorientation of global climate governance on the basis of experience and new insights.

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Chapter 9
Climate Change Assessment Using Statistical Process Control Methods

Branko Vučijak, Tarik Kupusović, Sanda Midžić-Kurtagić and Admir Ćerić

Abstract Statistical process control (SPC) uses the application of statistical methods and procedures to monitor and control a process, in order to evaluate two possible causes of variation in the process: natural (common) and assignable (special) causes. The aim of this activity is to improve the process' capabilities. If the variability of a process is within the range of natural causes, the process is said to be under statistical control. When that variability exceeds the expected natural causes range, it is a signal to look for, and to correct, assignable causes. SPC may even be used to "control" climate change, through comparison of present day variations with the natural variation capacity for change in air temperature, precipitation and sea levels in the past. Are today's frequent floods, tornados, warm winter periods or cold summer days actually caused by "natural" causes (should they be statistically expected), or has the "capability" of the natural processes changed? This paper will demonstrate the potential use of SPC methods in evaluating variations in temperature and precipitation that should be expected, based on the assessment of the statistical behaviour of data for these natural indicators during different periods. "Warning" and "action" lines will be assessed and compared for the selected periods. Also, the number of records below or above warning and action lines will be compared. This approach could be useful for spatial planners, even if the causes of the changes are global or not human-induced.

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_9,

Keywords Statistical process control · Control charts · Climate change · Monitoring data · Process capability

Short Introduction

Statistical process control (SPC) presents the application of statistical methods and procedures of monitoring and control of a process, in order to evaluate two possible causes of process variation: natural (common) and assignable (special) causes. This paper will demonstrate the potential uses of SPC methods in evaluating variations in temperature and precipitation that should be expected, based on assessment of the statistical behaviour of data for these natural indicators during different periods.

Introduction

There is no full scientific consensus regarding the issue of climate change. While temperature increase has been noticed and validated over the last 10–20 years, there are still different opinions on whether this increase is related to permanent effects on the climate, or whether it is yet another climate variation. Opinions also differ on the source of such change—is it human-induced, or just another whim of nature?

This paper presents a potential response to the question of whether the temperature increase confirms that there has been a change from the former average temperature values and that the natural processes "capability" has changed, or the "temperature process" is still in control and the increase is actually within the range of values that could statistically be expected.

This paper demonstrates the potential uses of selected Statistical Process Control (SPC) methods in evaluating variations in temperature. It is based on the assessment of the statistical behaviour of temperature data for the period 1961–1990 when the "process was considered to be incontrol", and then used for evaluating the behaviour of temperatures during the period 2000–2010. Data relates to the city of Sarajevo and the same measurement site.

The structure of the paper is the following: after the introduction, the next section is a reminder of the main aspects of climate change and its basis. Section Climate Change introduces the statistical process control concept, while the fourth one presents results of the application of the SPC mean chart to the series of temperatures in Sarajevo, Bosnia and Herzegovina, during the periods 1961–1990 and 2000–2010. Finally, paper ends with some conclusions both on the effects of climate change and on the applicability of SPC in this area.

Climate Change

Scientists define climate as the average weather for a particular region and time period, including temperature, precipitation, humidity, sunshine, cloudiness and wind, usually taken over 30-year period (NASA 2005). It is really an average pattern of weather for a particular region. The Earth's climate has changed many times during the past in response to natural causes, due to interaction between the sun, land, oceans and atmosphere, and the effects that they have on each other. But the term "climate change" is used to refer to the changes in the climate caused by human activities, mostly during the 20th and 21st centuries, where "greenhouse effect" is specifically emphasised.

For thousands of years, the atmosphere contained relatively stable levels of greenhouse gases, but during the 20th and 21st centuries, human influence has changed the previous balance, resulting in climate change. America's Climate Choices report of 2011 states that the average temperature of the Earth's surface has increased by about 1.4 °F (0.8 °C) over the past 100 years, with about 1.0 °F (0.6 °C) of this warming occurring over just the past three decades. Most of the world scientists agree that global temperatures will continue to rise (Committee on America's Climate Choices 2011).

Nearly all European regions are anticipated to be negatively affected by certain future impacts of climate change, and these will pose challenges to many economic sectors. Climate change is expected to magnify regional differences in Europe's natural resources and assets (IPCC, Summary for Policymakers 2007).

For the south-east European countries, including Albania, Bosnia and Herzegovina, Montenegro, Serbia and Turkey, the impacts of climate change may include: increased temperatures; a rise in the frequency of extreme weather events; increased coastal erosion; a rise in sea levels; an impact on marine biodiversity; rising water levels in tidal rivers; increased flooding; severe pressure on water resources; increased forest and scrubland fires; changing agricultural landscapes, including crop failure; changes in habitat composition and species distribution, richness and diversity; and increasing problems caused by invasive alien species. In addition, there will be more problems for local and regional communities that depend on the services provided by ecosystems (in the form of food, drinking water, fuel, building materials or as a harvestable resource) to sustain acceptable living conditions and welfare (Laušević et al. 2008).

Following the scenario of partially applied measures for the reduction of greenhouse gas emissions, the territory of Bosnia and Herzegovina could expect an increase in air temperature of 3–4 °C by the end of the 21st century. The next several decades could bring a significant reduction in the number of days with snow, as well as a reduction in rainfall during the warmer part of the year, which would result in a reduction in soil humidity and the availability of water resources (Spasova et al. 2007).

The concept of statistical process control Vilfredo Pareto (1848–1923), who was trained as an engineer but is best known for his economic and sociological works, has set one of the basic optimisation postulates of statistical process control (SPC). He noticed that many failures in a system result from a small number of causes, and that in the production process it is rarely some "general malaise" causing problems. Pareto found that even though some companies show both diligence and hard work, and even strong motivation in some cases, the quality of the product or service was still poor. Thus, in order to improve this system for production, management or providing services, it is necessary to find and correct these causes, also called "Pareto glitches" (Thompson and Koronacki 2002).

During the 1920s, Walter Shewhart developed the basic theory of SPC, which was later popularised worldwide by Edwards Deming. Both of them noticed that repeated measurements of a single process will exhibit some level of variation. Even though Shewhart originally started working with manufacturing processes, both he and Deming understood that such observations could be applied to any sort of process. If a process is stable, its variation will be predictable and it is possible to describe it with some of the several statistical distributions (whereby normal distribution is most often used). Today, methods are used in different types of issues besides manufacturing processes, like healthcare (Benneyan et al. 2003), software processes (Jalote and Saxena 2002), statistical inference at work (Bakker et al. 2008) and others. Still, it seems that SPC has so far been used only in a limited manner for environmental processes.

It is considered that the inherent nature of any process has some common variations in cause that it is not possible to alter without changing the process itself. But 'assignable' or 'special' causes of variation are unusual disruptions to the process, the causes of which can, and should, be removed, of course after being recognised as such. One key purpose of SPC is to distinguish between these two types of variation, aiming to avoid both overreaction and under reaction, leading to a lack of need to respond to the process. It assists in recognising situations where reaction relates to a cause that has sufficient impact, and which is practical and economic to remove, in order to improve quality (Woodall 2000).

Application of the concept of statistical process control aims to enable steady improvement in the quality of a product, even while dealing with the everyday crises which are an unavoidable part of any production or service process. It needs to be underlined that statistical process control is completely different from the end product inspection conveniently associated with "quality assurance". It generally consists of the three following phases:

1. Provision of a flowchart of the process, clearly separating process functions and steps;
2. Random sampling and measuring, usually at regular temporal intervals, during different phases/functions of the process;
3. Provision of "control chart(s)" aiming to recognise such "Pareto glitches", in order to discover and remove their causes.

All processes can be supervised and brought 'under control' by collecting and using their data. This includes process quality-performance measurements, which will provide the feedback required for corrective action, but only where found necessary. Statistical process control methods provide an objective means of controlling the quality in any transformation process. W.E. Deming wrote that quality and productivity increase as variability decreases, and, because variations are unavoidable, statistical methods of quality control must be used to measure and gain understanding of the causes of the variation.

The essence of statistical process control is to differentiate the various causes of process variation. Some variations belong to the category of chance or random variations, considered as inherent to the process, and they could be removed only by revising the whole process. However, other causes of variation, relatively large in magnitude and identifiable, are conveniently classified as 'assignable' or 'special' causes. When special causes of variation are present, variation is excessive and the process is classified as 'unstable' or 'out of statistical control'.

Thus, SPC tries to respond to the following two key questions: (1) "Is the process incontrol?", and (2) "What is the extent of process variability?" A response to these questions actually relates to the potential presence of any special causes of variation, and identifies whether or not variability is due only to natural process capability, in which case only the common causes of variation are present.

To control a process using data, it is necessary to monitor the current state of the accuracy and precision of the distribution of the data, which is done using control charts. A control chart has a function similar to that of the traffic signal, where the green light is given when the process is running properly and does not need any adjustment (process is under control), meaning that only the common causes of variation are present. The next level is the amber light, which signals that some discrepancy to the natural process might be possible. The red light clearly shows that assignable or special cause(s) of variation appeared before the occurrence of such data and the process is definitely out of control. However, such a control mechanism may only be used when the process itself is "in statistical control", meaning that it did not change its main behavioural characteristics, such as the mean value or variance.

Results of the Application of the SPC Mean Chart

The control chart used within this paper relates to the mean chart of data samples. Periodically, samples of a given size (e.g. four paint cans, five bottles of beverages, seven mobile phones etc.) are taken from the production process at decided intervals. They are considered to be representative for a given production process, when this process is believed to be incontrol and with no need for any adjustments. Specific value (e.g. volume, weight, etc.) is to be measured for each item of the sample. For each sample, the arithmetic mean (average) is calculated, and after taking the last sample, two more key variables are calculated. These key values are process mean value X, evaluated as an average of sample means, and process Standard Error SE, evaluated as standard deviation of sample means (relation between SE and standard deviation σ of the whole dataset or population is

SE = $\sigma/\sqrt{n}$, where n is sample size). If the process is stable, it may be expected that most of the individual sample means lie within the range X ± 3SE (Oakland 2003), based on the assumption of a normal distribution of data.

Which signals show that the process is not incontrol? The first such signal, having the probability of occurrence of less than 0.3 % in the case of a normal distribution of data (which should be expected for a sample of 28–31 in size), is that the individual sample mean lies outside the range X ± 3SE. The second signal is when the probability that the individual sample mean lies outside the range X ± 2SE is about 4.5 %, as this makes it very unlikely for two consecutive samples to have such characteristics. This is thus considered as an indication that the process may be out of control. The third signal is when there is the case that several consecutive sample means lie at the same side of the Process Mean Value, being consistently lower or higher. With 6 or 7 such values, probability of such an occurrence drops to around 1.4 or 0.7 %, which is again a signal that the process is getting out of control. That is the basis to establish "warning lines" LWL (lower warning line) and UWL (upper warning line) at X ± 2SE and "action lines" LAL (lower action line) and UAL (upper action line) at X ± 3SE (Oakland 2003).

For this research, every single month in one year is considered as one sample, and a sequence of 30 samples for the same month are taken for the period 1961–1990. The measurement station is in Sarajevo. Temperatures were recorded by the Hydro-Meteorological Institute, and can be considered as valid. Sample means for each of the months provide another data set. Their standard deviations were calculated and they represent the SE for that specific month. Finally, this process is repeated for the whole year, month by month. The control chart is then extended with the sample means for the period 2000–2010, still using the same warning and action lines to access its variations.

The results of these evaluations are presented in the following Figs. 9.1, 9.2, 9.3, 9.4, 9.5, 9.6, 9.7, 9.8, 9.9, 9.10, 9.11 and 9.12:

As may be seen from the control chart for the month of January during the observed period of 2000–2010, only one year (2007) had an average temperature higher than the UWL, which is not an indication that the process is out of control.

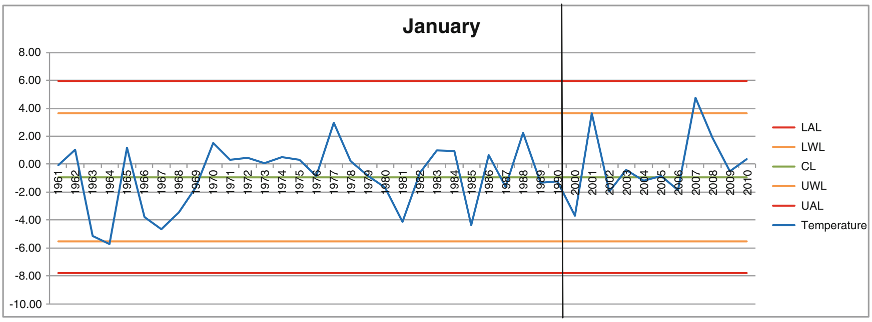

Fig. 9.1 Control chart for January temperatures

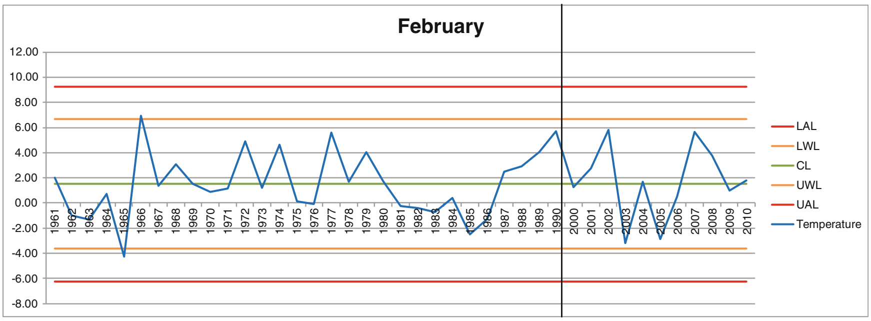

Fig. 9.2 Control chart for February temperatures

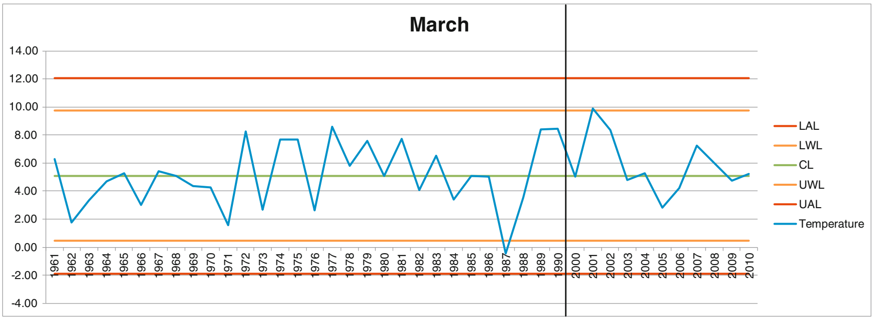

Fig. 9.3 Control chart for March temperatures

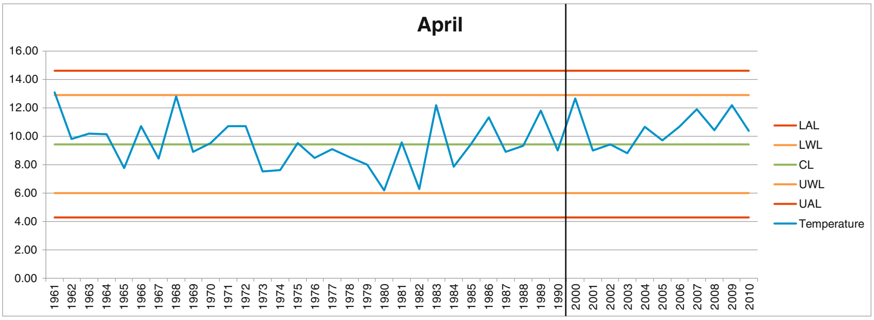

Fig. 9.4 Control chart for April temperatures

The control chart for the month of February shows that, in the period 2000–2010, the average temperature was fully within the range between the two warning lines, meaning that "the process" is fully in control.

The control chart for the month of March shows that, in the period 2000–2010, only one year (2001) had an average temperature higher than the UWL, which is not an indication that the process is out of control.

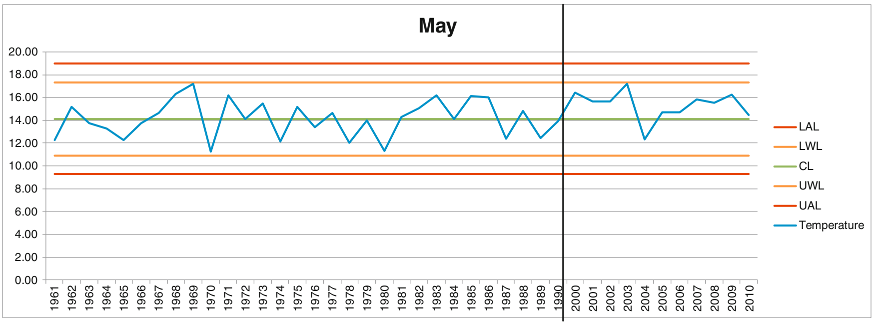

Fig. 9.5 Control chart for May temperatures

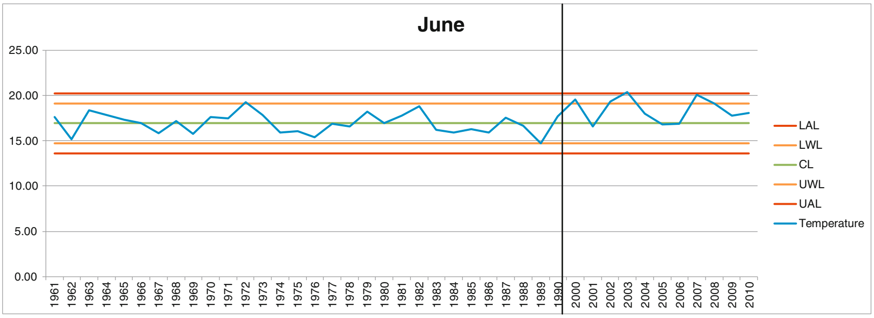

Fig. 9.6 Control chart for June temperatures

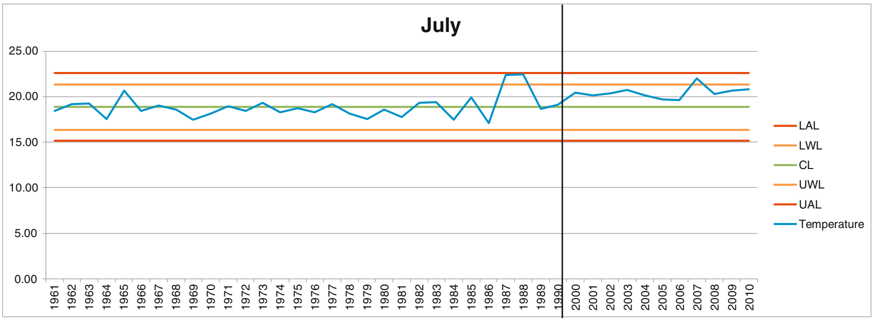

Fig. 9.7 Control chart for July temperatures

The control chart for the month of April shows that, during the period 2000–2010, the average temperature was fully within the range between the two warning lines, which again means that "the process" is fully in control.

Similar to the previous charts, the control chart for the month of May also shows that, in the period 2000–2010, average temperature was fully within the

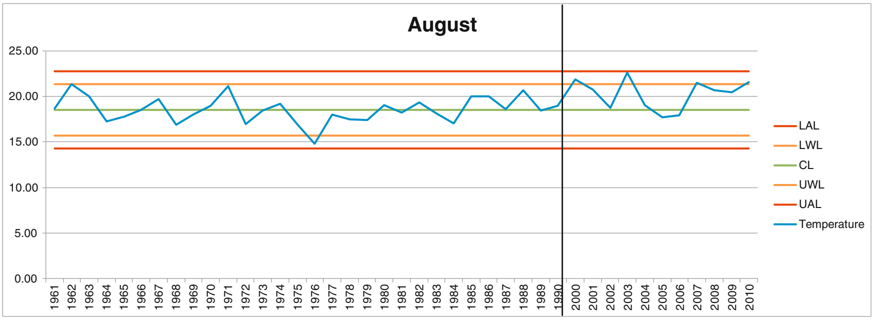

Fig. 9.8 Control chart for August temperatures

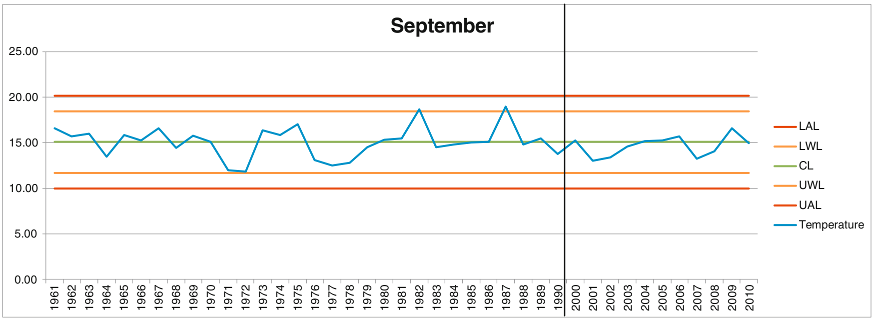

Fig. 9.9 Control chart for September temperatures

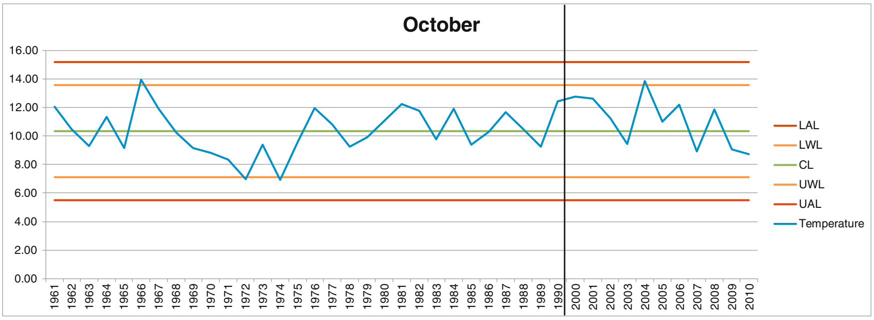

Fig. 9.10 Control chart for October temperatures

range between the two warning lines, which again means that "the process" is fully in control.

The control chart for the month of June shows different temperature behaviour during the observed period of 2000–2010. Namely, during four years (2002, 2003, 2007 and 2008) the average temperature was higher than the UWL, but this is still not an indication that the process is out of control. The average temperature from

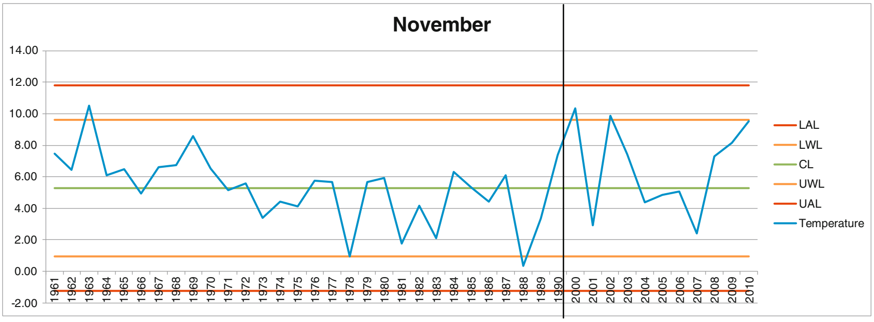

Fig. 9.11 Control chart for November temperatures

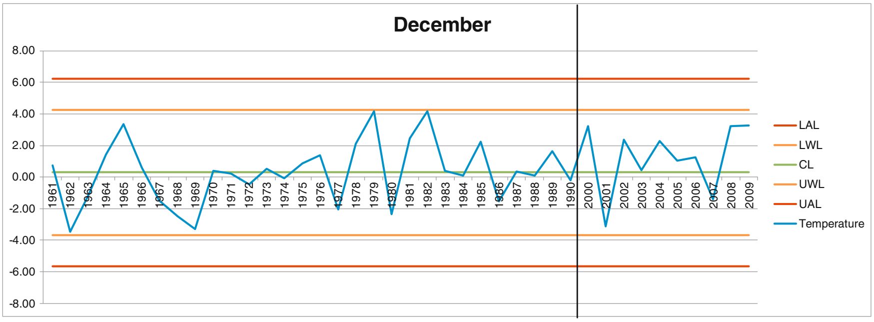

Fig. 9.12 Control chart for December temperatures

2003 was also higher than the upper action line (UAL), which is an indication that for this month and the year of 2003, the temperature has indicated possible special causes of variation, that were not existing during the period of 1961–1990.

The control chart for the month of July shows that, during the observed period of 2000–2010, only one year (2007) had an average temperature higher than the UWL, which is not an indication that the process is out of control. There was similar behaviour in the Julys of 1987 and 1988, which is not relevant for this study, even though this variation was included in the calculation of the control lines.

The control chart for the month of August again shows different temperature behaviour during the observed period of 2000–2010. During three years (2003, 2007 and 2010), the average temperature was higher than the UWL, however, this is still not an indication that the process is out of control.

Similarly to some of the previous charts (February, April, May), the control chart for the month of September also shows that, during the period 2000–2010, the average temperature was fully within the range between the two warning lines, which again means that the process is fully in control.

The control chart for the month of October shows that, in the period 2000–2010, only one year (2004) had an average temperature higher than the UWL, which is an indication that the process is in control.

The control chart for the month of November shows that during the observed period of 2000–2010, only two years (2000 and 2002) had average temperatures higher than the UWL, which is an indication that the process is still in control.

Similar to some of the previous charts (February, April, May, September), the control chart for the month of December also shows that, during the period 2000–2010, the average temperature was fully within the range between the two warning lines, which again means that the process is fully in control.

The comparison of the average monthly temperatures for the periods 1961–1990 and 2000–2010 in Fig. 9.13 clearly shows that, except for the month of September, all other months had higher average temperature values during the latter period. Variation in the average temperature increase is presented in Fig. 9.14. The average temperature increase for the whole year is 0.95 °C (red line), ranging from −0.43 °C in September to 1.58 °C in July (blue line).

Even though both Figs. 9.13 and 9.14 clearly show that the average temperature increased in the latter period observed, it may also be seen that the temperature values still mostly fall within the range of X ± 3SE, and there is only one example of a sample mean being higher than the UAL, and that is for the June of 2003.

When referring to consecutive individual sample means lying outside the range X ± 2SE in the period 2000–2010, which may be noticed in the month of June for the years 2002–2003 and 2007–2008, it may be seen that, both times, the values are actually at the UWLs (the same is the case for July 1987–1988).

When several consecutive sample means that lie at the same side of or on the centre line (being constantly higher) are concerned, the following periods have 6 or 7 such consecutive values: the month of April in the period 2004–2010 and the month of July in the whole period 2000–2010. The month of May in the period of

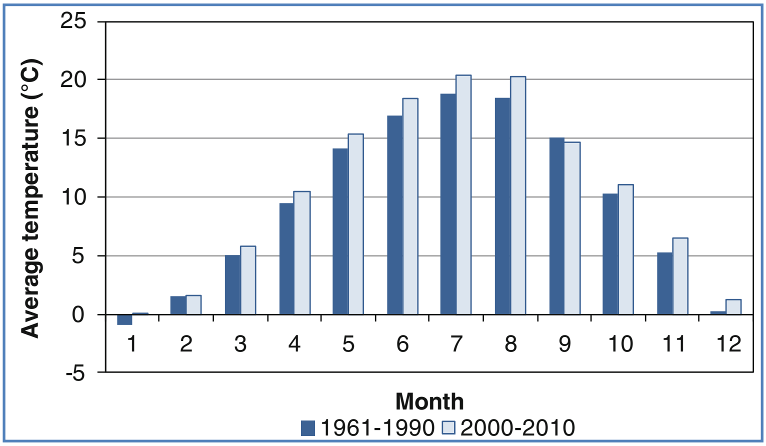

Fig. 9.13 Temperature comparison by month

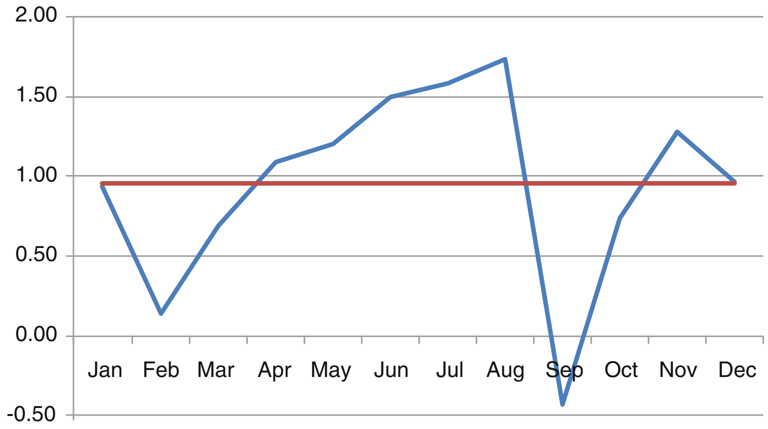

Fig. 9.14 Temperature differences between periods 1961–1990 and 2000–2010 by month

2000–2010 can also be stressed, even though the year 2004 does not meet this condition. The case of December in the period 2002–2009 is similar, where the year 2007 is an exception.

Thus, SPC clearly indicates temperature increase. However, this increase is not evenly distributed throughout the year, with the spring months of April and partly May the most affected, the summer months of June and July and the winter month of December.

Conclusion

The objective of this paper is to demonstrate the potential uses of SPC methods in evaluating variations in temperature, in order to check the most commonly accepted hypothesis that climate change is an ongoing process. The results achieved clearly show that SPC methods, in this case the sample means control chart, indicate specific behaviour of natural processes. However, the use of other types of control chart should also be implemented.

At the same time, results for Sarajevo prove that temperature increase, but it is not evenly distributed throughout the year. The behaviour indicating that the process is out of control may only be noticed during certain months of the year. This is primarily during the warmer months, April to July, and to some extent also during the winter month of December. Further research would be needed to justify why such distribution is occurring, and if it may be expected to continue as such.

This paper provided the first results using this approach, which has not been applied in this context before. It should be reapplied to data from other locations or types, e.g. precipitation. Also, other control charts, such as range charts showing differences in temperature range behaviour, should be applied.

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Part II
Renewable Energy Strategies and Methods

Chapter 10
Sustainable Energy Development in the Pacific: The Evolution of Energy Frameworks and National Policies

Anirudh Singh, Solomone Fifita, Rupeni Mario, Pritika Bijay and Anirudh Singh

Abstract Over the past decades, the region has been actively engaged in finding ways in which these challenges could be addressed, and solutions that would reduce the region's reliance on imported fuels. The earliest thinking relied heavily on the possible use of renewable energy to substitute for fossil fuels. Over the years however, there has been a gradual evolution of thought, with the consequence that recent energy strategies, at both the national and regional levels, have realised the limitations of this one-pronged approach. It has been realised that some energy use sectors will continue to depend on fossil fuels for a long time. The importance of energy efficiency and effective energy policies and plans is also acknowledged. Another important development has been the use of the whole-of-sector approach to the solution of energy problems. This paper traces the development in energy policies that have taken place in the Pacific over the last decade, and critically assesses the key elements of new thinking in energy planning for the region. After deliberating the need for energy policies in general, it examines the features of the Pacific Island Energy Policy and Plan (PIEPP), and discusses the possible reasons why it was unable to deliver its expected outcomes. The importance of the whole-of-sector approach, as well as other considerations that are now thought to be essential tools for energy planning and implementation in the Pacific region, is discussed. The present status of the development of a regional energy strategy, as embodied in the Framework for Action on Energy Security in the Pacific (FAESP), is then outlined.

Keywords Sustainable energy development · Energy policy · Energy efficiency · Pacific Island Countries (PICs) · National energy policy · FAESP

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_10,

Short Introduction

The Pacific Island Countries and territories (PICTs) face a number of common energy challenges. One of these is the lack of indigenous fossil-fuel resources This leaves these nations with no option but to import the required fuels from abroad at great expense. The remoteness of these island nations imposes further costs and introduces supply chain issues.

This paper traces the development in energy policies that has taken place in the Pacific over the last decade, and critically assesses the key elements of new thinking in energy planning for the region.

Energy Challenges of the Pacific

The Pacific Island countries and territories (PICTs) comprise 22 island nations and territories, stretching from the Northern Marianas in the north-west of the Pacific to French Polynesia and the Pitcairn Islands in the south-east. They include American Samoa, the Cook Islands, the Federated States of Micronesia, Fiji, French Polynesia, Guam, Kiribati, the Marshall Islands, Nauru, New Caledonia, Niue, the Northern Mariana Islands, Palau, Papua New Guinea, the Pitcairn Islands, Samoa, the Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu and the Wallis and Futuna Islands. The total population that inhabits these 79 million km^2 of the mid-Pacific region is about 10 million. However, when the population of 7 million belonging to Papua New Guinea alone is ignored, the true picture of a sparsely populated region of nations separated by vast distances emerges.

The PICTs are faced with many energy challenges because of their remoteness, sparse populations and their geological nature. Because of their general lack of indigenous oil reserves (except for Papua New Guinea), they are heavily dependent on imported fossil fuels for their energy needs. Almost all of this is required for their power generation and transportation needs, with 25 % of the imports going towards the former sector and 75 % towards the latter (Gould et al. 2011). Imported petroleum is responsible for more than 80 % of power generation in the PICTs. The Cook Islands, Kiribati, Nauru, the Solomon Islands and Tonga are entirely dependent on imported fuel for their power generation (Gould et al. 2011). Figure 10.1 indicates the large contribution imported fossil fuel makes to the power generation mix of selected PICs.

A matter of great concern to all PICs is that fuel import costs as a percentage of their GDP have more than doubled between 2002 and 2008. In the case of Fiji, the ratio of fuel import costs to GDP increased from 5 % in 2002 to 12 % in 2008, while this ratio increased from 12 to 25 % between the same years for Kiribati (Levantis 2008). Because of the almost total dependence of the PICs on imported fuels for power generation and transportation, a rise in fuel prices contributes to inflation, deterioration in balance of payments and lower real incomes in these

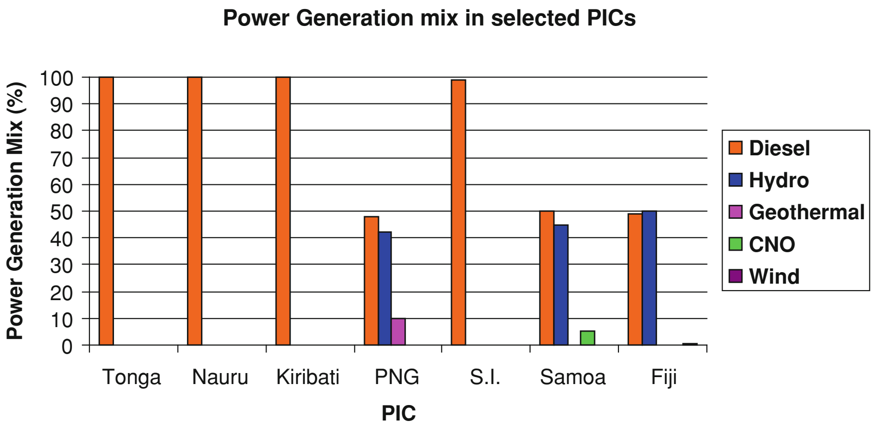

Fig. 10.1 Comparison of imported fossil fuel and other primary energy sources for power generation—selected PICs (*Source* Singh 2012)

countries (Gould et al. 2011). Some experts have predicted that the situation is currently (2012) developing towards another fuel price crisis for these countries. As global fuel prices have nearly doubled over the last two years (2010, 2011) an oil price shock to the PICs comparable to that of 2008 is imminent.

These economic ramifications of imported fuel prices has made the region well aware of the need to reduce, if not eliminate its imported fuel dependency. Ways that come to mind are substitution of imported fuels by indigenously-sourced energy supplies, the most obvious of which is renewable energy. Import bills can also be reduced by reducing the landed price of imported fuels, and by making more efficient use of this commodity through energy efficiency measures.

In working towards a viable solution to the fuel import issue, the region is faced with several challenges. These include the small, isolated nature of most PICs, the limited and varied availability of indigenous renewable energy resources, and the lack of human and institutional capacity to meet these challenges (FORUMSEC 2011). A crucial first step towards developing solutions to these energy challenges is the formulation of energy policies, both at the regional and national levels. This paper outlines the attempts that have been made over the last decade to achieve these aims.

Early Attempts at a Regional Policy

The PICs differ vastly in their demography, geography and geology. They range from low-lying coral atolls to mountainous volcanic island states, and from populations of a few thousand to several millions. There are also many social and cultural differences, including language differences. Apart from English and

French, the region boasts a rich diversity of indigenous languages. Geological differences between the volcanic islands and coral atolls mean the availability of energy resources such as hydropower and biomass resources is not even across these island nations.

While the PICs have many energy issues in common, there are also many differences in their energy needs and their ability to satisfy them. Each nation thus needs an energy policy that is tailor-made to suit its own requirements. However, there are also challenges each shares with other PICs, a notable example being the fossil fuel supply problems to remote small island states. There is, therefore, a need for regional policies to cater for such common requirements. These small nations also need guidance in the development of their individual national energy policies.

The first regional energy policy to be attempted was the Pacific Island Energy Policy and Plan (PIEPP) (Pacific Islands Energy Policy and Plan 2002). It was developed in 2002 by the Energy Working Group (EWG) of the Council of Regional Organizations of the Pacific (CROP) and was to act as a "guideline for a regional organization energy policy and for developing PICT national energy policies" (Wade et al. 2005). This plan was revised in 2003 to strengthen the renewable energy (RE) component and presented to the Regional Energy Ministers' Meeting (REMM) in Oct/Nov 2004 (Wade et al. 2005).

The PIEPP consists of six themes and four cross-cutting issues, collectively labelled as the ten sections. The six themes are: regional energy sector coordination; policy and planning; transportation; renewable energy; and petroleum. Rural and remote islands, environment, efficiency and conservation, and human and institutional capacity comprised the four cross-cutting issues.

The nature of a section was defined via the statement of a goal. For each section, policies were stated, a strategy or strategies adopted for its implementation, activities stipulated for the implementation of the strategies, and indicators of success (i.e. key performance indicators) identified for assessing the outcomes of each activity. The goal, policies and strategies of a typical section (Theme 5, renewable energy) are listed in Table 10.1.

The task of ensuring that each strategy was properly implemented was allocated to a specific regional organisation, called the "lead agency". In 2004, the overall administrative responsibility for energy was given to the Pacific Islands Applied Geoscience Commission (SOPAC). There were also assumptions associated with each strategy that had to be clearly recognised, and a timeframe implemented to indicate the expected time of completion.

All these features are exemplified using the case study of renewable energy strategy 5.1.1 in Table 10.2 below.

In December 2004, the PIEPP was separated into two complementary documents—the Pacific Islands Energy Policy (PIEP) which was a policy document only, and the Pacific Islands Energy Strategic Action Plan (PIESAP) which was the associated working document (FORUMSEC 2011). The two documents were endorsed by senior energy officials at their Regional Energy Meeting held in December 2004 in Madang, Papua New Guinea (FORUMSEC 2011).

Table 10.1 The goal, policies and strategies of PIEPP corresponding to theme 5 (Renewable Energy) (*Source* Pacific Islands Energy Policy and Plan 2002)

Theme	Goal	Policies	Strategies
5. Renewable energy	5. An increased share of renewable energy in the region's energy supply	5.1 Promote the increased use of proven renewable energy technologies based on a programmatic approach	5.1.1 Implement a regional RE programme 5.1.2 Ensure access to information and training materials in RE 5.1.3 Assess RE potentials in PICs 5.1.4 Assist PICs in obtaining funding for RE projects 5.1.5 Carry out feasibility studies of RE technologies in PICs
		5.2 Promote the effective management of both grid-connected and stand-alone renewable-based power systems	5.2.1 Support the establishment of stand-alone power systems by utility providers
		5.3 Promote a level-playing-field approach for the application of renewable and conventional energy sources and technologies	5.3.1 Remove biased barriers to the application of RE technologies
		5.4 Promote public–private partnerships and mobile external funding for RE	5.4.1 Implement externally-funded projects through public–private partnerships

Inadequacies of the Pacific Island Energy Policy and Plan (PIEPP)

Possible problems with the PIEPP became evident as early as 2004 (Wade et al. 2005) when it was observed that the division of responsibilities for the implementation of the plan would be a major difficulty. The plan was the responsibility of the Energy Working Group (EWG) of the Council of Regional Organizations of the Pacific (CROP) and was administered by SOPAC. However, the EWG seemed to have an "unclear mandate, outdated terms of reference, and … no budget for its meetings" (Wade et al. 2005). It is also obvious that while the EWG had the overall responsibility for the plan, the themes were apportioned to several different regional organisations, each of which had an interest in energy.

Table 10.2 The organisational features of RE strategy 5.1.1 of the PIEPP (*Source* Pacific Islands Energy Policy and Plan 2002)

Strategy 5.1.1 Design and implement a regional programme to promote the widespread and sustainable utilisation of proven renewable energy technologies

Activities	Lead organisation	Indicators	Assumptions/ Risks	Time frame
Install 10,000 solar water heaters in schools, hospitals and community based premise	SOPAC	Number of installed systems [Regional programme reports]	Resources (financial and TA) available	2012
Install 20,000 solar modules in rural electrification projects	SOPAC	Number of installed systems [Regional programme reports]		2012
Install 5 wind power projects with a combined capacity of 5 MW	SOPAC	Number of installed systems [Regional programme reports]		2012
Install 1pilot micro-hydro project	SOPAC	Number of installed systems [Regional programme reports]		2012
Support the use of bagasse and wood chips where feasible	SOPAC	Energy Mix statistics [Energy Sector annual report]		2012
Plant 0.5 million fuelwood seedlings in atoll countries	SOPAC	Energy mix statistics [Energy Sector annual report]		2012

In a review of the plan carried out in 2010 (Johnston et al. 2010), it became clear that there were several underlying flaws that presented serious barriers to its successful implementation. The two main objectives of the plan were to coordinate the regional energy sector planning and programmes of regional organisations, and to offer guidelines in the planning of National Energy Policies and Plans of individual PICTs. It was essentially found that while the plan was largely successful in its second objective, it was unable to carry out its first objective with any effectiveness. The main reason for this failure seemed to lie in the lack of clear vision for the regional energy programme, as well as uncertainty in the role the lead agency assigned to this task (SOPAC) was supposed to play. But there were several other serious failings pointed out by the review committee. Among these were:

- the objectives of the plan were vague, and lacked focus
- there were no guiding principles for energy sector development
- no proper timeframes had been set
- there were no clear allocations of responsibility
- there was no mechanism mentioned for the monitoring and evaluation of the success of the activities

- the plan did not emphasise that the region would be dependent on imported fossil fuel for a long time to come, and subsequently that fuel pricing and supply issues should be addressed as a priority
- the importance of data on energy in decision-making was not stressed

At the Pacific Energy Ministers' meeting (PEMM) at Nuku'alofa, Tonga, in April 2009, it was resolved that the lead role for energy in the region was to be given to the SPC. It then became evident that the PIEP and PIESAP had to be revised if the SPC was to succeed in its new role. This was brought to the notice of the Pacific Leaders at the Pacific Islands Forum Meeting in Cairns, Australia in August 2009. The ministers agreed on the need to review the PIEP and its associated Action Plan (PIESAP). The key priorities to be addressed in the review included strengthening coordination of regional services and donor assistance, and the delivery of energy services to the region through one agency (the SPC) and through one programme (FAESP 2010).

The ministers also called for (FAESP 2010):

- human capacity development to support national and regional energy programmes
- strengthening of national capacity in collection and analysis of energy data and information
- support for the regional bulk procurement initiative
- facilitation of investment in sustainable renewable energy technologies, energy efficiency and energy conservation

The document that resulted from this decision was the Framework for Energy Security in the Pacific (FAESP) (FAESP 2010) and its associated implementation plan, which were endorsed by the Pacific leaders in 2011.

New Thinking in Regional Energy Planning

A novel feature of FAESP is its use of the "whole-of-sector approach" (WOSA) in problem-solving. It is also based on a "many partners, one team" philosophy, which acknowledges that energy solutions for the region require input from many stakeholders, who should be accorded equal status, and consider the energy sector in its entirety rather than focusing only on a limited aspect. So what is the whole-of-sector approach?

This new approach to energy planning was used earlier for the first time in the formulation of the Tonga Energy Roadmap (TERM), the new national energy policy for Tonga, by the several development partners and other stakeholders involved in the exercise (Tonga Energy Roadmap 2010). The essential features of WOSA are described in a paper delivered by the World Bank at the Forum Energy Ministers Meeting (FEMM) in Brisbane, Australia, on 21 June 2010 (Fernstein et al. 2010). According to this paper, a successful WOSA at the national level requires that the government coordinates the activities of all relevant stakeholders involved in the planning, and allows access to all relevant energy information to the team members. In addition, the development partners should fund and coordinate the technical assistance required for the planning process.

The other features of this approach include

- a least-cost approach to meeting the overall objectives
- risk management through, for instance, the development of options to meet demand, especially electrical demand
- assurance of financial cost-effectiveness of the task
- environmental and social sustainability of the outcomes
- clear delineation of the roles of the government, utility providers and the private sector

The WOSA is not a new problem-solving methodology. It is a well-understood principle used in the past that includes (Fernstein et al. 2010):

- the need for high level leadership in National Energy Policy and Strategy development, with alignment across line departments
- energy being treated as an integrated sector in the overall infrastructure development of the nation
- the realisation that tasks should be realistic, time-bound, costed, and lead to measurable outcomes
- renewable energy should be considered for all its perceived benefits, including economic benefits, improving energy access, and its environmental and social impact
- energy plans should be linked to national energy budgets
- the role of the private sector must be recognised.

Features of the FAESP

The FAESP starts with the following clear statements of vision, goal and expected outcomes

Vision	An energy-secure Pacific
Goal	Secured supply,efficient production and use of energy for sustainable development
Outcomes	i) Access to clean and affordable energyii) Optimal and productive use of energy

The framework is based on eleven guiding principles (FAESP 2010), and the following seven themes which embody the principles:

- leadership, governance, coordination and partnership
- energy planning, policy and regulatory frameworks
- energy production and supply

- petroleum and alternative liquid fuels
- renewable energy
- energy conversion
- end-use energy consumption
- energy use in transport
- energy efficiency and conservation
- energy data and information
- financing, monitoring and evaluation

These statements of policies are realised via an implementation plan (called the Implementation Plan for Energy Security in the Pacific—IPESP) (SPC 2011) that assigns actual activities to the policies, apportions responsibilities and institutes a system of monitoring and evaluation. The overall structure of FAESP is depicted in Fig. 10.2 below.

The FAESP has learnt from the lessons provided by the PIEPP example, and is a product of an analysis and development process involving the cooperative efforts of many stakeholders, including regional agencies, development partners and country beneficiaries, that took two years and several stages of vetting and approval by Pacific energy officials and leaders.

It is a well-structured document which has a clearly stated vision, goal and expected outcomes. It is based on clearly-stated guiding principles that provide the basis for the rational development of the framework. Responsibility for activities is

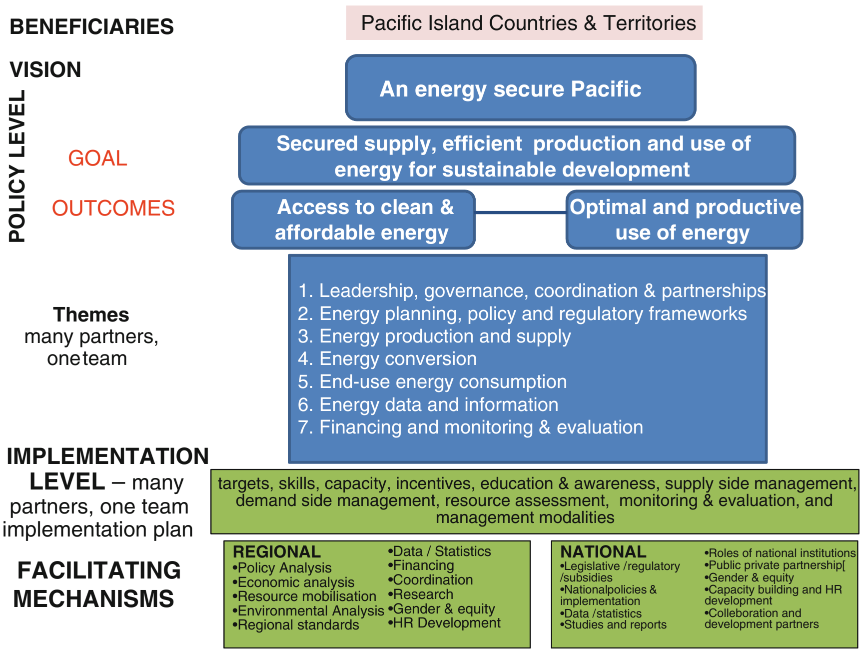

Fig. 10.2 Structure of FAESP (*Source* SPC Division of Energy)

Table 10.3 Comparison of features ofPIEP and FAESP

PIEP	FAESP
1. It has no clear allocation of responsibilities	SPC is the lead agency responsible for theFAESP
2. It has no guiding principles	It is based on eleven clearly-stated guiding principles
3. Its objectives are vague and lack focus	It has seven themes, each with a rationale, expected outcomes, long-term objectives and key priorities
4. Has no clearly-specified timeframes for its activities	The activities are assigned clearly-defined timeframes in the associated IPESP
5. The importance of energy data (statistics) for decision-making is ignored	The importance of energy statistics is clearly acknowledged in Guiding Principle 8 and is re-iterated in Theme 6 of the FAESP
6. It has no formal status	It was endorsed by the Pacific Energy Ministers' Meeting in Tonga in April 2009 and at the Pacific Islands Forum meeting in Cairns, Australia, in August 2009. Or Vanuatu in Aug 2010. The Brisbane ministerial meeting was in June 2010.
7. No monitoring and evaluation framework	Has an M&E framework in terms of the IPESP and the development of energy security indicators
8. No specific budget	Has an itemised budget which tallies to US$ 20 m (excluding personnel costs) for a 5-year timeframe

assigned unambiguously, and metrics for determining the successful achievement of outcomes are clearly stated. It is a pragmatic document that learns from previous experiences and includes new thinking in the formulation of strategies

Some of the obvious differences between the PIEP and FAESP are outlined in Table 10.3 below.

There are three notable new elements that FAESP introduces to regional energy planning. Firstly, it is based on the whole-of-sector approach. Secondly, it is sensitive to issues of sovereignty when it acknowledges the primacy of national energy policies over regional ones. Lastly, it formalises the need for inclusiveness in the "many partners, one team" philosophy it embraces.

National Energy Policies

All PICTs have some form of national energy policy or energy document that acts as a guide to national energy activities. The comprehensiveness of these documents varies from country to country. Over the past decade, national energy priorities have rarely changed as compared to current initiatives with the focus still on energy security, as outlined at the regional level, and, more specifically, on the reduction in the use of fossil fuels.

The challenge has always been on the availability of resources for the implementation of energy plans. More specifically, it has been to obtain these resources through national budget allocations. Generally speaking, these policies have not been realised in practical terms, as many countries are yet to have specific energy regulations and legislations enacted to support their policy statements.

Conclusions

Will FAESP work?

It is too early to make a definitive statement. But no plan is ideal, and the FAESP is bound to have problems that will only appear over a period of time. Considering the complexity of the situation, with such a diversity of people and their needs, and the heterogeneity of available energy resources, it will be very surprising if the FAESP succeeds in meeting all its requirements on its first application. Further reviews will therefore almost certainly be in order.

Perhaps a more appropriate question to ask is what the situation would have been in the absence of the FAESP. There can be no doubt that, having learnt the lessons of the past, this new regional energy plan will be a significant improvement over the last.

It must be noted in passing that the FAESP and its implementation plan have been designed to be administered by the CROP agencies. It would therefore be appropriate for all the CROP agencies to coordinate their efforts by putting together their annual work plans in one document, where it could be centrally monitored. There can be no doubt that the FAESP has already brought about a noticeable improvement in cooperation within CROP members, as compared to the PIEPP, with the result that some joint activities are now taking place. However, a combined work plan will bring about a vast improvement in the collaborative efforts of these Pacific organisations.

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Chapter 11
Promoting Renewable Electricity Generation in Developing Countries: Findings from Comparative Analyses in South America

Isabel Ribeiro and Jonathan Krink

Abstract Access to electrical energy has a key role with regards to socio-economic development and poverty alleviation in particular. Local generation and use of renewable energy offer significant potential for local economic development as well as different environmental benefits. However, in many regions, the lack of electrification is a major impediment to economic development. Even though most of the South American countries have specific and defined strategies as well as plans to improve renewable energy generation, actual implementation is threatened by a wide range of legislative, financial, political and technological problems. This paper presents the key findings of a study carried out as part of the Renewable Electricity Generation in South America (REGSA) project, which comprises comparative analyses of the legislative and institutional frameworks as well as the technical and socio-economic potential of electrical power generation by means of renewable energy in South America and in particular Bolivia, Brazil and Chile. In addition, the paper analyses the results of a mapping of best-practice renewable electricity generation projects in South America and the EU. Finally, it will conclude with some suggestions for fostering renewable electricity generation in developing countries.

Keywords Developing countries · Latin America · Renewable energy · Electricity generation

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_11,

Short Introduction

This paper presents the key findings of a study carried out as part of the Renewable Electricity Generation in South America (REGSA) project, which comprises comparative analyses of the legislative and institutional frameworks as well as the technical and socio-economic potential of electrical power generation by means of renewable energy in South America and in particular Bolivia, Brazil and Chile, analyzing the results of a mapping of best-practice renewable electricity generation projects in South America and the EU.

The REGSA Project

A well-established energy infrastructure that reliably supplies the population with electricity is an indispensable element in the process of socio-economic advancement in developing countries. Many South American countries, however, suffer a considerable lack of energy infrastructure. In addition to their different environmental benefits, renewable energy (RE) offers meaningful potential for improvement of energy supply and security in South America as well as poverty alleviation. Particularly rural and difficult-to-access regions can benefit from the implementation of RE with regard to the independent nature of RE generation.

The Renewable Electricity Generation in South America (REGSA) project is a technology and knowledge transfer project funded by the European Union. The project's overall objective is to promote renewable electricity generation in South America and contribute to increasing RE utilisation in Bolivia, Brazil and Chile.

In order to achieve good and sustainable results through technology and knowledge transfer in the field of RE between the REGSA partners, it is first essential to investigate the current situation and to explore existing structures. Within the framework of the work package 2 (WP2) of REGSA a survey was conducted with the objective of a comparative analysis of political and institutional frameworks for RE development and the status quo analysis of RE generation in South America.

Related Literature

Studies that analysed the situation of RE policy making and the use of REs in South America have been conducted at different times in the past. Subsequently some examples of international studies that are thematically similar to the one presented in this paper are given. In 1999 the GTZ published the first edition of the TERNA country survey conducted on behalf of the German Federal Ministry for Economic Cooperation and Development. Since then, three updated editions have been published—in 2002, 2004 and 2009. In the revised versions new country surveys were added and previous ones were updated. The survey sampled developing and emerging countries in Latin America, Africa, the Middle East and Asia. The survey aims to provide information that helps interested players to access new RE markets. It puts together detailed information about the framework and policy conditions in the surveyed countries as well as about the current RE situation (Posorski and Werner 2009).

In 2004 the GTZ published a paper in cooperation with the United Nations Economic Commission for Latin America and the Caribbean (ECLAC), focusing on the current status of RE in Latin America and the Caribbean with regard to policy making and baseline conditions. After presenting a background review of past efforts to promote REs in the region, it divides the area into six subregions comprising several neighbouring countries. The subregions are analysed with regard to the current state of renewable in the region. Moreover obstacles and opportunities for the penetration of REs and RE policy making are described. The paper points out the importance of the sustainability of RE production. This remark relates to the fact that the intensive use of hydroelectric power and power from biomass in some countries is practised without considering the negative environmental and social effects it generates. Finally, the need for improved cooperation between important governmental, non-governmental and private organisations and institutions is expressed (GTZ and ECLAC 2004).

The global energy network institute published a paper on the RE potential in Latin America in 2009. It aims to give an overview of the RE potential in every Latin American country and thus contribute to RE development in general, the reduction of greenhouse gases and their consequences. Every country was analysed individually for its solar power, wind power, hydro power, geothermal power and biomass potential. The paper provides a multitude of maps illustrating the potential distribution of these RE sources in the different countries. One of the main outcomes was that the big share that REs have in energy generation in Latin America is somewhat misleading because it almost entirely comprises hydro energy and biofuels. For a number of reasons the authors doubt the adequacy of the large-scale use of these RE sources. At the same time they see big potential for the expansion of the other ones (Meisen and Krumpel 2009).

In 2011 the MIT Center for Energy and Environmental Policy Research published a paper on support schemes for REs in South America. Initially it describes the South American perspective on REs from the security-of-supply point of view as well as from the economic point of view. It then reviews the RE support schemes that have been, are and could be developed in South America and names the most important support schemes, laws and stakeholders in each of the ten surveyed countries. It identifies long-term energy auctions as the main instrument for RE promotion in South America and leaves the question open if the increasing efforts to implement REs into the energy mix will be successful (Batlle and Barroso 2011).

In 2011 the UNEP's Technology Needs Assessment project presented the first edition of a new series called Technology Transfer Perspectives. This first edition investigates the possibilities for diffusing REs on the basis of a number of case studies of enabling frameworks in developing countries. Sample regions include South America. The report objective is to "provide insights for governments on how to reform their policies and institutions so as to provide clear and stable incentives that promote diffusion of climate-friendly technologies". The report is divided into two parts: enabling frameworks addressing specific technologies and enabling frameworks addressing multiple technologies. One major finding is that there is no "one" solution for the successful transfer and diffusion of technology. This obstacle is addressed by specifying appropriate policies and actions individually for each surveyed country (Haselip et al. 2011).

Within the framework of the work package 2 (WP2) of the REGSA project, this new survey was conducted with the objective of a comparative analysis of political and institutional frameworks for RE development and the status quo analysis of RE generation in South America.

South American Energy Markets

Figure 11.1 shows a map of South America.

The majority of all the countries that were researched for this survey display a similar energy market model. Table 11.1 shows the market designs and methods of electricity pricing by country.

The by far dominating energy market model is that of a pool marked with bidding competitions. In this case electricity generators obtain capacity rights in competitive auctions held by public utilities. These markets are wholesale-operated, meaning that the wholesale price (the marginal cost) is set by the generators hourly (Lennard 2003). This market model is presented by Argentina, Bolivia, Brazil, Chile, Ecuador, Peru and Uruguay. In the Colombian energy market, on the other hand, electricity is not sold at the hourly marginal cost but at the hourly power exchange price. Retailers act as intermediaries who buy and sell electricity at spot markets where energy is being traded and the power exchange price is set hourly. Consumers buy electrical energy from those retailers and can choose the cheapest one (Posorski and Werner 2009).

Chile, Colombia, Ecuador and Peru present capacity payments, i.e. additional costs for energy purchase during peak periods, as an indication for greater energy demand and therefore an incentive for the creation of new capacity (Lennard 2003; Oren 2000).

Paraguay and Venezuela are the only two countries surveyed that have kept the integrated model of a public monopoly.

Fig. 11.1 Map of South America (http://www.world-atlas.us)

Renewable Energy Support Schemes in South America

In the first decade of the 21st century the vast majority of South American countries have come to realise that renewable energies (RE) are an inevitable part of their future energy supply (Batlle and Barroso 2011; Haselip et al. 2011). Initiatives to promote RE generation emerged in a variety of forms on national and local levels. Fiscal and tax incentives, soft loans and RE funds are moderate ways to support the implantation of REs and can be found in many countries. However, a number of countries have also introduced more impelling measures. Energy contract auctions, tenders, renewable portfolio standards and capacity payments

Table 11.1 Market designs, methods of electricity pricing and existence of capacity payments in the surveyed countries

	Argentina	Bolivia	Brazil	Chile	Colombia	Ecuador	Paraguay	Peru	Uruguay	Venezuela
Market model	Pool financial BC	Pool financial BC	Pool financial BC	Pool financial BC	Pool(PX) financial BC	Pool financial BC	Monopoly	Pool financial BC	Pool financial BC	Monopoly
Wholesale market operation spot price	Marginal cost hourly	Marginal cost hourly	Marginal cost hourly	Marginal cost hourly	Power exchange price hourly	Marginal cost hourly		Marginal cost hourly	Marginal cost hourly	
Capacity payment				Yes	Yes	Yes		Yes		

have become an important and in some countries *the* major instrument for RE market stimulation (Batlle and Barroso 2011; Haselip et al. 2011).

Subsequently, the main steps in the implementation of RE in each country surveyed are described.

In **Argentina** in 2007 the secretary of energy passed the 26 190 law, which aims to increase the percentage of renewable energy sources in power supply to at least 8 % by 2016. To reach that target the Ministry of Federal Planning, Public Investments and Services (Ministerio de Planificación Federal, Inversión Pública y Servicios) initiated a programme for the generation of RE (RENGEN) in 2010 (Posorski and Werner 2009; IEA 2010). The system operator CAMMESA (Compañía Administradora del Mercado Mayorista Eléctrico S.A.) and the public service corporation ENARSA play an important role in this plan, as they hold energy contract auctions and guarantee energy purchase (Batlle and Barroso 2011).

In 2007 **Bolivia** passed a national development plan (Plan Nacional de Desarrollo) in which the government commits itself to the complete electrification of Bolivia by 2025. To achieve that goal, the governmental programme, Electricity for Living with Dignity (Electricidad Para Vivir con Dignidad), among other efforts was initiated and coordinated by the Vice Ministry of Electricity and Alternative Energies. This programme also promotes the use of REs. For example, the biggest project within the programme, the Decentralized Infrastructure for Rural Transformation (Infraestructura descentralizada para la transformación rural—IDTR), has a budget of $15 million that exclusively promotes the implementation of solar home systems for rural electrification (Rutschman 2010).

In 2002 **Brazil** introduced a feed-in programme for wind and biomass energy called the PROINFA (Programa de Incentivo às Fontes Alternativas de Energia Elétrica) programme (Batlle and Barroso 2011). Prior to that the Brazilian government enacted the 10438 law, which was responsible for the start of PROINFA (IEA 2002), however was not specific to RE development. It was connected to energy purchasing contracts with the state-owned company Eletrobras but was criticised for a lack of efficiency. In 2007 a second initiative to foster REs was launched by implementing a reduction of cost for transmission and distribution tariffs beneficial to the consumer and subsidised by the government (Batlle and Barroso 2011). Today the energy contract auctions have become the major instrument for general market expansion and RE market stimulation in Brazil. Pre-investment appraisal subsidies and tax incentives are also present in Brazil.

The production of electricity through hydroelectric power plants covers the majority of Brazil's electricity demand and is treated preferentially compared to the other RE resources. Therefore it must be viewed separately from them.

In 2008 **Chile** passed the 20.257 law, which aims to increase the RE share in energy production to 5 % by 2010 and 10 % by 2024 (Wright and Adlerstein-Gonzalez 2009). Generators that do not fulfil this obligation by the prescribed time will be fined US$28/MWh and US$42/MWh after a three-year violation period. With not enough RE projects in sight it has become questionable if the renewable portfolio standard will be successful. Energy providers have asked for alternative solutions such as a feed-in tariff (Batlle and Barroso 2011).

In 1995 **Colombia** created a national development plan for alternative energies (Plan de Desarrollo Nacional de las Energías Alternativas), which makes suggestions for strengthening RE sources. However, this proved to be nothing more than lip service, as no action was taken in the years to follow (Projekt-Consult GmbH and Loy 2007). In 2001 the Colombian government created a framework for the promotion of renewable energies with the passing of the 697 law. This law was designed for developing the Program of Rational and Efficient Use of Energy and Other Forms of Non-Conventional Energy, PROURE (Programa De Uso Racional y Eficiente de Energía y Fuentes no Convencionales). Since then the promotion of RE has emerged in the form of tax incentives. PROURE is supervised and led by the Ministry of Mines and Energy (Projekt-Consult GmbH and Loy D. 2007). In 2010 the 180919 resolution was issued and follows an action plan to further develop PROURE from 2010 to 2015 (Mojica 2011).

In 2000 **Ecuador** introduced a feed-in tariff for photovoltaic energy generation. However, the Ecuadorian government has never fulfilled its duty of payment, which it imposed upon itself. Minor efforts to promote PV technology were made in 2003 and 2006 by setting up a few hundred isolated systems. The rural electrification project for Amazonian homes (Perva) presently aims to electrify 15,000 households with PV systems until 2013 (Batlle and Barroso 2011). In 2011 the administrative institution, CONELEC (Consejo Nacional de Electricidad), passed the regulation, CONELEC 004/11, which introduces a feed-in tariff for the next fifteen years regarding energy generation from wind, sunlight, water, biomass and geothermal sources (Gipe 2011). However, due to the recent regulation passed by president Correa that enables the state to fully regain control of the countries electric system, private investments are expected to be held back significantly (Batlle and Barroso 2011).

In **Paraguay** 99 % of the generation capacity is hydroelectric. No incentives for the development of other REs exist and no initiatives are presented (Batlle and Barroso 2011).

In 2005 **Peru** passed the law of promotion and use of non-conventional energy recourses in rural, isolated and frontier zones of the country, law no. 28546 (Peru 2005). A regulation with force of law was passed in 2008 proclaiming the fostering of REs a matter of national interest and exigency. This regulation, called the 1002 decree, promotes wind, solar, geothermal, hydroelectric and biomass power generation. Hydroelectric power is only considered an RE source if it comes from power plants of 20 MW installed capacity or less. It furthermore specifies that the Ministry of Energy and Mines must define a target percentage of the share of RE in the national electricity consumption every five years. For the first five-year period this percentage was set to 5 % (SNMPE 2011). To achieve these goals the country has now introduced energy contract auctions in order to stimulate RE investment.

In 2005 **Uruguay's** Ministry of Energy and Mines and the national energy supplier UTE (Administración Nacional de Usinas y Trasmisiones Eléctricas) took their first step in integrating REs into their energy mix by enacting the 389/005 decree. It allowed UTE to call for tenders for RE generation projects. But the limitations were too many and thus only one small wind power project was realised. In 2006 the 77/006 decree was issued where limitations had been reduced but not sufficiently (UNFCCC—CDM—Executive Board 2006). In this manner the policy process continued increasing project sizes, lately attracting wind power projects of up to 150 MW (Batlle and Barroso 2011). In 2009 the 18.585 law was passed, which promotes solar thermal energy. It requires hotels, hospitals, public buildings and new buildings to generate 20 % of the energy needed to heat water with solar/thermal power (Epp 2010).

In **Venezuela** no initiatives for the development of other REs exist and no incentives are presented. In 2009 the Organic Law of the Electric System and Service (Ley Orgánica del Sistema y Servicio Eléctrico) came into effect. In article 21 the government raises the prospect of a development plan for the national electric power system that will include the use and development of renewable energies. However, a development plan incorporating these targets has yet to be created (Batlle and Barroso 2011; Venezuela 2010).

The Tables 11.2, 11.3 and 11.4 give a summarised overview of the institutional and legal frameworks in the different countries.

Renewable Energy Generation in South America

The data that is the basis for this comparative analysis dates back to 2009 (Argentina, Colombia, Peru and Bolivia) and 2010 (Brazil, Ecuador, Uruguay, Chile and Germany).

Figure 11.2 shows the share that each of the renewable energy sources—water, wind, sunlight and biomass—have in the entire range of energy generation technologies of the different countries.

The most obvious fact displayed in Fig. 11.2 is that hydroelectric power is the dominating RE in South America. Argentina, Bolivia and Chile generate approx. one-third of their entire energy from water power, Brazil and Colombia about three quarters and Uruguay almost covers its whole energy demand with water power. Ecuador and Peru are somewhere in the middle. Furthermore, Fig. 11.2 shows that all other RE sources only play an insignificant role in the energy production of these countries. In Brazil the production of biofuels from biomass is quite important for the transportation sector and in Chile and Ecuador this also amounts to about one percent of the country's energy generation. Energy production from wind accounts for approx. half a percent in Brazil and Chile and 0.7 % in Uruguay. Solar power generation is practically non-existent in the surveyed countries. It has no or less than a 0.1 % share in the different countries' energy production.

For a more detailed analysis it is necessary to put these percentages into perspective of the amount of energy that the single countries produce. In Brazil for example, which is the country with the biggest energy demand of the surveyed

Table 11.2 Overview of the institutional frameworks in Argentina, Bolivia, Brazil, Chile and Colombia

	Argentina	Bolivia	Brazil	Chile	Colombia
Policies	Secretaría de Energía (SENER)	Vice Ministry of Electricity and Alternative Energies (Ministry of Hydrocarbons and Energy)	Ministério de Minas e Energia (MME)	Ministerio de Energía	Ministerio de Minas y Energía
Regulator	Ente Nacional Regulador de la Electricidad (ENRE)	Electricity Supervision and the Social Control Authority (AE)	ANEEL	Comisión Nacional de Energía (CNE)	Comisión de Regulación de Energía y Gas (CREG)
Supervisor	ENRE	Electricity Supervision and the Social Control Authority (AE)	ANEEL	Superintendencia de Electricidad y Combustibles (SEC)	La Superintendencia de Servicios Públicos Domiciliarios (SSPD)
System operator	CAMMESA	National Committee for Charge Dispatch (CNDC)	Operador Nacional del Sistema Eléctrico (ONS)	Centro de Despacho Económico de Carga (CDEC)	XM filial de ISA S.A
Planning	Ministerio de Planificación Federal, Inversión Pública y Servicios	Vice Ministry of Energy Development (Ministry of Hydrocarbons and Energy)	Empresa de Investigación Energética (EPE)	Comisión Nacional de Energía (CNE)	Unidad de Planeación Minero Energética (UPME)
Environmental authority	Secretaría de Ambiente y Desarrollo Sustentable (SEMARNAT)	Ministry of the Environment and Water	Ministério do Meio Ambiente	Ministerio del Medio Ambiente y CONAMA	Ministerio del Ambiente, Vivienda y Desarrollo Territorial
RE promotion	Dirección Nacional de Promoción (DNPROM)			Centro de Energías Renovables (CER)	
Conflict solving	ENRE			Panel de Expertos	Superintendencia de Servicios Públicos Residenciales

Table 11.3 Overview of the institutional frameworks in Ecuador, Paraguay, Peru, Uruguay and Venezuela

	Ecuador	Paraguay	Peru	Uruguay	Venezuela
Policies	Federal Ministry of Policies/ Ministerio de Electricidad y Energía Renovable (MEyER)	Viceministerio de Minas y Energía	Dirección General de Electricidad	Ministerio de Industria, Energía y Minería	Ministerio del Poder Popular para la Energía Eléctrica (MPPEE)
Regulator	CONELEC	ANDE	Dirección General de Electricidad	Unidad Reguladora de Servicios de Energía y Agua (URSEA)	MPPEE
Supervisor	CONELEC	ANDE y Contraloría General de la República	Organismo Supervisor de la Inversión en Energía (OSINERG)		MPPEE
System operator	CENACE	ANDE	Comité de Operación Económica del Sistema Interconectado Nacional (COES)	Administración del Mercado Eléctrico (ADME)	MPPEE
Planning	CONELEC	ANDE y Secretaría Técnica de Planificación	Ministerio de Energía y Minas	Dirección Nacional de Energía y Tecnología Nuclear (DNETN)	MPPEE
Environmental Authority	Ministerio del Ambiente	Consejo Nacional del Ambiente (CONAM) y la Secretaría del Ambiente (SEAM)	Consejo Nacional del Ambiente	Dirección Nacional de Medio Ambiente (DINAMA)	MPPEE y Ministerio del Ambiente
RE promotion	MEyER	ANDE	Fondo Nacional del Ambiente (FONAM)	DNETN	Dirección General de Energía Alternativa
Conflict solving					

Table 11.4 Overview of the legal frameworks in the different countries

	Argentina	Bolivia	Brazil	Chile	Colombia	Ecuador	Paraguay	Peru	Uruguay	Venezuela
General law	Law 24.065	Electricity law 1604	Law 10 848	General Law of Electric Service (DCL4)	Laws 142 and 143	Law of the Electricity Sector Regime (LRSE, ROS 43)	Law 167/93	Law of electric concessions	National Electricity Law (Law no. 14.694)	Organic Law of Electric System and Service
Renewable law	Law 26 190		Law 10438	Law 20.257	Law 697 and resolution 180919	CONELEC - 004/11		Law no 28546 and decree 1002	Law 18.585 and decree 77/06	

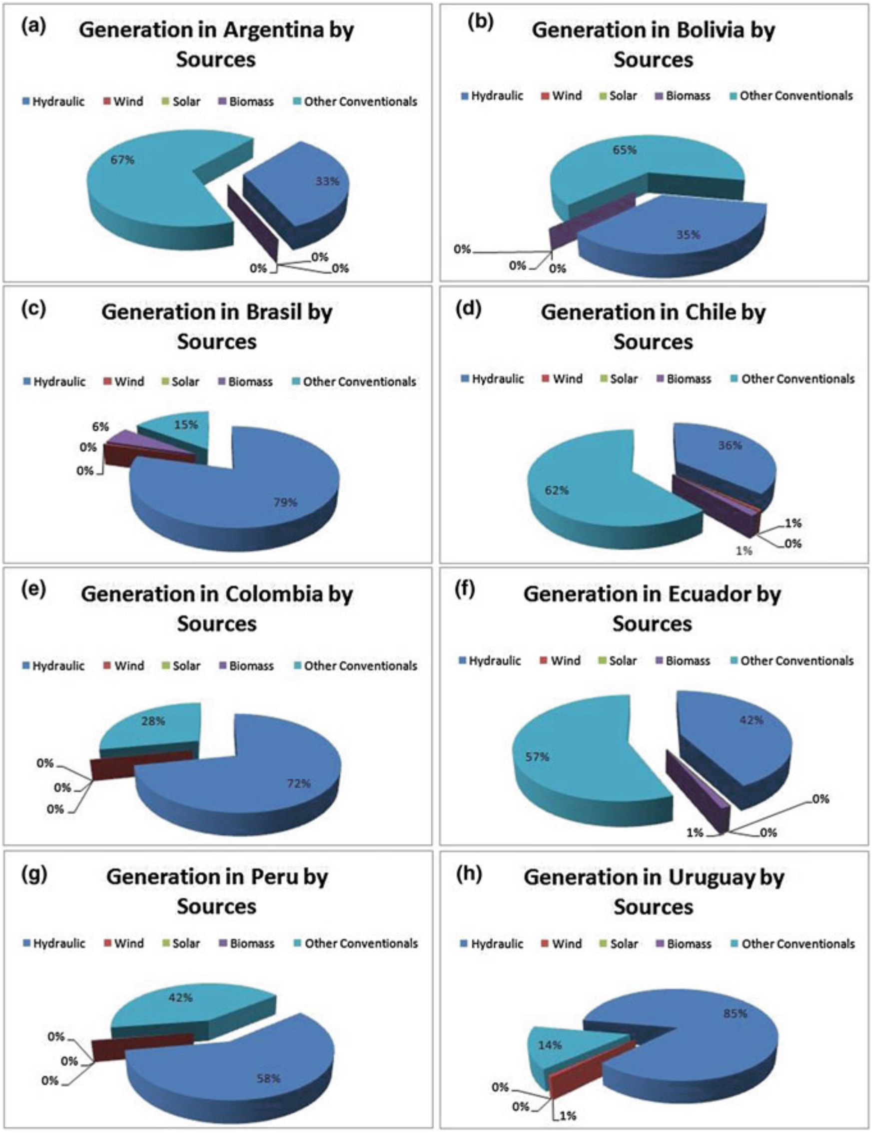

Fig. 11.2 Distribution of the energy generation among the different energy sources in the countries surveyed

countries, the 0.43 % that wind energy contributes to the energy production represents 927 MW installed capacity and the 6 % that is the energy production from biomass equals 7.8 GW installed capacity.

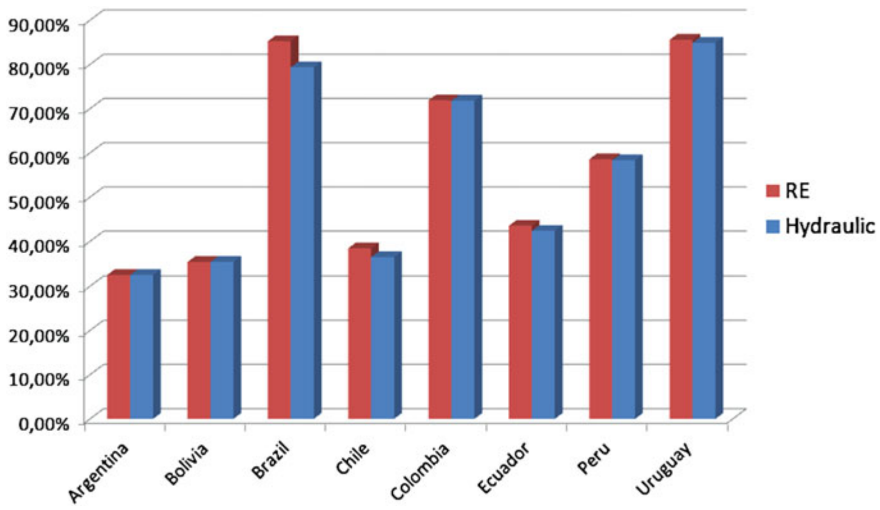

Fig. 11.3 Share of RE and hydroelectric power in the entire range of energy production technologies of the different countries

The Controversy of Hydroelectric Power

On average RE contributes 54 % to the energy supply of the surveyed countries. That is quite an impressive number especially compared with ratios of OECD countries, which do not even come close to that figure. However, this impression can be very misleading. As we have seen above REs are dramatically underrepresented with the exception of hydroelectric energy. Figure 11.3 illustrates the dominating position that hydroelectric power generation takes among the REs in the countries surveyed.

Whether or not hydroelectric power can be called sustainable and in some cases even renewable is somewhat questionable and therefore problematic. This applies particularly to large-scale hydroelectric plants, which of course make up the biggest share of installed hydroelectric capacity (Meisen and Krumpel 2009).

There are two main reasons for this controversy. Firstly, many South American countries have become dependent on hydroelectric energy production. That makes them very vulnerable to dry periods and the ensuing fall of water levels. Secondly, large hydroelectric projects have been the cause for large environmental and social problems. The damming up of big rivers and the consequent flooding of vast areas has led to the loss of valuable natural reserves and was the reason for the relocation of indigenous peoples from their traditional territory (UNFCCC—CDM—Executive Board 2006).

Even though it is arguable to what extent these criticisms are applicable, it becomes clear that some perceive large-scale hydroelectric generation as not the most adequate solution.

Conclusion

The survey showed the existence of similarities and differences among South American countries regarding RE development. Particularly in the comparison of preferences for the different RE technologies, similarities become apparent. The fact that all RE sources besides hydroelectric only play an insignificant role in the energy production is certainly partly due to the level of complexity that is inherent to the different RE technologies. But it may well be suspected that a lack of appropriate RE incentives is also a reason.

Furthermore, the analysis shows that there are initiatives for the development and the promotion of RE in South America. However, despite the big RE potential, large-scale implementation of RE generation has yet to be realised.

All in all the survey conducted in the WP 2 shows that most of the countries surveyed perceive RE to be an inevitable part of their future energy supply. It is thus crucial that existing efforts are duly supported by means of appropriate knowledge and technology transfer.

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Chapter 12
Knowledge Exchange and Application of Hydropower in Developing Countries

Christoph Rapp, Andreas Zeiselmairm, Emile Lando and Mfetoum Moungnutou

Abstract This paper presents some activities of the Munich University of Technology's *Fakultätsplattform Entwicklungszusammenarbeit* (Faculty Platform for Development Cooperation), an association that supports knowledge exchange with developing countries, focusing on a design project for a micro hydropower plant for a renewable-energy vocational school that is being carried out in collaboration with two Cameroonian partners. The power plant, which is situated in a remote area, will provide the school with electricity and serve as an example for the education of the students. During a two-week research stay in Foumban, close to Bafoussam, several possible sites were surveyed. The result of the trip was a feasibility study that examined four different layout options. Due to social and ecological reasons, a site was chosen where only part of the water discharge at a natural step is used. A head of 10.88 m is gained within approximately 100 m of D = 0.5 m penstock. The hydropower plant has an estimated output of 15 kW. A crossflow turbine, combined with a synchronous generator, will supply the island network. As hydrological data is scarce, the emphasis has been placed on ensuring flood protection.

Keywords Knowledge exchange · International collaboration · Hydro power · Regional involvement

Short Introduction

The Munich University of Technology, in collaboration with two Cameroonian partners, focused on a design project for a micro hydropower plant for a renewable-energy vocational school, which will provide the school with electricity and

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_12,

serve as an example for the education of the students. This paper presents the activities during two weeks of site research, including the feasibility study for different options.

Preface

We can learn from history that engineering expertise to protect people from natural hazards and control water and food supplies paved the way to civilization. Nowadays, building infrastructure is the basis of a developed society, and civil engineers are therefore essential. This was the background thinking for the foundation of a platform for knowledge exchange at the Faculty for Civil Engineering and Geodesy at the University of Technology in Munich, Germany (www.ez.bv.tum.de).

The scope of the initiative is manifold. Lectures form its core, which have been held at Jordan University of Technology and Eduardo Mondlane University in Mozambique, where support is also being given to set up a hydraulics laboratory. These lecture courses comprise topics in renewable energy supply for buildings and hydraulics or hydraulic engineering. In the hydraulic laboratory, practical training is given to students and teachers, for which certain measurement devices are provided. The work has been recognised by the Mozambican Prime Minister, who even visited the hydromechanics laboratory of the TUM while on a state visit to Germany in May 2011.

Additionally to the academic exchange, joint projects between students from Germany and countries in Latin America and Africa are being realised with the involvement of local populations. For instance, the power supply for a medical care centre in Burkina Faso was designed; a primary school in Mozambique was electrified; and a kindergarten with autonomous power supply was planned and constructed near Cape Town. Various projects were conducted in the Ecuadorian rainforest, where, among other things, the drinking water supply of a village and a micro hydropower plant were designed (Zeiselmair et al. 2011; Hansinger et al. 2011).

In 2010 a letter of intent was signed by the association Green Step e.V (Green Step is the vocational school's implementation organisation) and TUM's platform for knowledge exchange, aiming to build a hydropower plant (approx. 15 kW) for the electrification of a renewable-energy vocational school in Foumban near Bafoussam in Cameroon. The power plant would serve not only as power supply, but also as an example for the students. During a research trip in May 2011, a possible site was located and two Cameroonian partners were identified:

Action pour un Développement Équitable, Intégré et Durable (ADEID), an organisation that builds different plants using renewable sources and operates several micro hydropower plants;

Institut Universitaire de Technologie de Douala, Cameroon.

Within this consortium, the partners have worked collaboratively on the survey of the site, the design of the plant and on clarifying legal issues.

Introduction

A vocational training school for renewable energies is being erected close to Foumban, Cameroon. Its focus lies on practical application, such that the students gather experience in production, distribution, installation and maintenance of these technical products, since such responsibilities are generally not taught in this country. Consequently, pico hydropower plants and solar thermal systems will be produced and sold in the school (Hertlein 2011). Therefore, power is not only needed to provide classrooms with electricity, but also to operate manufacturing machinery such as a lathe, welding rectifiers and drills. However, special emphasis is placed on ensuring that the facility fulfills its main function, which is to serve as an example to the students. Additionally to these conditions, the generated energy should be used to electrify the area in the vicinity of the plant. This issue will contribute to improving living conditions and enhancing development.

To successfully implement the scheme, local and international partners work in their particular fields of expertise under the general management of Green Step. The German association *Ingenieure ohne Grenzen* (Engineers without Borders) is working on the school's business plan, whilst the University of Applied Sciences in Regensburg (Germany) and the University of Guelph (Canada) are designing a pico hydropower turbine that will be produced and sold at the school. The *Fakultätsplattform Entwicklungszusammenarbeit* is constructing the hydropower plant in collaboration with ADEID and the University of Douala. ADEID is also responsible for legal issues (e.g. water rights), whereas the latter assists in providing hydrological data. Finally, Green Step coordinates the partners, handles the funding, deals with social aspects and runs the school.

An appropriate site for the hydropower plant was found in the proximity of the school. The constructional tasks include the overhaul of an already existing weir, integrating the intake structure with a sand trap (Fig. 12.1). An approximately 100 m long penstock, with a head of 10.88 m, will deliver the water to a crossflow turbine generating 15 kW. The power house is placed on the left embankment to ensure flood protection. The design of the structure minimises the ecological impact. An already existing channel on the right embankment serves as a fish pass.

Scope

The school's scope is to educate students in renewable-energy technologies, which makes it an obvious step to provide the school with energy from such sources. The poor reliability of the electricity supply makes the usefulness of an independent island grid evident. A feasibility assessment was carried out for various systems, whereby a high potential for hydropower was identified due to the reliable precipitation and topography of the area. Consequently, as a field trip, the school's hydropower supply was examined for possible installation sites in its proximity, and relevant data was collected for further analysis.

Fig. 12.1 Downstream view with weir overhaul and intake structure

Off-site tasks included negotiations with stakeholders and material suppliers, as well as gathering particular local know-how. Many examples showed that the sustainable development of comparable projects could only be realised in collaboration with future associates, local authorities and residents, who help with information and labour. Therefore, a fairly decisive concern is the legal and administrative part of the planning, to ensure that ADEID's experience and expertise in erecting locally built water turbines is a major benefit.

Hydrology

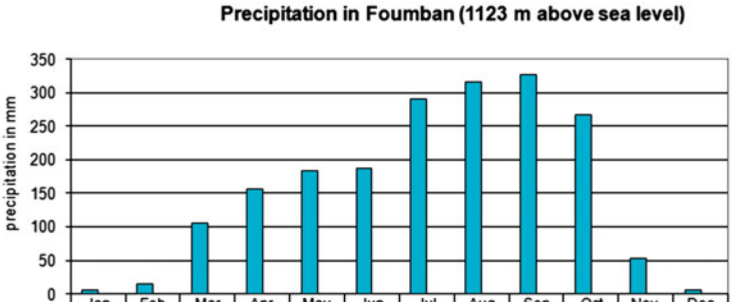
Climatic Boundary Conditions

Cameroon is characterised by a great variation in types of climate—this is why it has been called "Africa in miniature". The country ranges from the wet southern equatorial regions to the arid parts in the "extreme North". Cameroon can be subdivided into four climatic and geographic zones: the Sudano-Sahelian, the savanna, the coastal and the tropical forest zones (Molua and Cornelius 2011).

Foumban, the location of the hydropower installation, is located in the tropical forest zone, which has mostly wellwatered surface water (Atlas dupotentiel hydroélectrique du Cameroun 1983). The surface is mainly covered by metamorphic and igneous rocks. The type of climate in this area is known as "equatorial monsoon". It is determined by two distinct seasons. The dry season lasts from November to March; the rainy season from April to October. The precipitation maximum can be observed from July to September. The total annual precipitation in Foumban is around 1,908 mm (Fig. 12.2).

Hydrological Characteristics

Cameroon has two major catchment areas. The area around Foumban is part of the western highlands, also called the "Cameroon Volcanic Line". It is part of the Atlantic drainage basin, which is dominated by the Sanaga river system. The



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly precipitation in mm	5	14.1	105.7	155.8	182.6	187.2	290.3	316.4	326.5	266.1	53	5.5
Days with precipitation > 1mm	1.1	2.4	9.5	15.4	19.1	20.2	23.3	24.4	24.9	22.9	6.3	1.1

Fig. 12.2 Average annual precipitation in Foumban (Obermeier 2011)

catchment area of the river at the installation site is characterised by a longitudinal tributary area, which ranges around 11.5 km from the spring to the installation site. It has several smaller confluences (Fig. 12.3).

In order to obtain approximated discharge-variation values, comparisons to neighbouring river gauges were made. Figure 12.4 below shows the hydrograph of the rivers Noun and Mbam (Distances and directions of gauges from site; measurement period. Noun, Bamendjing, 43 km west, 1965–1973. Noun, Bafoussam, 48 km south-west, 1952–1975. Mbam, Mantoum, 36 km South–East, 1965–1980). The runoff has been normalised by the annual average, worked out from the monthly mean values. The red line indicates the base flow-reduced hydrograph of the Noun catchment area (excluding the outflow of Bamendjing reservoir). Through its very similar characteristics, this curve should fit the hydrograph at the site best.

The discharge measurements available have all been conducted during the dry season, so that they can be assumed as low-level discharges. This has also been verified by local residents. Currently, further data are obtained through two fixed-level gauges that have been installed and operated by ADEID. One is located

Fig. 12.3 Catchment area (*Source* Google Maps)

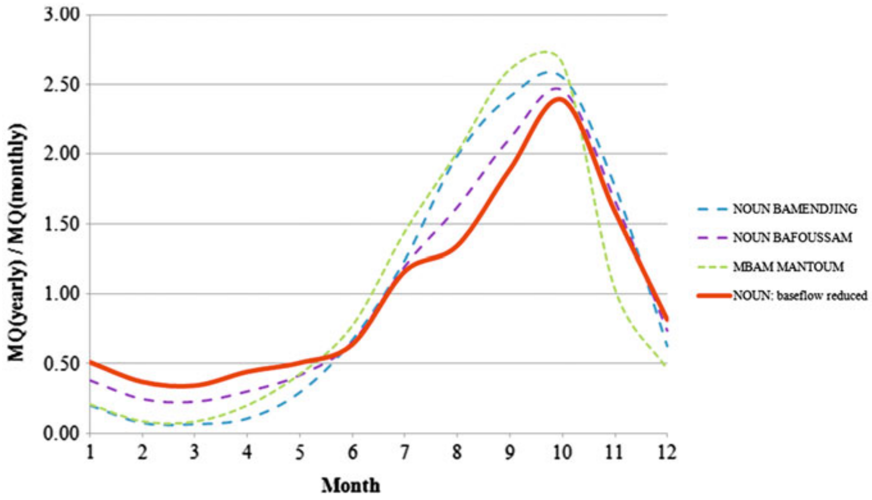


Fig. 12.4 Discharge hydrograph of gauges at comparable neighbouring rivers (The Global Runoff Data Centre 2011)

above the weir intake; the other one is placed close to the powerhouse installation site. A resident working close to the site will check the water level daily and hand the data over to ADEID.

Conclusions

Unfortunately, there is a major lack of hydrological data. However, the project is not endangered by this, as the site boundary conditions are nearly perfect. It should be mentioned that the power output requirement allows a comfortable safety margin—for low runoffs and for flood events. Due to the doubtful runoff data, special emphasis has to be placed on flood security. The discharge measurements were taken in May, which is at the end of the dry season (see Fig. 12.4). Hence, one can conclude that the measurements reflect runoff minima.

Site Survey

The first step of the on-site research was to get a better understanding of the geographical, hydrological and morphological situation in the school's surrounding area. Therefore, the most important task was to explore the water course of the nearby river and possible feeder streams.

Discharge Measurement

In order to get an estimate of current discharge at different parts of the river, several measurements were taken. The techniques used were based on flow velocity and cross-section analysis. At specific locations, hydrological methods were applied, e.g. flux approximation at critical-flow conditions. Subsequent to the on-site measurements, two fixed water gauges were installed by ADEID to assess the annual flow duration curve. The data is needed to estimate flood scenarios and energy yield.

Surveying Data

The possible sites were surveyed with a tachymeter. The exact head differences were of major interest, and the elevation and position of probable penstock tracks were also captured.

Flood Security and Occurrence

Assessing the difficulty of flood protection is a hard, but also an essential, task in the planning process in such areas. Due to the fact that there is almost no reliable river discharge or area precipitation data available for most parts of Cameroon, one has to rely on other sources. The most efficient and easiest method was to consult nearby residents and workers around the sites. As this information is rather vague and most likely to be biased, it is even more important to set a sufficient safety margin. For example, concerning the occurrence of floods, one statement from a local worker was “about two to three times a year; for about one week the water level is about here”. Historical maximum flood levels for this creek are essential for the design; however, information on these could not be collected.

Sites

The investigations resulted in two possible installation sites with quite different characteristics. Each site would further allow two different layout options each (see Figs. 12.5 and 12.6).

The following table gives a comparison between the two possible installation sites and their different layout options (Table 12.1).

Fig. 12.5 Overview of geographical position of different installation sites (GPS data on Google Maps)

Fig. 12.6 Possible installation sites. *Left* weir at Cascade 1; *Right* Cascade 2

Table 12.1 Comparison of different installation sites and layout options

Installation site comparison	Big waterfall with already existing weir (cascade 1)		Waterfall below local washing area (cascade 2)	
Head	10.88 m		3.71 m	
Discharge	Approx. 300–500 l/s		Approx. 1 m^3/s	
Power output	10–30 kW		15–25 kW	
Inlet structure	+ (integration into already existing weir)		– (to be built at left embankment)	
Water rights/usage	+/– (water partly used only by local water supply company SNEC—negotiations ongoing)		– (intensively used as the local washing and bathing area)	
Layout type	Layout 1 Penstock along embankment	Layout 2 Penstock on cascade course	Layout 1 Conventional turbine	Layout 2 Water wheel
Penstock length	○ approx. 100 m		+ approx. 10–15 m	+/
Flood safety	+	–	○/–	○
Overall result	+	–	–	○/–

Large Waterfalls with Already Existing Weir (Cascade 1)

At the grand cascade an output of 10–30 kW, depending on the method, can be generated. With a head of 10.88 m only a minor part of the water is needed to meet the required power output. The first layout (Cascade 1—Layout 1) marks the option where the penstock is aligned along the orographically left embankment of the waterfall (see Fig. 12.7). This is also the preferred layout. The advantage of this is a more or less constant penstock slope and therefore fewer pipe bends. A second central advantage is that it is less prone to damage caused by floods, since it is away from the main flow path and does not need to be fixed upright above the ground. The advantageous location of the intake structure, as well as of the powerhouse, makes this option the preferable one.

Another possibility for the penstock track would be to guide it along the course of the waterfall itself (Cascade 1—Layout 2). There are some islands along the waterfall, where fixing the pipe to the underground rock would be possible. The big issue here is the flood risk, since at higher flow rates this layout could be affected by floating debris. However, the underground conditions are clear and do not bear any risks.

Cascade Below Local Washing Area (Cascade 2)

Cascade 2 offers an output potential of 15–25 kW. One option for this cascade would be the use of a conventional turbine with a short penstock track of only around 10–15 m (Cascade 2—Layout 1). The intake could be placed on the orographically left side, right above the cascade, whereas the powerhouse would be located on a minor rocky spot. As the discharge is quite high ($Q \approx 1\ m^3/s$), the use of great pipe diameters or more than one pipe would be necessary.

Using an overshot water wheel is another option, although this brings a number of uncertainties (Cascade 2—Layout 2). The intake situation is similar to Layout 1. A channel will have to be constructed with a diameter of around 2.50 m to channel the water right above the wheel. The water wheel could be stationed as indicated in Fig. 12.8. The generator and electrical equipment could be placed on top of the

Fig. 12.7 Installation site Cascade 1, with two different layout options

Fig. 12.8 Two different layout options at Cascade 2

embankment. The power transmission could be realised with a gear belt. Here, difficulties arise, such as the high level of construction effort, especially concerning the fixing and foundations. The latter is also quite undetermined, due to the lack of investigation of the underground conditions. Another drawback is the safety issue, as the area above this site is intensively used by residents as their local washing and bathing area.

A comparison in terms of flood security leads to the observation that a conventional turbine with penstock has the advantage of being more hidden. The second issue is that a turbine/powerhouse can be easily fixed, and does not have to deal with dynamic forces as a water wheel does.

Conclusions

As the first option at the big cascade promises to be the most attractive, the main focus will be placed here. The second cascade, below the local washing area, would be an alternative to Cascade 1, although its power output is smaller. As the location is frequently used by locals, compensatory measures would be necessary.

Design

In the following, Layout 1 of the big cascades is described in more detail. Due to flood-security reasons the powerhouse will be placed 2 m above the regular water level of the plain. There, a perfect place was found, where the powerhouse can be anchored to the rocks and natural shelter is provided. Including the height of the powerhouse structure, the geodetic head reduces to 8.38 m (Fig. 12.9).

Fig. 12.9 Overview of intake situation at Cascade 1

Intake

The intake structure is placed on the orographically left side, and will be integrated into the weir (see Fig. 12.10). The tulip-like inflow opening is incorporated into locked housing, which also includes the sand trap. This structure guarantees the correct amount of water for SNEC and the slaughterhouse. Emphasis is placed on safety issues, as locals fish on the weir and children play or swim in its proximity. The opening of the whole structure is parallel to the main flow direction and equipped with a narrow rack. It should be noted that frequent rack cleaning will be necessary and will be conducted by the school staff.

Pipe Layout

As a constant pressure turbine is proposed the Darcy-Weisbach equation underlies the pipe design in the following notation according to the energy plan (Fig. 12.11).

$$H_{geo} = \frac{8Q^2}{D^4\pi^2 g}\left(\frac{\lambda l}{D} + \zeta_I + \sum \zeta_B\right) + \frac{Q^2}{A^2_{Nozzle\perp} 2g} \tag{1}$$

Applying Eq. 1, the pipe diameter was optimised using the data in Table 12.2 and a discharge dependent efficiency factor between 40 and 76 %.

Examining Eq. 1 for different pipe diameters and appropriate turbine layouts (see 6.3) yields Fig. 12.12. From the graph, it can be seen that a pipe diameter (PVC pipe diameters in Cameroon were considered only: d = 0.125 m, d = 0.25 m, d = 0.50 m) of 0.50 m is essential for a reasonable output, but also maintainable water-hammer pressure peaks. The nozzle area is subject to the turbine design in 6.3.

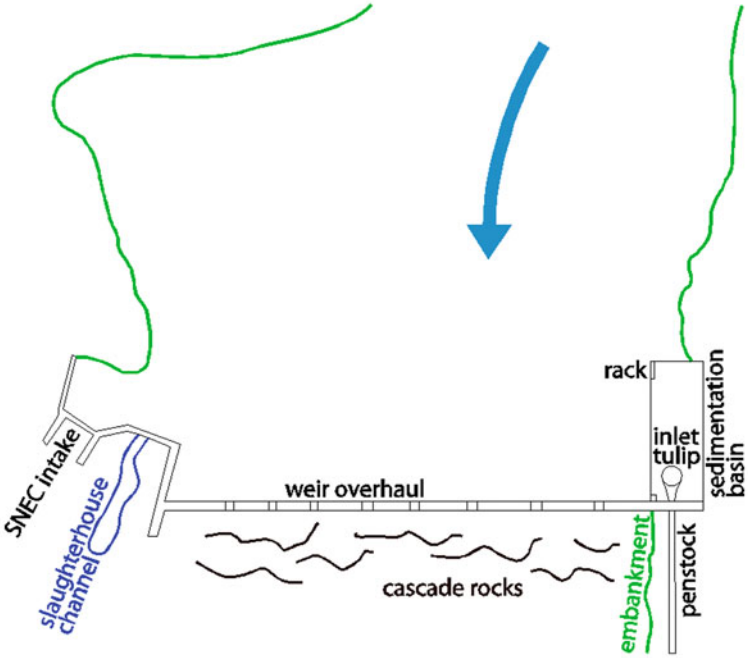


Fig. 12.10 Sketch of weir and intake situation

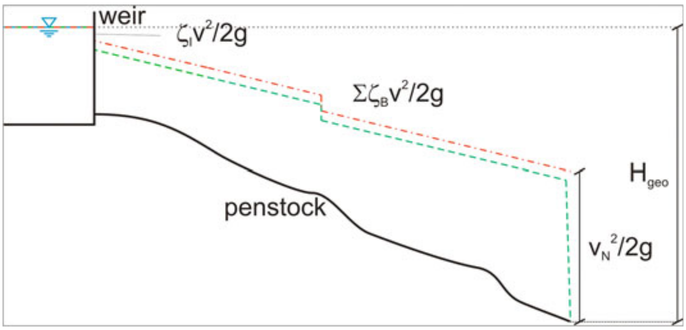


Fig. 12.11 Energy plan of the proposed layout

Table 12.2 Input data

Geodetic head	$H_{geo} = 8.38$ m	Kinematic viscosity	$v_{(25\ °C)} = 9E\text{-}7\ m^2/s$
Pipe length	$l = 100$ m	Inflow loss	$\zeta_I = 0.5$
Roughness	$k_s = 8E - 6$ m	Sum of bend losses	$\sum \zeta_B = 2.5$

The use of two or more smaller pipes is not an alternative, as can be seen from Fig. 12.12. The following specifications were obtained using a pipe diameter of 0.50 m (Table 12.3).

Turbine

A crossflow turbine has been chosen due to its robust construction and perfect applicability at the suggested site. Crossflow turbines, also called Ossberger or Banki turbines, are radial-flow impulse turbines. Because of their low maintenance requirements and simple construction, they are frequently used as small and micro hydropower plants in remote areas. As the mechanical system is not very sophisticated, repairs can easily be performed by local mechanics. The proposed discharge ranges from 0.025 to 13 m^3/s for heads of 1–200 m (NHT Engineering and IT Power Ltd 2004).

Although the peak efficiency of a crossflow turbine is somewhat less than other conventional turbines, it has the advantage of a flat efficiency curve under varying loads. This can yield better annual performance at variable discharge rates. To achieve good part-load efficiency it is possible to divide the split runner and turbine chamber at a ratio of 1–2 at varying flow rates (Giesecke et al. 2009). Since the turbine runs at low speed it is not severely affected by suspended solids. The

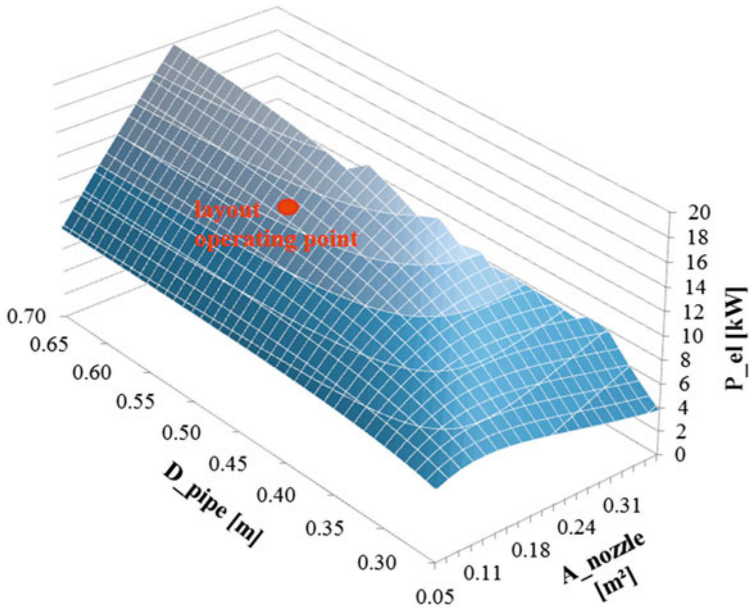


Fig. 12.12 Operating point of the system—pipe diameter dimensioning

Table 12.3 Hydro power plant specifications for different discharges

Q [m^3/s] (discharge)	A_{nozzle} [m^2] (adjusted nozzle area)	H_n/H_b (net head/gross head) in (%)	v_{pipe} [m/s] (pipe velocity)	v_{nozzle} [m/s] (velocity at nozzle)	Δp [bar] (Joukowsky hammer)	p_{total} [bar] (total max. pressure)	P [kW] ($\eta_{HPP} \cdot \rho \cdot g \cdot Q \cdot H_N$)
0.100	0.031	99	0.51	3.19	0.98	1.80	4.5
0.150	0.047	98	0.77	3.17	1.48	2.30	7.8
0.200	0.064	96	1.02	3.15	1.97	2.79	10.7
0.250	0.080	95	1.27	3.12	2.46	3.28	13.3
0.300	0.097	92	1.53	3.08	2.95	3.77	14.3

high durability, low price, simple construction and reliable operation make these turbines ideal for use in developing countries.

Constructional Tasks

Weir Overhaul/Intake Construction

The large amount of leakage that is currently experienced at the weir makes an entire overhaul mandatory. In order for the facility to be able to exploit a steady discharge, it is important to keep a constant water level above the weir. In the event of very high discharges, a secured HQ release will be provided on the top of the weir. The process of concreting the weir will be carried out section by section.

Penstock Fixation

The fixation of the penstock depends on the ground conditions. With Layout 1, there is a certain thickness of the topsoil layer. Below the soil, solid rock is expected, as it forms the basis of the whole cascade. At the current stage, it is assumed that the reinforcing steel can be anchored to these rocks. Further analysis is mandatory in order to give final instructions.

Powerhouse

The powerhouse contains the core of the whole facility and therefore requires special safety precautions. The first issue to be considered is flood protection. As the generator and further electric equipment is located in the powerhouse, it has to stay dry under any conditions. Further safety precautions against electric shock also have to be taken. In addition, all facilities must be inaccessible to any unauthorised persons (health and safety, sabotage, etc.) (Fig. 12.13).

Social and Ecological Impact Assessment

The main issue regarding the ecological consequences of the newly built hydropower plant concerns its impact on fish and riverine fauna. As the weir will be kept in its current dimensions, the construction will not cause any deterioration in the situation for organisms. Nevertheless, an improvement of the current situation will be aspired to. Harming fish with the turbine can be avoided by using a rack with narrow spacing at the intake; the velocity head is negligible anyway. Additionally, a channel supplying a slaughterhouse with water can be modified to serve as a fish pass. The site is ideal because already existing structures are used. The plant will therefore not have an impact on the flood security of the residents.

Education Concept

The hydropower education will focus on hydraulics, hydraulic engineering and hydrology. A concept for descriptive courses has been published in (Rapp 2006). However, an entire engineering course cannot be offered—and is not intended. Basic, applicable know-how will be provided so that the students are enabled to conduct similar projects. This prerequisite implies secure ground conditions and flood safety, both for the plant itself and the surrounding area. Ecological impact minimisation and awareness will be the principles to be taught.

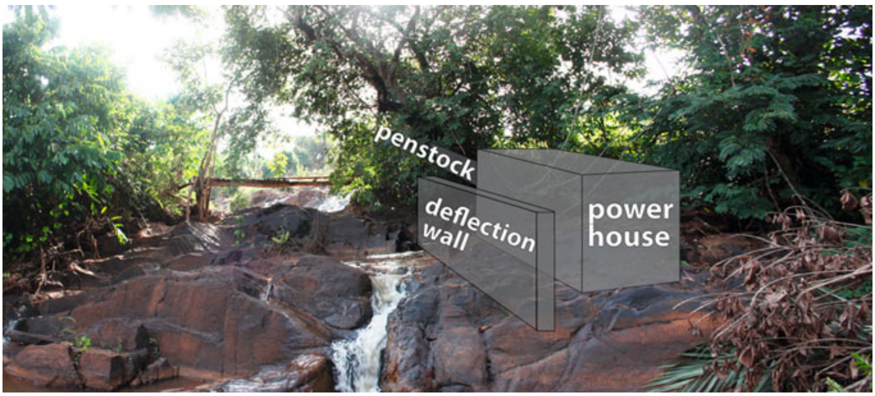


Fig. 12.13 Sketch of powerhouse construction and layout

Outlook

The result of this paper is that construction can be carried out very efficiently under the evaluated circumstances. With the examined site layout, the ecological impact can be minimised to an almost negligible value. The social impact on the local residents can be rated positively throughout. Long-term operational safety has a very high priority.

To be able to make a final proposal and determine all duties necessary, there is still research to be done, which is already in progress. For example, the recording of a hydrograph by installing a fixed water-level gauge is currently being organised by ADEID. The issue of electrical distribution, control and supplying energy consumers will be dealt with in another study. All in all, the proposed design serves as an example for a hydropower plant built in an area where hydrological data is scarce, but flood security can be guaranteed. It improves the quality of life of the locals, whilst causing no identifiable ecological deterioration.

Acknowledgments The authors gratefully acknowledge the contribution of the *Technische Universität München*, the *Verein zur Förderung des internationalen Wissensaustauschs e.V.* and Green Step e.V.

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Chapter 13
"Sustainable Energy for All" Approach to SIDS: A Case Study from Dominica

Raúl Iván Alfaro-Pelico

Abstract The Commonwealth of Dominica, amongst the least populated islands in the Caribbean (70,000 pop.), identified the potential to upgrade and expand its hydropower generating capacity from various sites in the country. One site is located in Newtown, outside of Roseau (Dominica's capital city). It offers the possibility of increasing its share of clean energy in the country's electricity mix through small-scale hydro developments. Dominica has also considered the development of additional hydropower resources within the Roseau valley, a protected area, though it requires addressing ecosystem-based climate resilience concerns in an integrated manner. This may pose a sustainable energy challenge in the short term; in the long run, Dominica plans to become carbon negative through the addition of geothermal energy to its electricity mix. The Government's commitment to these plans has been internationally declared, as part of the United Nations Secretary-General "Sustainable Energy for All" (SE4All) initiative. SE4All provides the country with a chance to contribute to its global objectives, by addressing national electricity demand where 70 % of the country's energy matrix comes from fossil fuels (the remainder coming from hydropower). In response to the request for assistance to reduce its reliance on costly fuel imports, UNDP support to Dominica's efforts is following an approach targeting the adoption of green, low-emission and climate-resilient development strategies (GLECRDS). Through the GLECRDS approach, UNDP is helping other developing countries – several of them, small island developing states (SIDS)—to combine and sequence different sources of finance to address broader sustainable development concerns.

Keywords Sustainable energy · Development · Climate change · SIDS · EITT · GLECRDS · Mitigation · Adaptation

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_13,

Short Introduction

Dominica's sustainable energy agenda is linked to the country's specific vulnerabilities to climate change. As one of the wettest Caribbean islands (2,500–3,800 mm average annual rainfall), Dominica is highly exposed to landslides in its mountainous terrain. Coupled with its exposure to hurricanes (particularly since Hurricane David in 1979) and sea level rise (with estimated increases for the region at an average of 3 mm annually), the country faces the challenge of protecting key economic sectors from long-term climatic impacts, e.g. terrestrial biodiversity subject to increased severity of extreme weather patterns (e.g. drought, storms, floods) affecting the country's hydroelectric potential (MAE 2001).

Dominica's Commitment to SE4All

Dominica is one of the many examples worldwide of direct linkage between sustainable energy and economic development. These linkages inspired the emergence of the Sustainable Energy for All (SE4All) initiative, also drawing from the personal experience of its precursor, UN Secretary-General Ban Ki-moon recalling the importance of energy for development during his youth in post-war Korea (UN 2012a). SE4All responds to the UN General Assembly of December 2010 declaring 2012 as the International Year of Sustainable Energy for All, and the mandate given to him for the coordination of activities to raise awareness on the subject (GA Resolution 65/151). Launched in September 2011, SE4All is not limited to the several awareness-raising events taking place during 2012. Indeed, the initiative's implementation roadmap includes several activities all the way to the achievement of the SE4All goals by 2030. Prior to the 2012 UN Conference on Sustainable Development (Rio+20), countries interested in supporting the initiative were requested to commit to it. Dominica is one of the several signatories of the Barbados Declaration on Achieving SE4All in all SIDS of May 2012 (including 20 SIDS from Africa, the Caribbean and Pacific regions), which along other developing and developed countries worldwide have confirmed actions towards the initiative.

In the aftermath of Rio+20, the SE4All initiative has positioned itself as a global effort heralded by government, civil society and the private sector. Ban Ki-moon has convened broad-based support globally with a simple message: sustainable development is not possible without sustainable energy. It represents a strategic positioning of energy concerns in the global development agenda, as the pursuit of Millennium Development Goals (MDGs) moves towards attaining Sustainable Development Goals (SDGs) in a post-2015 context. The three SE4All main goals, depicted in Fig. 13.1, are also straightforward:

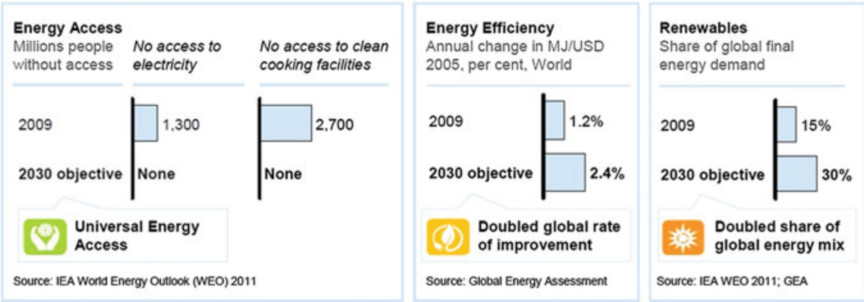

Fig. 13.1 SE4All 3 key objectives (UN 2012a)

The Commonwealth of Dominica lies in almost in the centre of the arc of Caribbean islands known as the Lesser Antilles, between the French overseas departments of Guadeloupe to the north and Martinique to the south—see Fig. 13.2. It covers some 290 square miles (750.6 km^2.) and has 148 km of coastline.

The country is richly endowed with 365 rivers, warm tropical climate and an average daytime temperatures range from 75 to 80 °F, with cooler temperatures in the mountains. The dry season is from January to April. The rainy season is from July to October. The terrain is rugged and mountainous; the highest point is Morne Diablotin which rises to 4,747 ft. Dominica is heavily forested (60 % of the

Fig. 13.2 Map of the Eastern Caribbean

country is covered by vegetation) and has the second largest thermally active lake in the world, also known as “the Boiling Lake”, as an indication of its geothermal potential.

As a Small Island Developing State (SIDS) in the Caribbean, Dominica is the least populated country in the Organization of Eastern Caribbean States (OECS) sub-region (70,000 inhabitants approx.). Its economy shows a GDP of approximately US$400 m, GNI per capita of US$4,770 and a current installed capacity of 21 MW. The country is planning to invest in increasing the capacity beyond 100 MW, through the development of geothermal resources. However, progress in this area is also contingent upon the completion of interconnection investments with their neighbouring French islands, considering that the excess capacity would have to be exported:

At present, 7.6 MW of grid-connected hydroelectricity is generated in Dominica (WB 2011). The introduction of low-volume, continuous-flow systems has made hydropower technologies readily applicable for small streams. However, poor agricultural practices and inadequate forest management have decreased flows in rivers and streams on many islands in the Caribbean (WB 2011). With the reported decreased water flow, only Dominica and to a lesser extent St. Vincent and the Grenadines may be able to economically exploit hydropower—see alternatives suggested by the same study in Table 13.1:

Hydro itself is highly site-specific, and detailed studies must be conducted at potential sites to arrive at more accurate projections of the economic viability of development. Dominica has preliminarily identified the potential to upgrade and expand its hydropower generating capacity from various sites in the country.

One such site is located in Newtown, outside of Roseau, Dominica’s capital city (see Fig. 13.3). The expansion of existing facilities offers the country the possibility of increasing its share of clean energy in its electricity mix through small-scale hydro developments. For instance, Dominica has considered the

Table 13.1 Caribbean viable electricity options (*Source* World Bank)

Country	Distillate	Coal	LNG	Wind	Geothermal	Hydro*	Bioinass*
Antigua and Barbuda	✔	✔		✔			✔
Grenada	✔	✔		✔	✔		✔
St. Vincent and the Grenadines	✔	✔		✔		✔	✔
St. Kitts	✔			✔			✔
St. Lucia	✔	✔		✔			✔
Dominica	✔			✔	✔	✔	✔
Nevis	✔			✔	✔		✔
Barbados	✔	✔	✔	✔		✔	✔
Guadeloupe	✔	✔	✔	✔	✔		✔
Martinique	✔	✔	✔	✔	✔		✔
Haiti	✔	✔	✔	✔		✔	✔
Jamaica	✔	✔	✔	✔		✔	✔
Dominican republic	✔	✔	✔	✔		✔	✔

✔ = Viable option
*The resources are site specific and need to be studied further

Fig. 13.3 Map of Dominica

development of additional hydropower resources within the Roseau valley, a protected area, though it requires addressing ecosystem-based climate resilience concerns in an integrated manner.

Indeed, the country’s ecosystems are among the richest in the Lesser Antilles. The forest systems are extensive, with all forest zones and types represented. These highly valued ecosystems are under threat from impacts of human activities (see Fig. 13.4), e.g. poorly managed mining and quarrying activities, unplanned infrastructural development:

In spite of the country’s rich river endowments, ecosystem considerations need to be considered for small hydropower developments in the short term. In the long run, Dominica plans to become carbon negative through the addition of geothermal energy to its electricity mix. The Government’s commitment to these plans has been internationally declared, as part of the SE4All initiative, as follows (AOSIS 2012):

1. Increase renewable energy generation from the current 30 % from hydro to 100 % by adding geothermal energy to the mix; and
2. Become carbon negative by exporting renewable energy to its neighbours—Guadeloupe and Martinique—by 2020.

The importance of sustainable energy for Dominica and other SIDS seems overlooked in international climate change negotiations. However, the firm position of SIDS on the debate regarding the mitigation responsibilities of industrialized nations is equal to their emphasis on addressing their concerns over domestic energy demand, in as much as it impacts their national budgets and

Fig. 13.4 Extractive industries (*Photo* BERNARD engineers)

development strategies (Alfaro-Pelico 2012a). Yet, the 3 global objectives of the SE4All initiative on energy access, energy efficiency and renewable energy are an ambitious global effort begging the question of its applicability to SIDS.

SE4All Opportunities for Dominica

SE4All proposes a framework of actions for governments, civil society and the private sectors to contribute to meeting the global goals, summarized as follows:

1. *Energy Access*—Ensuring universal access to modern energy services, by bringing the number of people with no access to electricity (estimated at 1.3 billion in 2009) or to clean cooking facilities (2.7 billion in 2009) down to zero by 2030;
2. *Energy Efficiency*—Doubling the rate of improvement in energy efficiency, by increasing the percentage annual change in MJ per dollar from 1.2 % (2009), to 2.4 % by 2030;
3. *Renewable Energy*—Doubling the share of renewable energy in the global energy mix, by increasing the share of global final energy demand from 15 % (2009) to 30 % by 2030.

The Secretary-General's High-Level Group on SE4All has developed a global action agenda (UN 2012b), which suggests 7 sectors of action, and 4 enabling areas of support across these sectors—see Fig. 13.5, from which areas of high-impact opportunity are identified:

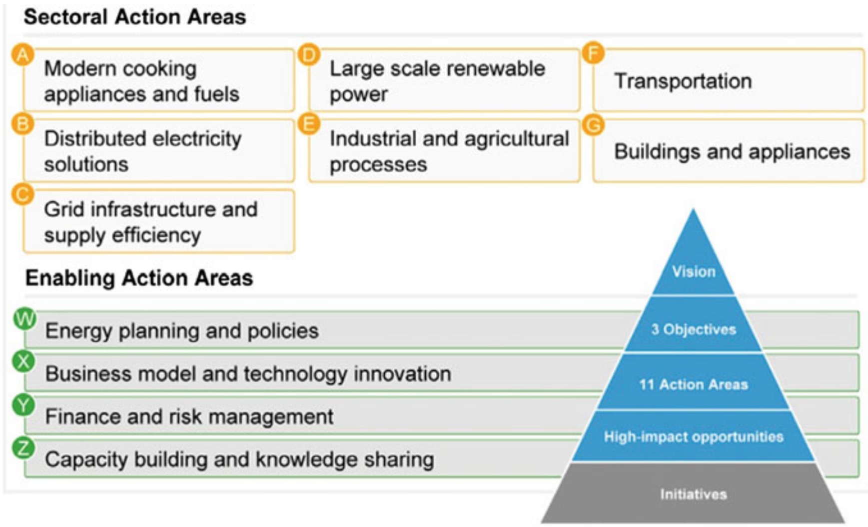

Fig. 13.5 SE4All action areas

The broad and structured SE4All framework can apply to any country, business or organization. Dominica itself can contribute to the 3 global objectives, but may also obtain assistance in the pursuit of its own national sustainable energy goals, through the proposed agenda action. For instance, the SE4All Sectoral Action Area D "Large-scale renewable power" sets forth a number of high-impact opportunities (HIOs), which are relevant to Dominica's plans (e.g. coordinating grid-connected infrastructure strategies for different renewable energy project developers). Such an action would, for instance, ensure that the country's hydropower and geothermal investors do not face the same barriers, or constraints limiting successful renewable energy deployment.

Meanwhile, the SE4All Enabling Action Area Y "Finance and risk management", proposes a number of HIOs critical for the mobilization of appropriate levels of funding for sustainable energy developments (e.g. developing a coordination mechanism for sustainable energy finance that can match funding needs with existing sources of philanthropic, public, and private finance). This HIO area has become increasingly important for Dominica, first, considering the large amounts of investment required for large geothermal development. Secondly, funding to realize its small scale hydropower potential would readily address immediate energy demands, but also requires accessing sources of funds that are catalytic of additional finance. A variety of sources can be tapped into from Dominica's national and international climate finance landscape.

Domestically, Dominica key sustainable energy investors are their utilities. Dominica Electricity Services Limited (DOMLEC) is the sole electrical utility in the country, which is heavily involved in assessing and realizing the national geothermal potential. Meanwhile, the Dominica Water and Sewage Company

(DOWASCO) is the national water utility. DOWASCO will play a critical role in the success of hydropower developments, jointly with DOMLEC. The SE4All framework also accommodates for the role different stakeholders can play in the process—see Fig. 13.6. For instance, the above investment plans need strong commitment from the Ministry of Environment and Natural Resources, Physical Planning and Fisheries; and that of Public Works, Energy and Ports.

Civil society is represented by a wide array of actors. These range from the communities heavily dependent on the rivers for their livelihoods (including indigenous groups such as the Karibs, after which the entire Caribbean region is named), to schools and training organizations that would need to prepare the local population to fully benefit from sustainable energy developments (e.g. climate change awareness-raising, learning skills for potential employment).

The private sector should also play a major role, as energy developments also create business opportunities for local entrepreneurs (e.g. ESCOs, services, supplies). Internationally, Dominica's commitment to SE4All also opens the door for different forms of assistance from the same type of stakeholders.

Donor governments such as Denmark are fully committed to supporting sustainable energy developments in small islands, as confirmed by its \$15 million contribution to the SIDS DOCK initiative in the aftermath of the 2009 UNFCCC Conference in Copenhagen (COP-15). Dominica is eligible to funding from this initiative, as are other members of AOSIS.

Other forms of assistance are also available to Dominica, through international climate finance mechanisms such as the Global Environment Facility (GEF), or technical cooperation through other platforms (e.g. Clean Energy Ministerial initiative on the Sustainable Development of Hydropower). International companies and civil society can also play a role (e.g. foreign-based NGOs, academia) in supporting Dominica and other SIDS realize their sustainable energy ambitions.

Fig. 13.6 SE4All stakeholders

Coordination across groups	Public sector	Private sector	Civil society
Policies and institutions	++	+	+
Technological innovation		+	
Finance solutions	++	++	+
Implementation capacity	++	++	++

The challenge for a small island will be harnessing all kinds of financial and technical assistance, in a manner that is conducive to national sustainable development objectives. Indeed, this same challenge is faced by larger countries.

UNDP's Approach to SE4All Support in Dominica

A key role for UNDP, as part of the UN global development network, is to support country-driven sustainable development efforts in an integrated manner. The convening power of the UN Resident Coordination system, often led by the UNDP Resident Representative in each country, is critical to ensure that energy interventions indeed contribute to development.

The linkages between energy and development has been previously established, and the SE4All initiative has helped highlight its importance towards attaining the Millennium Development Goals (MDGs)—see Table 13.2. This has also underscored the importance of energy in a post-2015 scenario set for the attainment of Sustainable Development Goals (SDGs).

The 2012 UN Conference on Sustainable Development (UNCSD or Rio+20) became a major platform for this thrust. Indeed, more than US$50 billion have been mobilized toward sustainable energy, based on commitments made by countries, business and other partners. It is, however, not so clear how these commitments will materialize in countries such as Dominica, amongst other developing countries.

Table 13.2 MDGs vis-à-vis sustainable energy [*Source* Alfaro-Pelico (2012b)]

SUSTAINABLE ENERGY FOR ALL

MDG Goal	SUSTAINABLE ENERGY Linkages
Goal 1: Eradicate extreme poverty and hunger	• Access to cleaner energy services will help reduce the fuel import bills choking the budgets of developing countries (particularly, SIDS)
Goal 2: Achieve universal primary education	• Lightning in schools during the day, and at home in the evenings help children do more homework
Goal 3: Promote gender equality and empower women	• Availability of modern energy services frees (girls') and young women's time from survival activities (gathering fuel-wood, fetching water, cooking inefficiently, crop processing by hand, manual farm work)
Goal 4: Reduce child mortality	• Globally indoor air pollution contributes to respiratory infections that account for up to 20 percent of the 11 million child deaths each year
Goal 5: Improve maternal health	• Energy services are needed to provide access to better medical facilities for maternal care (for example, adequate operating theaters)
Goal 6: Combat HIV/AIDS, and other major diseases	• Electricity in health centers enables night activities, and allows equipment use (for example, medicine sterilization, medicine refrigeration)
Goal 7: Ensure environmental sustainability	• Using cleaner, more efficient fuels will reduce greenhouse gas emissions, which are a major contributor to climate change

The situation is similar at the on-going international climate change negotiations, where hundreds of billions of resources are earmarked to address climate change (e.g. US$30 billion annually of fast-start finance pledged from 2010, US$100 billion annually expected to be channelled through the Green Climate Fund from 2020).

However, countries face the challenge of accessing these funds. Some of these shortcomings often arise by design, especially if one takes a closer look at the far-from-straightforward global climate finance architecture—see Fig. 13.7 for more details.

The complexity of the financing landscape to address climate change creates an additional burden on developing countries to access "new and additional" predictable sources of funds. Even when funds are accessed (for instance, those channelled through multilateral mechanisms such as the UNFCCC), countries need to integrate them with other sources (e.g. own national budgets, private finance, foreign aid), in order to deliver effectively on the intended development impacts.

This has been one of the entry points for UNDP's assistance. Dominica is amongst the many SIDS eligible to access funding from the Global Environment Facility (GEF)—several countries have benefited from the GEF after ratifying the

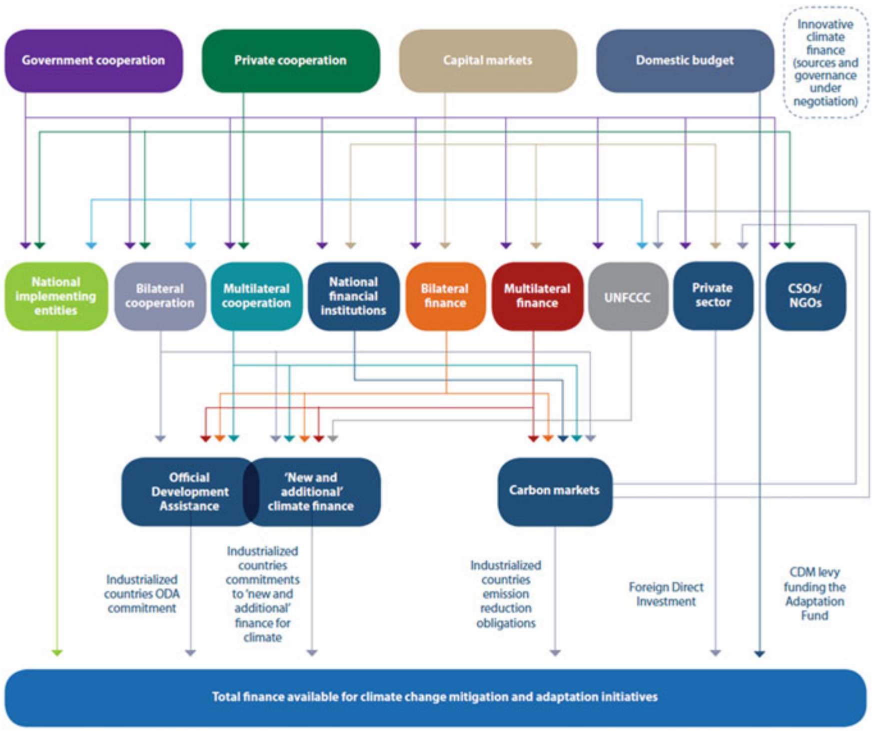

Fig. 13.7 Climate finance landscape [*Source* Glemarec (2011)]

3 Rio Environmental Conventions (outcomes of the 1992s Earth Summit): climate change (UNFCCC), biodiversity (CBD) and land degradation (UNCCD).

In the current fifth replenishment cycle (GEF-5), Dominica may access up to US4 million for projects addressing climate change mitigation concerns (amongst other), through several implementing agencies (UN agencies and development banks accredited by the GEF). Its request for UNDP assistance is drawing from its green, low emission, climate resilient development strategy (GLECRDS) approach:

As depicted in Fig. 13.8, UNDP's GLECRDS framework considers the integrated nature of climate change adaptation and mitigation concerns. Although climate funds often come with a tag (e.g. GEF's Special Climate Change Fund is primarily devoted to adaptation), UNDP's support towards the deployment of sustainable energy technologies considers also the mitigation side of the same coin.

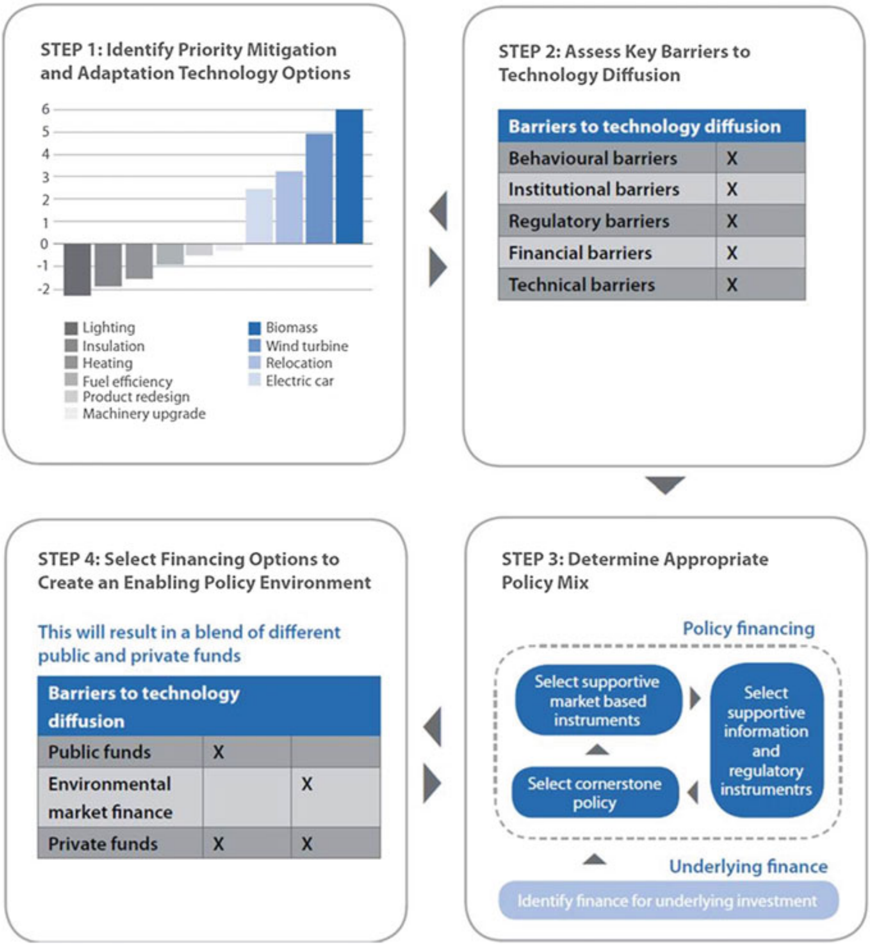

Fig. 13.8 UNDP's GLECRDS framework [*Source* Glemarec (2011)]

For instance, Dominica's hydropower plans need addressing the "green" concerns noted earlier (human-induced contamination), the "low emission" goals intended with GEF funds (cleaner energy matrix) and "climate resilience" risks (water resource challenges, e.g. prolonged dry seasons). Broader climate considerations, alongside sustainable development objectives, i.e. social inclusion (e.g. gender impacts, indigenous community involvement), economic growth (e.g. energy intensity, fiscal balances), informs UNDP's four-stepped GLECRDS approach. The GLECRDS framework allows for integrated sectoral considerations, which are consistent with Dominica's SE4All agenda.

As a result, Dominica's investments in hydropower will require the involvement of a wide range of stakeholders beyond DOMLEC or its energy ministry. Consultations with the environment ministry are providing for a broader understanding of the policy, financing, capacity and technology constraints requiring a more comprehensive analysis, beyond the information provided by standard environmental impact assessments (e.g. integrated resource assessments, water availability maps, river flow analyses).

Therefore, UNDP's work in the energy, infrastructure, transport or technology (EITT) sectors takes low emission considerations beyond mitigation, within the GLECRDS framework—see Fig. 13.9:

In doing so, UNDP has been promoting sustainable energy interventions at very different scales (see Fig. 13.10) with GEF funding, and in partnership with both public and private sector stakeholders:

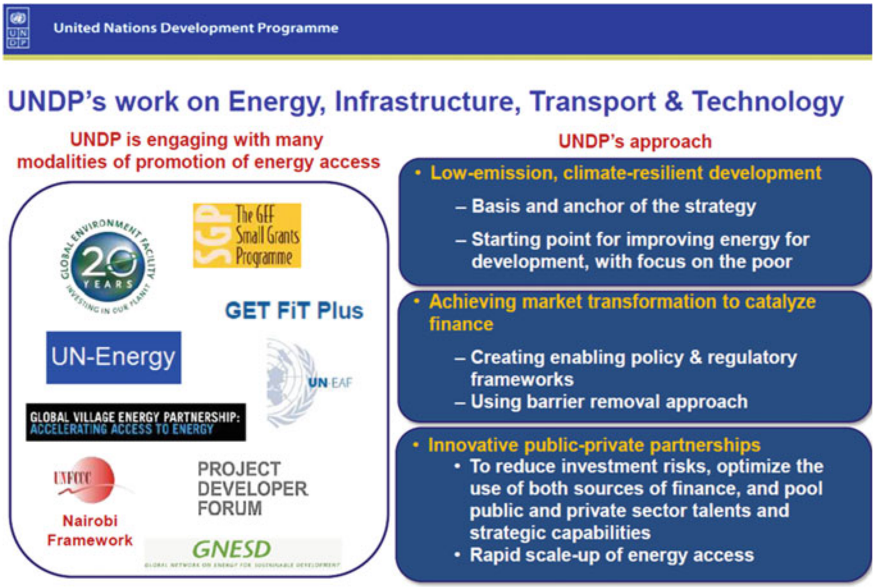

Fig. 13.9 UNDP low-emission EITT approach [*Source* Alers (2011)]

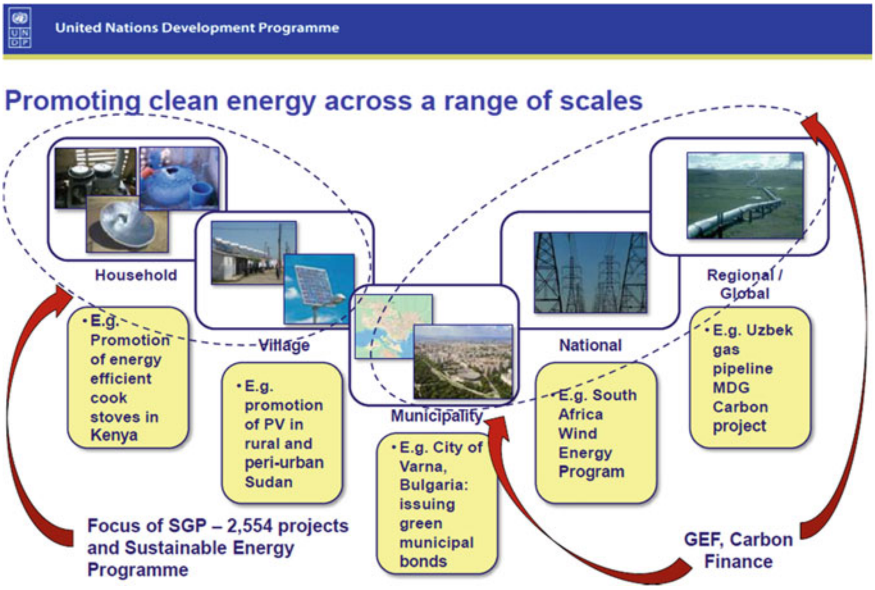

Fig. 13.10 UNDP sustainable energy approach [*Source* Alers (2011)]

This multi-scale support is successfully achieved by assisting countries combine and sequence their different forms of climate finance [Alers, Glemarec (2011)]—see Fig. 13.11:

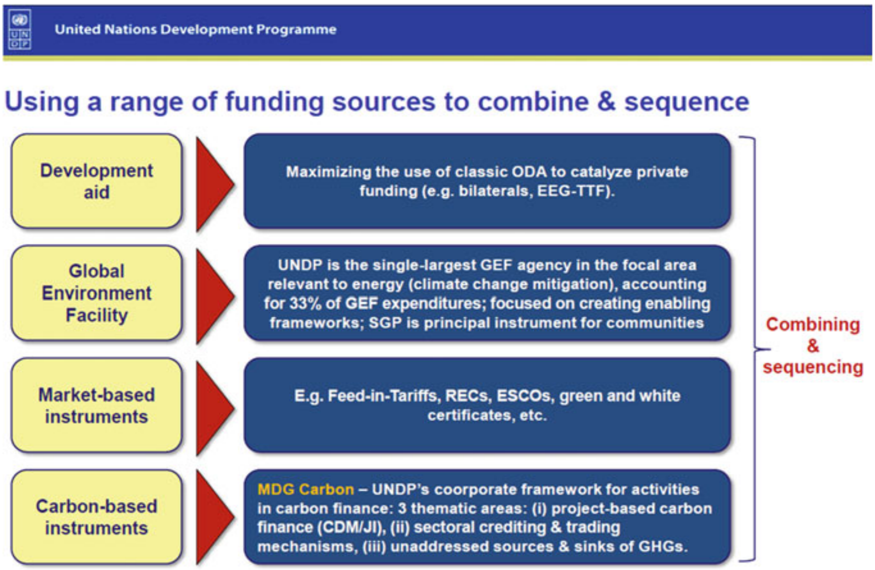

Fig. 13.11 UNDP combining and sequencing approach *Source* Alers (2011), Glemarec (2011)

For instance, Dominica's low carbon development proposal being submitted for GEF funding may combine US$2–4 million from GEF's trust fund with direct or indirect contributions (grant or in-kind) from development aid (e.g. $0.3–1 m Denmark government's donation to SIDS DOCK, $0.2–0.6 m UNDP grants both from core and non-core sources) and market-based instruments (e.g. $1.2–6 m from DOWASCO and DOMLEC's capital outlays to be repaid through tariffs or other means).

However, it is the catalytic nature of GEF funds that may unlock the potential to access the alternative sources of finance within the same project (combining), and help restructure the terms of other funds (sequencing, by blending existing grant finance with other non-grant resources, e.g. soft or hard loans from Dominica's Agricultural Industrial and Development Bank, or the Caribbean Development Bank).

Conclusion

Dominica's ambitious sustainable energy objectives match its potential to deliver on its sustainable development goals 100 % through cleaner sources of energy (e.g. hydropower and geothermal). The approach the country takes in responding to the challenge might well determine its chances of success, as it is the case for other SIDS.

Dominica's commitment to the "Sustainable Energy for All" is certainly a step forward in this direction. Not only does it demonstrate the country's firm stance on responding to national sustainable energy objectives, but it also shows how other countries can benefit, starting with the neighbouring islands of Guadeloupe and Martinique.

These values are shared by other SIDS signatories of the Barbados Declaration, proving how serious about climate change mitigation these countries are, even when they agree the main burden of reducing greenhouse gas emissions should be placed on to developed countries. The SE4All framework and the UN Secretary-General action agenda launched ahead of the Rio+20 conference provides guidance on how countries can go about pursuing sustainable energy.

The multi-stakeholder approach is very typical of UN-led processes, but it has also proven critical in many countries worldwide to bring sustainable energy to their homes. It shows that industry alone cannot address the energy challenge, nor can development aid finance such an undertaking, nor can interventions ignore the voice of indigenous communities, or neglect the importance of empowering women in the process. The other challenge is bringing all parties and resources (time, money, and their expectations) to the table in a way that it does not compromise the delivery of the intended sustainable development goals. The international climate negotiation process, and its outcomes (cycles, finances, and their intentions), provide an example of how complex the process can be.

It is down to countries to determine their approach and partners to their causes. Dominica’s long-term partnership with UNDP draws from a track record of integrated development assistance, which ranges from supporting the country’s poverty eradication efforts to providing advice to its energy investment plans in such a way that it helps the country pursue green, low emission, development strategies.

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Chapter 14
A Comprehensive Study of the Wind and Solar Potential of Gau Island, Fiji

Ravita D. Prasad

Abstract In Vadravadra village, Gau Island, electricity is provided by a 15 kW diesel generator which is switched on for four hours every evening, and fuel usage is approximately 3,200 L/year. The problem faced by villagers is the constant rise in the price of diesel, which is added to the transportation costs of travelling from the main islands to this remote island, resulting in villagers currently paying approximately FJ$2.80/litre. This paper attempts to determine energy produced (kWh) from wind and solar for electricity generation at the site, as well as the cost of energy (COE). The first section presents the energy supply and demand for the village. The second section gives the wind and solar resource characteristics for the site. The annual average wind speed for the site is 6.2 m/s and the average insolation is 5.50 kWh/m^2/day. The third section presents the wind energy potential and size of a stand-alone solar system. Using a 15 kW wind turbine with 0.25 as the overall power coefficient, the estimated annual wind energy yield is 33,700 kWh. With five days storage, the stand-alone solar system requires 84 batteries and 308–125 W PV modules. The next section presents optimum hybrid configuration for the site using HOMER, and finally some conclusions are drawn.

Keywords Small wind energy · Solar energy · Hybrid system · Battery storage · Cost of energy

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_14,

Short Introduction

The main islands of Fiji have grid-connected electricity, but on small islands, electricity is provided by diesel generators. The constant rise in the price of diesel causes problems for local inhabitants, and they are looking for alternative sources of electricity production.

Currently in Fiji, there is no working stand-alone wind/solar hybrid system, though there are wind and solar resources at most sites, incl. Vadravadra village, Gau Island (e.g. the annual average wind speed for this site is 6.2 m/s). This study has found that the hybrid system—if built correctly—can provide energy, educational, health and environmental benefits to the villagers on Gau Island.

Introduction

Fiji is one of the island countries in the South Pacific region. It has approximately 330 islands, of which about one third are inhabited. The total population of Fiji is about 840,000 (Fiji Islands Bureau of Statistics 2010). The main islands of Fiji, Viti Levu and Vanua Levu, have grid-connected electricity. However, small islands get power from diesel generators through the rural electrification programme. Biodiesel and biofuel are slowly being integrated into existing diesel generator sets. One island (Koro Island) currently gets electricity from biofuel. Now, since diesel costs are constantly increasing, small, remote islands are looking for alternative sources of electricity production. Currently in Fiji there are no working stand-alone wind/solar hybrid systems. However, plans are in place to revive the Nabouwalu wind/solar/diesel hybrid system in Vanua Levu, which successfully worked for three years before the renewable component stopped working due to lack of maintenance (Developing Renewables 2006).

Gau Island is situated to the east of Viti Levu (Fig. 14.1a). Vadravadra village, belonging to the district of Sawaieke, is located on Gau Island within the Lomaiviti province (Fig. 14.1b). The location of Vadravadra village is at latitude 18°06’S and longitude 179°20.6’E.The main means of transportation to the island are a monthly boat service and a weekly flight, scheduled on Wednesdays. There is no electrical grid available on the island. Electricity is supplied by a 15 kW diesel generator for only four hours every evening.

Current Energy Supply and Demand in the Village

Vadravadra village has 44 households and a population of 174 individuals. The village currently has an 18.5 kVA (15 kW) DG set that was installed in 1999 with the support of the government of Fiji under the Rural Electrification (RE) program

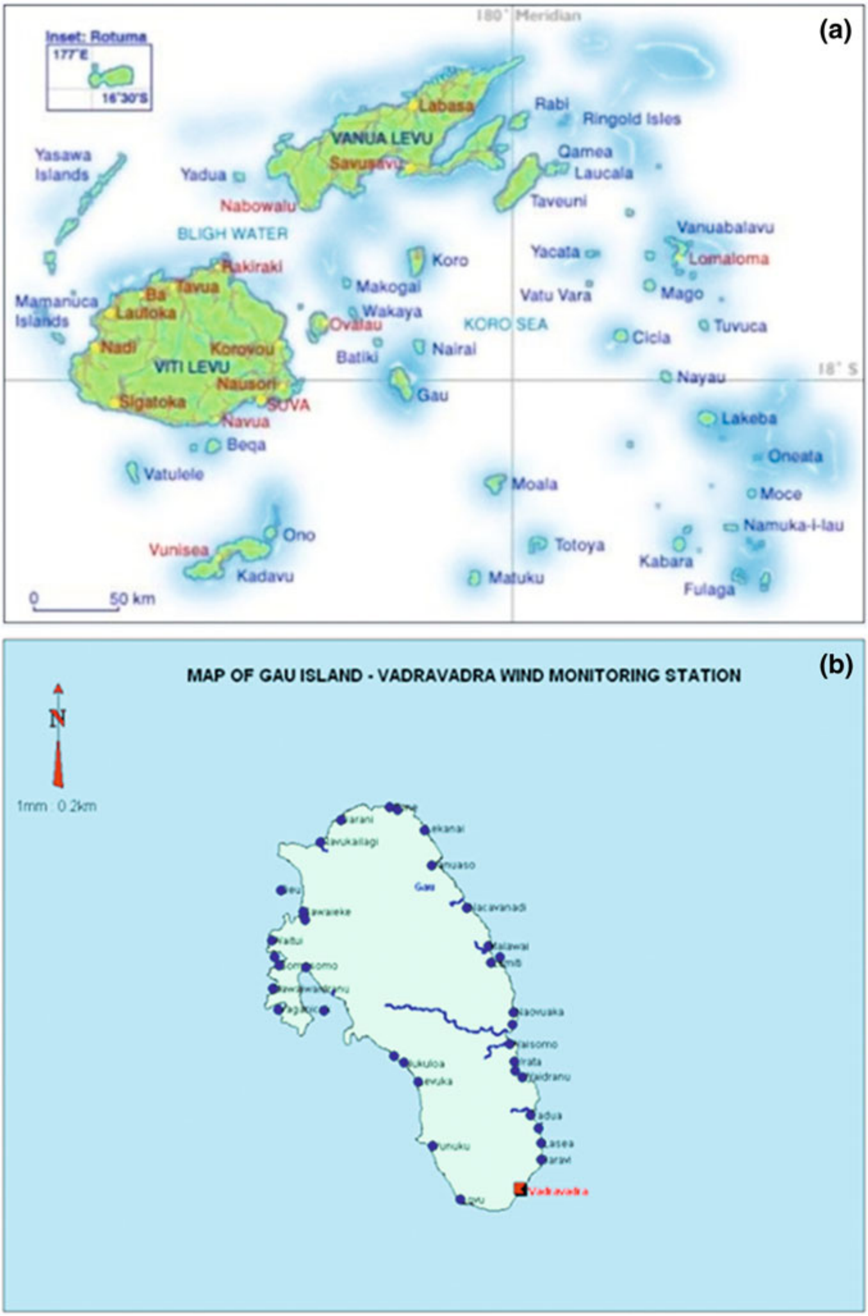

Fig. 14.1 **a** Map of Fiji'sislands **b** Map of Gau Island, showing Vadravadra village marked in *red*

of the Department of Energy (DOE). This generator operates for four hours every evening, and the fuel consumption is approximately 2.2 L/h. Hence, in a month (30 days), fuel consumption is 264 L, which means 3168 litres of fuel consumed per year, at a yearly fuel cost of FJ$8870.

Table 14.1 shows the current load if electricity is assumed to be produced for 24 h. If electricity is supplied for 24 h, current electricity consumption per capita corresponds to approximately 150 kWh/year. The electricity usage for the village was collated by the Fiji Department of Energy (FDOE). Figure 14.2 shows the daily variation in load when using the information in Table 14.1.

The Problem on Gau Island

Currently, Vadravadra village's electricity is not produced from renewable sources. People have to purchase diesel fuel from the mainland, transport it to the island and then use it in their generators for electricity to be provided for 4 h in the evenings every day. Recently, the price of diesel fuel has been rising, and varies at between FJ$2.30 and FJ$2.80/L. The total price of diesel fuel in a month would be approximately FJ$740 if FJ$2.80/litre is taken as the cost of diesel fuel. This is a huge cost in the context of people's average monthly income. As in any ordinary

Table 14.1 Electrical load at the Vadravadra site

Load	Power (kW)	Hours used[a]	Energy (kWh)	Time[a]
Light	2.03	6	12.18	6–10 p.m. and 4–6 a.m.
Fridge	2	24	48	24 h
TV	0.466	6	2.796	4–9 p.m.
Washing Machine	0.4	1	0.4	10–11 a.m.
Radio	1.541	5	7.705	6–9 a.m. and 2–4 p.m.
Mixer	1	1	1	3–4 p.m.
Daily total			*72*	
Annual consumption			*26,310*	

[a] Values are assumed

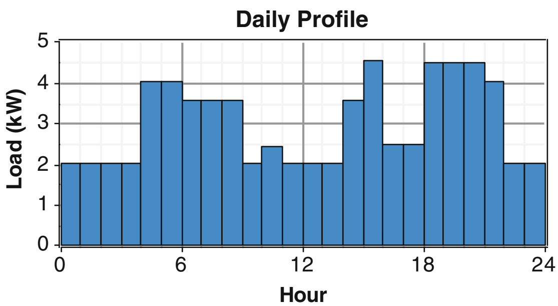

Fig. 14.2 Daily load profile at the Vadravadra site

village, villagers sell cash crops, for example, copra. For most households copra is the second most important crop for their income; pandanus leaves (mat selling) are the most important. Copra is sold through the village cooperative, then transported and sold in Savusavu. The villagers are beginning to plant dalo to be sold in Suva.

News recently appeared in the local newspaper that Gau Secondary School does not have access to electricity, meaning that boarding students have to use kerosene lamps in order to study (Avinesh 2011). This shows the energy security issues on remote islands in Fiji. People on remote islands are desperate for access to electricity just to cover their basic needs.

Wind and Solar Resource Characteristics

Wind Characteristics

For the Vadravadra site, wind speed and direction data were analysed for three consecutive years (2003–2005), recorded by the FDOE at a height of 27 m on the 137 m Delainasinu hill. Wind characteristics, such as monthly variation in wind speed, diurnal variation in wind speed, wind speed frequency and duration curves and turbulence intensity curves, all help wind energy developers make better decisions in installing a wind turbine at a particular site.

From the three-year wind data analysis, the annual average wind speed for the site is 6.2 m/s and the average turbulence intensity is 0.174. The wind-speed frequency for the site is shown in Fig. 14.3. This curve will be used to estimate the wind energy output from the site using the selected wind turbines' power curve.

It can be observed in Fig. 14.3 that, for the majority of the time (75 %), wind speed is between 3.5 m/s and 8.5 m/s. This graph can be used while choosing an appropriate wind turbine by looking at its cut-in (v_c), rated (v_r) and furling (v_f) wind

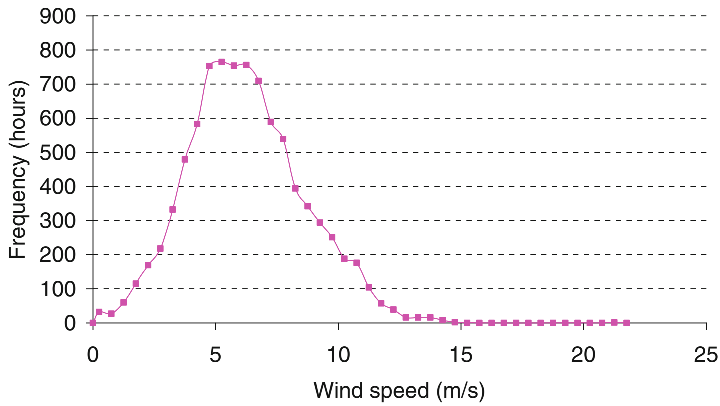

Fig. 14.3 Wind speed frequency curve for Vadravadra village

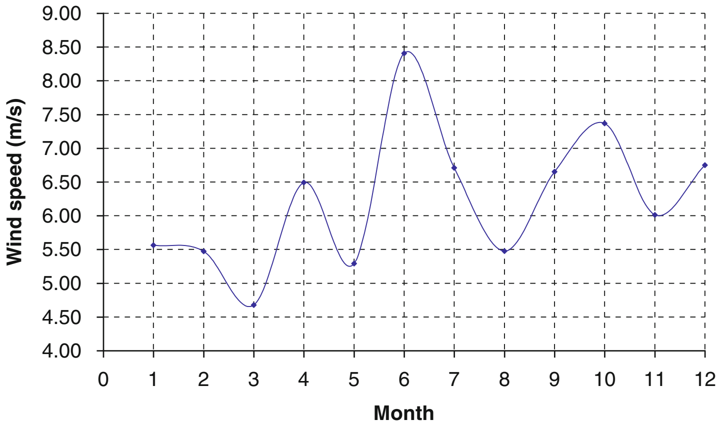

Fig. 14.4 Monthly wind speed variation in Vadravadra village

speed. It would not be desirable to have large v_r *and* v_c compared to the wind-speed characteristics for the site, since this would decrease the capacity factor for wind turbine. $v_c = 3.5$ m/s and $v_r = 8 - 10$ m/s can be chosen for the site.

In Fig. 14.4, the highest wind speed of 8.50 m/s is in June, and the lowest wind speed is 4.60 m/s, recorded in March. This graph can be used to plan for monthly wind-energy production and determine months when backup power would be needed, and when excess energy will be generated.

From the daily variation in wind speed (Fig. 14.5), it is seen that during the day, wind speed is lower, while during the night, wind speed increases. There is a peak in wind speed in the middle of the day, but even this is much less than wind speed late at night. High wind speeds around midnight would mean more wind energy production. However, the load requirement for villagers at midnight is not great, so the excess wind energy produced could be stored in a battery bank, for example.

From the wind rose for the Vadravadra site (Fig. 14.6), the prevalent wind is from the east. This should help planners in the installation of the wind turbine at the site by enabling them to orient an upwind wind turbine in the correct direction in order to reduce fatigue, and other loads, on the wind turbine and its blades.

Solar Resources

Since the solar insolation data is not recorded for Vadravadra, the data has been obtained from the NASA website (NASA 2011) by entering the latitude and longitude of the site.

The 22-year average solar radiation for Vadravadra, for a solar panel tilted at 18° towards the equator, is 5.50 kWh/m^2/day. The monthly variation in solar radiation data is shown in Fig. 14.7. Comparison of Figs. 14.4, 14.5, 14.6, 14.7 shows that when the solar radiation is less, during the middle of the year, the wind

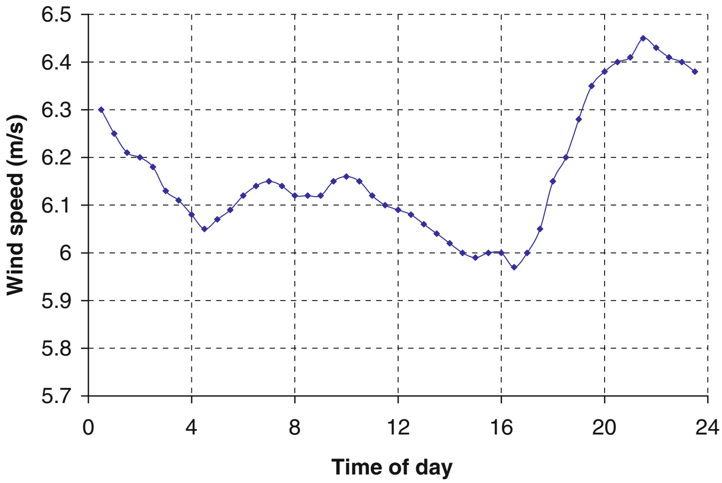

Fig. 14.5 Diurnal variation in wind speed

speed values are high, and when wind speed is low (during the beginning of the year) the solar radiation is high. This means that solar and wind-speed data complement each other. Hence, for an energy planner it would be wise to set up a solar PV/wind hybrid system to fully exploit the renewable energy resources.

Wind and Solar Energy Potential

Selecting the Wind Turbine

Not just any wind turbine should be installed at the proposed site. The wind-speed characteristics for the site should match the wind speed specifications of the wind turbine. This means that the cut-in and rated wind speed $(v_c \; and \; v_r)$ of the wind turbine should not be very high. Also, the chosen wind turbine should be able to meet b oth actual energy demand for the site, and to compensate for a 10 % increase.

Considering the wind-speed characteristics at the site, the electrical demand ($\sim$26,000 kWh/year), and the fact that, once electricity is available for 24 h a day, electrical demand will increase, a Hannevind 15 kW, three-bladed wind turbine has been chosen for the site. The specifications of this wind turbine are: $v_c = 2.5\,\mathrm{m/s}$; $v_r = 9\,\mathrm{m/s}$; diameter of blades = 10 m; a permanent-magnet generator and a self-supporting lattice tower is recommended with height options of 21/27/33 m. This wind turbine has been chosen because it has a low cut-in wind speed, a low-rated wind speed, and a 10 m wind-blade diameter. The diameter of wind turbine blades is directly proportional to the electrical power output (P_e) from the wind turbine, because P_e output from any wind turbine is given by Manwell et al. (2002) and Prasad et al. (2009).

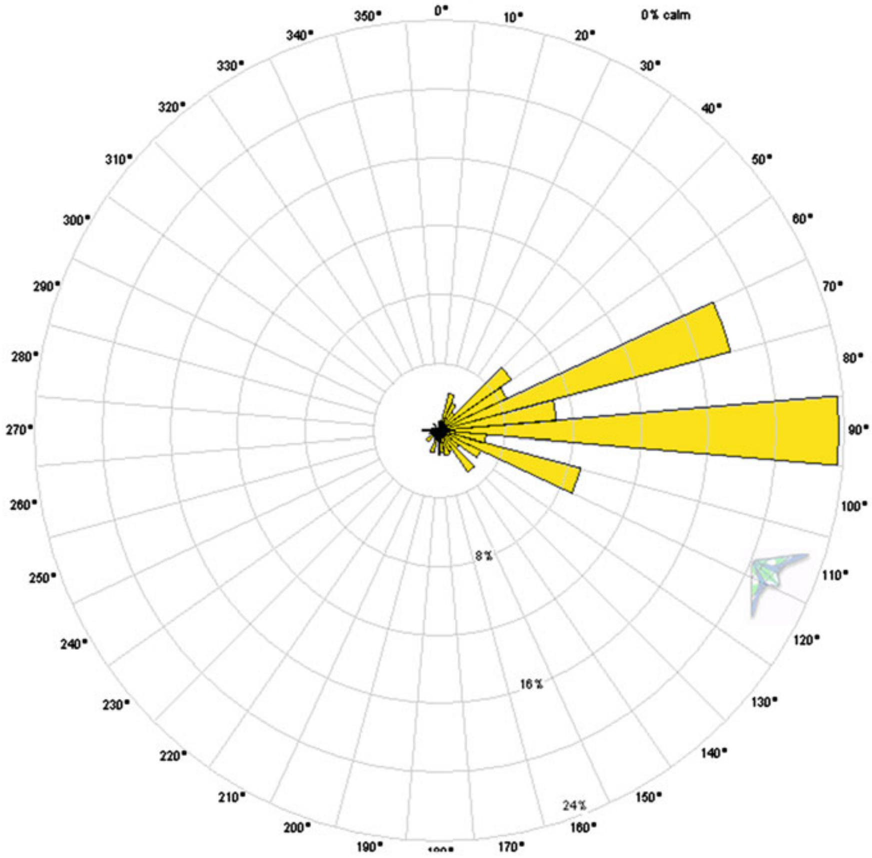

Fig. 14.6 Wind rose for Vadravadra village

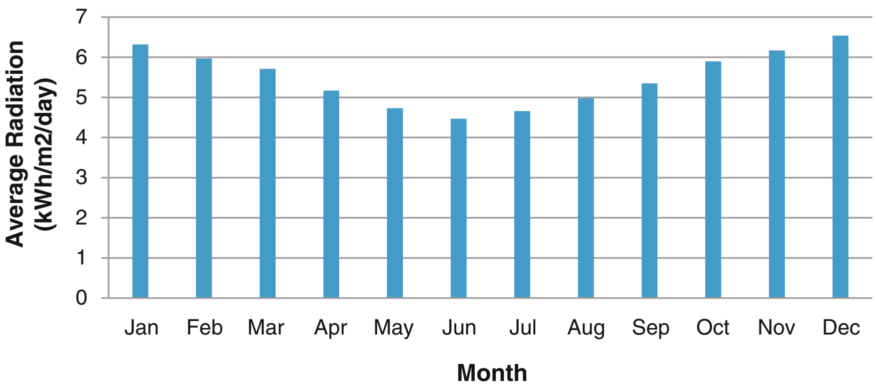

Fig. 14.7 Monthly variation in solar radiation

$$P_e = \frac{1}{2} C_{op} \rho A v^3, \tag{14.1}$$

where

C_{op} is the overall power coefficient of the wind turbine, which takes into account the aerodynamic efficiency, mechanical efficiency and electrical efficiency;
ρ is the density of air (1.2 kg/m^3);
A is the area of the turbine blades;
v is the wind speed

From Eq. (14.1) it can also be noted that wind speed plays a major role in the P_e output. If the wind speed doubles then the output power from the wind turbine is multiplied by eight. The power output curve is shown in Fig. 14.8.

The efficiency of the 15 kW wind turbine is shown in Fig. 14.9 (Better Generation 2011). In terms of the efficiency variation of the Hannevind 15 kW wind turbine, with respect to wind speed, the turbine has high efficiency (more than 30 %) at 3–10 m/s. In Fig. 14.3 it can be seen that most of the time, wind speed is 3–10 m/s, which implies a high wind-energy yield.

Estimated Wind Energy Output

The annual energy (E_{ann}) yield was calculated using Eq. (14.2).

$$E_{ann} = \sum_{i=v_c}^{v_r} P_{e_i} t_i \tag{14.2}$$

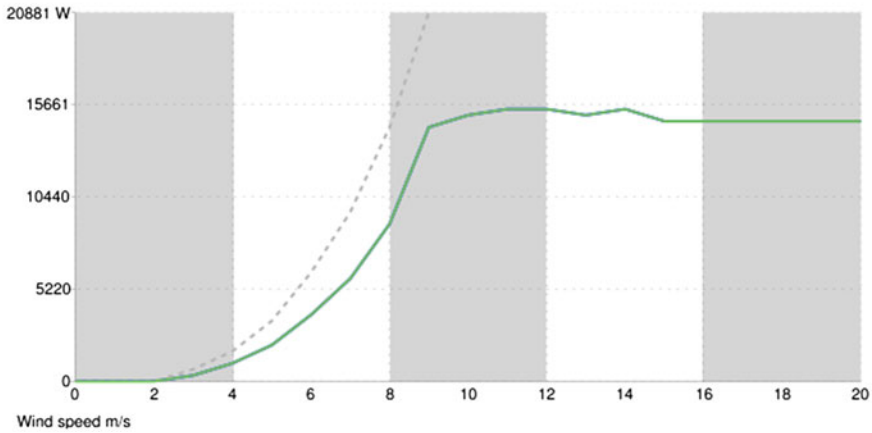

Fig. 14.8 Hannevind 15 kW wind turbine power output, based on manufacturer's data

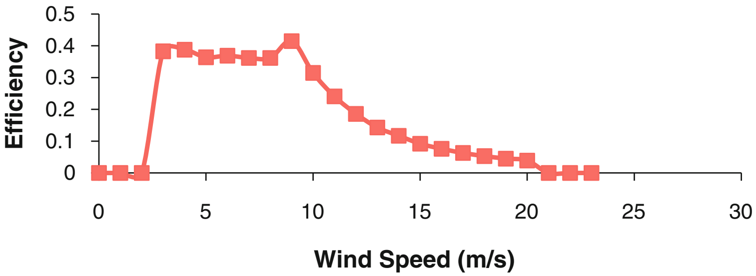

Fig. 14.9 Efficiency variation of Hannevind 15 kW wind turbine

where

i is the wind speed;

P_{e_i} is the electrical power from the wind turbine at a particular wind speed i;

T_i is the number of hours in a year for which wind speed is i

When the overall power coefficient of the 15 kW wind turbine is taken as 0.25, the estimated annual wind energy yield is 33,700 kWh. However, considering the manufacturer's power curve, the annual energy output from the wind turbine is estimated to be 42,900 kWh. Using error analysis, the annual mean energy yield from the Hannevind 15 kW in Vadravadra could be $38,300\ \text{kWh} \pm 20\,\%$. Considering Fig. 14.10, energy output of more than 1,000 kWh is mostly for a wind speed of 5–11 m/s.

Sizing the Stand-Alone Solar System

The annual average number of consecutive "no-sun days" for the site is calculated to be 5.2 days. However, Table 14.2 (NASA, 2011) also shows that in August there are nine no-sun days. To calculate the battery storage size, the maximum

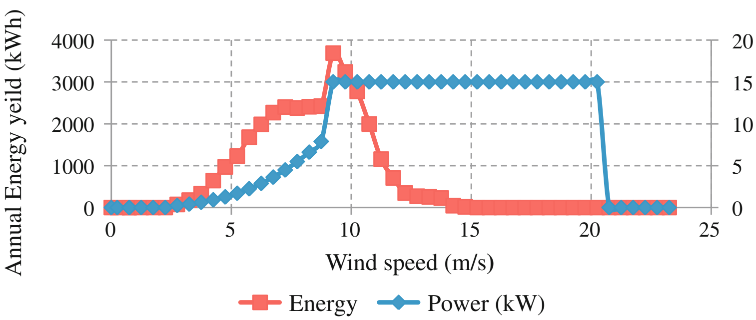

Fig. 14.10 Energy yield and power output at $C_{op} = 0.25$

Table 14.2 Average no-sun days for different months

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No-sun day	4.2	3.46	5.28	6.84	3.36	4.98	4.41	8.98	6.17	4.92	4.78	5

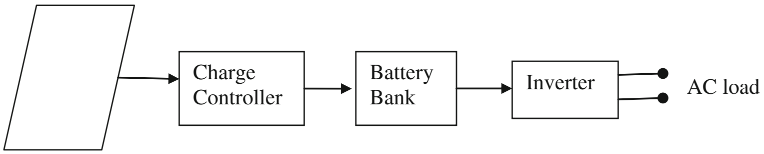

Fig. 14.11 Stand-alone solar system

number of no sun days should be taken so as to not to undersize the system. However, during design, the tradeoff has to be between supplying electricity continuously (i.e. 100 % of the time) and cost.

A stand-alone system will have the components shown in Fig. 14.11. To size the system, one needs to work back from the AC load and try to determine the size of battery bank and the size of the solar panels. The number of batteries and PV modules needed in a stand-alone system is determined during sizing. In sizing the stand-alone solar system for Vadravadra, the following data will be used:

The AC load for the village is 72 kWh/day. There will be five days of storage with a Surrette 12 V battery of capacity 600 Ah. The coulomb efficiency is taken as 80 %. The system voltage will be 24 V. A 12 V, 125 W solar module, which has a rated current of 7.2 A, is to be considered. The efficiency of the inverter is taken as 90 %. According to Fig. 14.7, June has the lowest solar insolation, 4.47 kWh/m^2/day, and hence 4.47 h of full sun per day.

Step: 1. ***Total daily AC load***

72 kWh/day + (20 % × 72) = 86.4 kWh/day = 86,400 kWh/day
20 % is taken to cater for any unexpected rise in energy demand during the day.

Step: 2. ***DC load input to inverter***

$$\frac{86,400 \text{ Wh}}{0.9} = 96,000 \text{ Wh } d.c.$$

Step: 3. ***Battery storage capacity***

$$Battery\ storage\ capacity\ (\text{Wh}) = \frac{total\ daily\ load\ demand \times No.\ of\ no\ sun\ days}{\eta_{Coulomb}}$$
$$= \frac{96,000\ (5)}{0.80} = 600,000 \text{ Wh}$$

Step: 4. ***Calculating the size of battery***

1. Since the system voltage is 24 V, two batteries will be placed in series.
2. Battery Ah for storage

$$\text{Ah}\,\textit{for battery} = \frac{600{,}000\ \text{Wh}}{24\ \text{V}} = 25000\ \text{Ah}$$

Number of parallel strings:

$$\#\ \textit{of parallel strings} = \frac{25{,}000\ \text{Ah}}{600\ \text{Ah}} = 42\ \textit{parallel strings}$$

Altogether, there are two batteries in series with 42 parallel strings = 84 batteries in total.

Masters (2004) gave the following formulae for storage capacity providing electricity 99 % of the time and 95 % of the time:

$$\textit{Storage days}\ (99\%) \approx 24.0 - 4.73(\textit{Peaksunhours}) + 0.3(\textit{Peaksunhours})^2 \tag{14.3}$$

$$\textit{Storage days}\ (95\%) \approx 9.43 - 1.9(\textit{Peaksunhours}) + 0.11(\textit{Peaksunhours})^2 \tag{14.4}$$

From Eq. (14.3) nine storage days is calculated; Eq. (14.4) calculates 3.1 storage days.

With nine days storage, the number of batteries comes to 150, which would increase the cost of the system; with three days storage the number of batteries comes to 50.

Step: 5. ***PV sizing***

Number of PV modules in series is

$$\begin{aligned}\#\ \textit{of PV modules in series} &= \frac{\textit{System voltage}}{\text{V}_{\textit{PV}\text{mod}\textit{ule}}}\\ &= \frac{24\ \text{V}}{12\ \text{V}} = 2\ \text{mod}\,\textit{ules in series}\end{aligned}$$

Since the AC load is 86,400 Wh/day, and the DC load for input to inverter is 96,000 Wh/day, the ampere-hours needed at the inverter is

$$\text{Ah}\ \textit{needed}\ @\ \textit{inverter} = \frac{96{,}000\ \text{Wh}}{24\ \text{V}} = 4{,}000\ \text{Ah/day}\ @\ 24\ V$$

One string has two modules; therefore, Ah to inverter is

$$7.2\ \text{A} \times 4.47\,\text{h}\,\textit{full sun} \times 0.90 \times 0.90 = 26.1\ \text{Ah/day}$$

Hence, the number of parallel strings is

$$\#\ of\ parallel\ strings = \frac{4,000\ \text{Ah}}{26.1\ \text{Ah}} = 153.3 = 154\ parallel\ strings$$

Therefore the PV array will have two modules in series with 154 parallel strings, giving a total of 308 PV modules. Since one module is 125 W, the rated power of the whole array would be 38.5 kW. Having this huge number of PV modules will also increase the cost of the system. Hence, the next section analyses the possibility of wind/solar hybrid systems.

Stand-Alone Wind/Solar Hybrid Configuration

Since there is no grid connection to the island, to make the system reliable and efficient, a wind/solar/diesel hybrid configuration has to be analysed using HOMER software. Wind and solar data were available during the writing of this paper, and these data have therefore been used to run the software. The daily load for the site was taken as shown in Fig. 14.2. This was used for weekdays and weekends. The hybrid components that were considered in HOMER were wind turbine, solar panel, battery, diesel generator and converter. A Hannevind 15 kW wind turbine was the type considered, and the power curve was taken from the manufacturer's data. A diesel generator was considered for the simulation to make

Table 14.3 Cost input in HOMER

Technology	Capital cost (FJ$)	Replacement costs (FJ$)	O&M costs (FJ$)	Expected lifetime	Efficiency
Wind turbine	FJ$6,000–6,500/kW	FJ$6,000–6,500/kW	3 %	20 years	
Solar Panel (BP solar 165 W)	FJ$1,510/unit or (FJ$9,200/kW)	FJ$1,510/unit	3 %	20 years	Derating factor 80 %
Diesel generator	FJ$1,500/kW	FJ$1,200/kW	FJ$0.05/hr O&M and		
FJ$3.00/l Fuel	Model determines				
Converter	FJ$1,500/kW	FJ$1,500/kW	FJ$100/yr	15 years	90 %
Surrette batteries (6 V, 460 Ah) determines	FJ$1,300/unit	FJ$1,300/unit	FJ$50/yr	Model	
Yearly O&M			FJ$1,000		
Fixed capital cost (transportation, road building and foundations, etc.)	FJ$100,000				

Table 14.4 Summary of the simulations run in HOMER

Hybrid system components	Electrical Load					
	Case 1: 71 kWh/day [8.5 kW peak]			Case 2: 85 kWh/day (20 % increase in load [10 kW peak])		
	Wind + solar + gen	Wind + gen	Wind + solar	Wind + solar + gen	Wind + gen	Wind + solar
Wind Turbine						
Size (kW)	15	15	15	15	15	15
Annual production (kWh/yr)	46,399	46,399	50,188	46,399	46,399	50,188
CF (%)	35.3	35.3	38.2	35.3	35.3	38.2
Levelised cost (FJ$/kWh)	0.286	0.286	0.267	0.286	0.286	0.267
PV						
Size (kW)	1	–	10	1	–	10
Annual production (kWh/yr)	1,588	–	15,878	1588	–	15,878
CF (%)	18.1	–	18.1	18.1	–	18.1
Levelised cost (FJ$/kWh)	0.857	–	0.865	0.857	–	0.865
Renewable Fraction	0.90	0.89	1.00	0.86	0.84	1.00
Diesel Generator						
Size (kW)	5	5	–	5	5	–
Annual production (kWh/yr)	5,491	5,818	–	8,104	8,538	–
Hours of operation (/yr)	1,703	1,,669	–	2,202	2,248	–
No. of starts (/yr)	408	458	–	659	700	–
Lifetime	8.81	8.99	–	6.81	6.67	–
CF	12.5	13.3	–	18.5	19.5	–
Fuel consumption (L/yr)	2,054	2,122	–	2,907	3,034	–
Specific fuel (L/kWh)	0.374	0.365	–	0.359	0.355	–
Efficiency (%)	27.2	27.9	–	28.3	28.6	–
Marginal generation cost (FJ$/kWh)	0.750	0.750	–	0.750	0.75	–
Total annual production	53,478	52,217	66,067 (Fig. 13)	56,091	54,937	66,067
Battery						

(continued)

Table 14.4 (continued)

Hybrid system components	Electrical Load					
	Case 1: 71 kWh/day [8.5 kW peak]			Case 2: 85 kWh/day (20 % increase in load [10 kW peak])		
	Wind + solar + gen	Wind + gen	Wind + solar	Wind + solar + gen	Wind + gen	Wind + solar
Number	10	10	60	10	10	100
Expected life	4.61	4.75	8	5.03	5.24	8
Converter (Inverter and Rectifier)						
Size (kW)	5	5	10	5	5	10
Emission						
CO2 (kg/yr)	5409	5588	0	7655	7989	0
Excess electricity (%)	49	47.5	57.3	42.3	40.9	47.9
Total NPC (FJ$)	348,780	337,967	542,876	371,535	362,645	649,685
Levelized COE (FJ$/kWh)	1.581	1.532	2.308	1.403	1.370	2.302
O&M (/year)	14,281	14,091	18,495	16,954	16,990	24,533

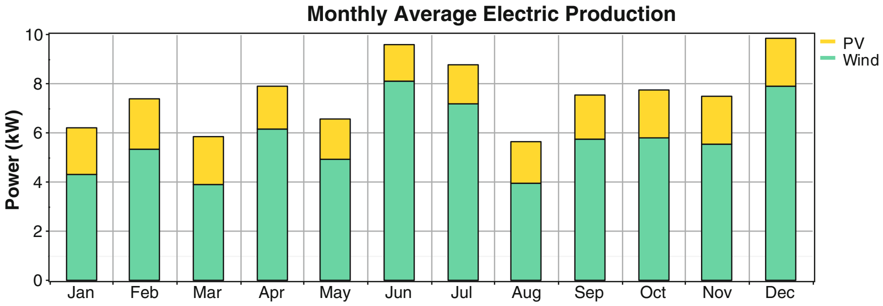

Fig. 14.12 Monthly average electric production

the whole hybrid system more reliable. It was assumed that two batteries were in series and the bus voltage was 12 V. Two types of load were considered during HOMER simulations: (1) current load and (2) 20 % increase in load. Furthermore, for each load, three different kinds of stand-alone hybrid systems were considered: (1) wind/solar/diesel generator, (2) wind/diesel generator and (3) wind/solar. All hybrid systems used batteries as the storage system.

The cost of the different equipment is shown in Table 14.3. The operation and maintenance costs are taken as 3 % of the capital cost, and the replacement cost is taken as the capital cost. The project lifetime was taken as 20 years, with an interest rate of 10 %; the diesel fuel cost was taken as FJ$3.00/L. Table 14.4 summarises the outcome of the optimised results in HOMER, and Fig. 14.12 shows the monthly energy yield from wind and solar when the electrical load for the site was 71 kWh/day.

For each of the different scenarios in Table 14.4, the diesel fuel consumed per year is less than what is actually being used at the village. This would imply that the burden on diesel fuel would be less. Considering Table 14.4, the cost of energy (COE) for the wind/solar hybrid system is the highest (FJ$2.308/kWh for the Case 1 load and FJ$2.302/kWh for the Case 2 load) due to the high number of batteries needed, large converter size and the greater number of PV modules. Hence, the option of just solar/wind hybrid is not very financially viable. For the two cases of electric load, wind/diesel generator gives the lowest COE of FJ$1.532/kWh for Case 1 and FJ$1.370/kWh for Case 2 with ten batteries and 5 kW converters in both cases. The wind/solar/diesel generator hybrid system is not very different from the wind/diesel system, since the percent of electricity from PV is less than from wind.

In addition, comparing the cost of energy generation from each of the three sources (wind, PV and diesel generator), wind has the lowest COE, FJ$0.286/kWh. PV costs FJ$0.857/kWh and the diesel generator costs FJ$0.750/kWh.

Conclusions

Vadravadra village on Gau Island is remote and not connected to any grid electricity. Energy is provided for four hours every evening by a 15 kW diesel generator. Due to rising fuel costs and the irregular supply of fuel to the island, the villagers are looking for alternative sources of electricity. This study has found that the site has an abundance of wind and solar resources. The HOMER simulation results show that wind/diesel hybrid configuration is the best option for the site, with the cost of energy ranging from FJ$1.37 to FJ$1.53/kWh with an increase in electrical load. Now, with the preliminary wind and solar resource survey carried out, the Fiji Department of Energy is looking for funds to implement this hybrid system to benefit the villagers on Gau Island in terms of education and health, as well as to reduce their carbon footprint.

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Chapter 15
The Potential for Using Renewable Sources of Energy in Mauritius

Jaykumar Chummun

Abstract Whilst the rich nations of the world experience different crises, vulnerable countries like Mauritius can only be spectators and watch the negative impacts of climate change on their already fragile economies. The current energy crisis is one example: the price of fossil fuel is going up constantly and the situation is only getting worse thanks to unrest in supplier countries as well as the ever-present threat from Somalian pirates in the Indian Ocean. The effects of CO_2 emissions from fossil fuels on climate, and the effects of pollution on air quality and health, should not be ignored. The only way forward to face the problems mentioned is to become self-dependent in energy through using clean and renewable resources, preferably available locally. The habits of the population need to change and there is a need for better awareness on the proper use of energy. This paper aims to highlight the potential of locally available sources of renewable energy such as solar, wind, and others, for domestic or other uses. The country is already making full use of its bagasse and hydro resources for energy, while there is a potential to further exploit solar and wind for generation of power. The use of other sources, such as geothermal and piezoelectric generators may also be considered in the medium and long term. It is expected that the investment cost of the required facilities will become more affordable in the future.

Keywords Clean and renewable energy · Energy self-dependency

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_15,

Short Introduction

This paper discusses the potential for using renewable sources of energy in Mauritius (country that imports its energy) and as the world is facing with the energy crisis in great extent, Mauritius becomes more vulnerable. For that reason, country as Mauritius has to think about becoming more self-dependent in energy by using clean and renewable resources. For that reason, this paper aims to highlight the potential of locally available sources of renewable energy such as solar, wind, and others, for domestic or other uses.

Introduction

The Republic of Mauritius exports mainly to European countries. The current recession faced by all countries, including those in Europe, has already started to affect the Mauritian economy. The signs are that the economic situation will be getting worse in 2012, and Mauritius is doing its best to mitigate the impact of the world economic slowdown. The Mauritian textile, sugar and tourist sectors have all been continuously re-adjusting their respective strategies as well as carrying out reforms to be able to survive. So far the country has done well, but the further challenges ahead will require still more creativity and reforms.

As well as reforming the existing economic pillars, diversification of the Mauritian economy has always been an important issue on the Mauritian economic agenda, and the country is looking for investment in new sectors. The recent budget speech put a lot of emphasis on facilitating SMEs, among other things. These are encouraged to develop their marketing strategies, as government declares itself ready to help them in that endeavour.

Energy is a very important factor that always comes into the equation when considering the and economic development of any nation. With the continuous increase of activities in the country, the demand for energy is also increasing. The energy generated in Mauritius has increased from 2015.9 GWh in 2005 to reach 2668.7 GWh in 2010 (CSO 2010). According to Elahee (2011), the expected demand in 2015 will be around 3340.0 GWh.

Dependence on fossil fuels may make countries like Mauritius increasingly vulnerable. The world is expecting to face further increases in oil price due to the instability in some of the OPEC countries, coupled with the recent US and EU sanctions against Iran. The constant threat from Somalian pirates in the Indian Ocean may make the problem worse for Mauritius. The world has a limited reserve of oil, and it is therefore very unlikely that the price of oil will go down unless an alternative and cheap source of energy is found. Pollution due to the use of fossil fuels, and its impact on the quality of air and health, should not be ignored. Furthermore, the tsunami in Japan in 2011 has shown that nuclear energy might not the ideal alternative to fossil fuels.

To sustain its economic growth Mauritius should be able to meet its increasing energy demand as well as face the current world economic crisis. Therefore, Mauritius is facing a real challenge, and there is a need to become more creative and to tap further the locally existing sources of energy. Like many tropical countries, Mauritius has a substantial potential to tap renewable energy (RE) sources that are abundantly available. This paper highlights the present status of the use of RE in Mauritius and discusses the potential of tapping new resources for the future.

Use of Renewable Energy in Mauritius

Mauritius is not new to the use of RE: the country has been using renewable energy since 1903 in the form of hydro-power (Sahai 2004). Mauritius is even considered to be a leader in the field of RE (UNDP 2011). The increase in energy demand soon after the Second World War encouraged the local authorities to consider sugar cane bagasse as a source of energy. Thus, the St Antoine Sugar Factory was the first to export its surplus electricity, made from bagasse, to the grid in 1957 (Deepchand 2001).

The 'Maurice Ile Durable' (MID—Mauritius Sustainable Island) project was launched in 2007 by the Prime Minister of Mauritius with a view to decreasing the island's dependency on fossil fuels and encouraging the use of renewable energy sources locally available. The project also targets improving the efficiency of the energy sector. Projects encouraging for example the use of solar water heaters and energy-efficient lighting have already been launched.

In 2010, the country produced 24.3 % of its energy requirements from available renewable energy and is aiming to increase this value to around 35 % by 2025. Table 15.1 shows the evolution of the use of renewable energy since 2008 and the target set for the future up to 2025. The goals mentioned were set out in the 'Long-Term Energy Strategy' plan in 2009 as a '*roadmap to address the energy and environmental challenges lying ahead*' (Republic of Mauritius 2009).

Hydro-Power

Hydro-power is one of the cleanest ways of generating power (Dincer 2000; International Hydropower Association 2003) and provides 20 % of the world's energy generation (Yüksel 2008). Although the initial investment is considerable, hydro-power has several advantages, such as low operating and maintenance costs, long life and the fact that it produces no waste (International Hydropower Association 2003). Mauritius is already making full use of this resource: there are eight hydroelectric stations that can generate around 100 GWh yearly, representing

Table 15.1 Actual and targeted power generation by source

Source of energy	Actual						Projection		
	2008 (CSO 2009)		2009 (CSO 2010)		2010 (CSO 2010)		2015	2020	2025
	GWh	%	GWh	%	GWh	%	%		
Renewable									
Bagasse	486.4	19.0	485.0	18.8	550.4	20.5	13	14	17
Hydro	108.0	4.2	122.4	4.7	100.7	3.7	3	3	2
Waste to energy	–	–	–	–	–	–	5	4	4
Wind	0.4	0.0	1.5	0.1	2.5	0.1	2	6	8
Solar PV	–	–	–	–	–	–	1	1	2
Geothermal	–	–	–	–	–	–	0	0	2
Sub-total	**594.8**	**23.3**		**23.6**		**24.3**	**24**	**28**	**35**
Non-renewable									
Fuel oil	833.7	32.6	953.3	37.0	995.5	37.0	31	28	25
Coal	1,128.7	44.1	1,015.3	39.4	1,039.5	38.7	45	44	40
Sub-total	**1962.4**	**76.7**		**76.4**		**75.7**	**76**	**72**	**65**
Total		**100.0**		**100.0**		**100.0**	**100.0**	**100.0**	**100.0**

slightly less than 4 % of its consumption (Central Electricity Board 2009; CSO 2010; Republic of Mauritius 2009).

According to the Long Term Strategy Plan (Republic of Mauritius 2009), there exists the possibility to generate 2GWh/year of power on La Nicolière Feeder Canal at Trente Chutes, using the facilities available at the Midlands Dam. The government's strategy is to encourage investment with the setting up of mini and micro hydro plants around the island, wherever the potential exists. The power output, however, depends heavily on the weather and it can fluctuate between 5 GWh per month in a dry season to 20 GWh per month in a wet one. Since 2011, Mauritius has been facing a period of drought and has had to cope with the shortage of power from hydroelectric stations by using coal and/or fuel oil.

Sugar Cane as a Source of Energy

Sugar cane is a very good source of green and renewable energy (Mauritius Sugar Producers Association 2011). During harvesting the sugar cane is separated from its top and straw, while bagasse and molasses remain following the industrial processing of the sugar cane. The tops are generally used as cattle feed but have the potential for being used as a source of raw material for paper (Deepchand 1987). According to Chung Tze Cheong et al. (2011), about 40 % of the island's surface area is used for agricultural purposes, while 90 % of that area is under sugar cane production (Ramjeawon 2008). In 2010, an area of 58,755 hectares of sugar cane plantation yielded 4,365,852 t of sugar cane (Central Statistics Office 2011).

Bagasse

Bagasse is the fibrous biomass remaining after sugarcane has been processed to extract sugar. Typically sugar mills generate about 30 % by mass of bagasse expressed on total amount of cane crushed (Deepchand 2005; Lee and Mariatti 2008). Bagasse is burnt to produce steam and electricity (cogeneration) for the needs of industry, and the excess electricity is usually sold to the wider consumer electricity grid (Contreras et al. 2009; Jaguaribe et al. 1992). The cost of collection of bagasse is insignificant, as it is produced and used on-site with very little storage time (Atchison 1957; Cao et al. 2006; Lynch and Goss 1932). The net calorific value of bagasse is about 8000 kJ/kg at a moisture content of 48 %. In 2010, 1,406,371 t of bagasse was used to generate 550.4 GWh of power.

Together with ACP countries, Mauritius is playing an active role in research and development to produce new varieties of sugar cane with a higher percentage of biomass. In 2007, the MSIRI developed a new variety of sugar cane that can yield 15–25 % more fibres. New high-pressure boilers have already been proven to use bagasse more efficiently (Republic of Mauritius 2009), and this experience could benefit the country.

Ethanol from Molasses

After extracting sugar from the cane juice, molasses is obtained and can be distilled into ethanol. The latter has been used as a replacement for gasoline in Brazil since 1975 (Walter and Cortez 1999), and is gaining more popularity. According to the MSPA, Mauritius can produce an average of 35,000 t of ethanol from the 150,000 t of molasses that are obtained annually (Mauritius Sugar Producers Association 2011). In the near future, the Omnicane Ethanol Holding Limited is expected to sell 15 million litres of anhydrous ethanol that would be blended with gasoline and sold as E10 fuel locally (Omnicane 2011). The country is encouraging the use of biofuels and plans to mix 25 million litres of ethanol with gasoline in the medium term.

Solar Energy

Solar energy is free, clean, inexhaustible, and available almost everywhere on our planet. Solar energy is mostly used in two forms: thermal and photovoltaic. Solar water heaters are designed to tap the heating effect of solar radiation. They are the most widespread solar energy conversion device (Budihardjo and Morrison 2009) and also the most economical alternative renewable energy systems (Mekhilefa et al. 2011). The photovoltaic (PV) devices convert sunlight directly to electricity. These devices require little maintenance and have a life of 20–30 years with low running and maintenance costs (Singh and Singh 2010). A typical solar water

Table 15.2 Number of hours of bright sunlight received in Mauritius (Mauritius Meteorological Services 2011)

Region in Mauritius	Hours of sunlight/day	
	Summer	Winter
High grounds	6.0	5.0
Coastal regions	7.5 to over 8.0	7.5

heater can provide about 75 % of the domestic needs for hot water and may cut the monthly energy bill by at least 20 % (Houri 2006).

Like most tropical islands, Mauritius is blessed with abundant sunshine and benefits from more than 2900 h of sunlight per year. The northern and south-western parts of Mauritius receive a solar radiation of 6 kWh/m^2/day (Mauritius Meteorological Services 2011). Table 15.2 summarises the average amount of bright sunshine received on the island.

Despite the abundance of sunlight in Mauritius, the amount of electricity harnessed from solar power generated is still very insignificant. Therefore there is huge potential for using solar energy in Mauritius.

Use of Solar Water Heaters

Solar water heating is the most common form of conversion of solar energy in Mauritius. To encourage the use of solar water heaters, the Development Bank of Mauritius has been providing a concessionary rate of interest on loans for their purchase since 1992. However, until 2008, only 25,000 households out of 330,000 were using solar water heaters. In 2009, the loan facility was replaced by an outright grant of Rs. 10,000 for the purchase of solar water heaters. 29,000 households have benefitted from the scheme, and the number of solar waters heaters in use on the island is expected to have reached more than 50,000—no survey has confirmed this value yet, however. Given the success of the grant, the government has proposed an improved scheme that would be implemented in 2012 (Government of Mauritius 2011). Undoubtedly, the number of solar heaters will continue to increase in the country.

Use of PV

Unlike the solar water heaters, the initial high cost of installing PV panels has been quite prohibitive, which explains why PV has not gained much popularity as a source of renewable electricity.

To encourage the use of PV as well as wind and hydro sources of electricity, the Small Scale Distributed Generation (SSDG) project was launched in December 2010. This project is limited to a capacity of 2 MW over the island from 200 ‘Small Independent Power Producers’ (SIPP). The Central Electricity Board

Table 15.3 Feed-in-tariff for SIPP (Central Electricity Board 2010)

Feed-in tariff for 15 years	Source of electricity		
	Wind Mauritian rupees (Rs) per kWh	Hydro	PV
Micro (up to 2.5 kW)	20	15	25
Mini (2.5+ to 10 kW)	15	15	20
Moyen (10+ to 50 kW)	10	10	15

(CEB—the public utility company responsible for the generation, transmission, distribution and sale of electricity in Mauritius) will pay the latter a 'Feed-in-Tariff' per kWh of electricity exported to the national grid. The Feed-in Tariff, valid for 15 years, is shown in Table 15.3. Currently, households drawing their electricity from the national grid pay the CEB Rs. 3.16–8.77 per kWh consumed, depending on the total amount of electricity consumed.

If the SIPP's annual production/consumption ratio is greater than 3, the Feed-in-Tariff is decreased by 15 %.

It is expected that the project will be a boost for eventual SIPPs and that the power generated using solar PV will constitute 2 % or more of the country's energy demand in 2025. On the other hand, the future of PV would seem to be very bright if the following points are considered:

- New technologies with solar tracking systems allow for improved energy capture as well as improved photovoltaic energy output for cloudy conditions (Kelly and Gibson 2009, 2011);
- The availability of integrated photovoltaic and thermal solar systems—a device that generates electricity and heats water simultaneously, resulting in improved efficiency (Kumar and Rosen 2011);
- PV technology is becoming more economical and more efficient (Clark 2011).

Wind Energy

Wind energy is another clean source of energy that is compatible with the environment and will never run out (Ilkılıç et al. 2011). Interest in wind energy started to grow in 1973 after the first world oil crisis (Michalak and Zimny 2011). The world wind energy capacity has increased from 6.1 GW in 1996 to 159.2 GW in 2009, representing an average annual growth rate of 30 % (Schaefer et al. 2012). The rapid growth since 1995 has led to improved efficiency and reduced cost of wind turbines, making wind energy increasingly competitive (Dincer 2011). To find the potential of wind energy in a country, a survey was carried out for the EU based on wind speeds of over 5 m/s at a height of 10 m (Meyer 1999).

A study carried out by the United Nations Development Programme (UNDP) in the mid 1980s found that Mauritius has an annual average wind speed of 8.1 m/s at 30 m above ground level in some, and therefore can be considered for harnessing wind energy. Wind turbines were installed in the late 1980s; however, they were destroyed by cyclones and the project was then neglected.

The following wind farm projects are now being considered (Central Electricity Board 2009):

- Omnicane would install a 22 MW wind farm at Britannia (Omnicane 2011);
- An 18 MW project would be installed by Aerowatt (Mauritius) in the village of Plaine des Roches; Another project in Curepipe Point on a 'Build Operate Own' model is taking shape, which would generate a power of 20–40 MW;
- The CEB has already carried out a feasibility study to install a wind farm with the potential of 5 GW. It is currently seeking funding for the project.

These interests clearly show that there is potential for tapping wind energy in Mauritius, and these opportunities should not be missed—provided that due consideration is given to the environment.

Waste to Energy Project

Foolmauna et al. reported that in 2010, an amount of 427,680 t of waste was sent to landfills in Mauritius, representing about 1 kg of waste per individual per day. While this figure is set to continue to increase, only 9 % of that amount is recycled (Mohee et al. 2010).

One way of reducing the volume of waste to be land-filled is by incineration (Tchobanoglous et al. 1993). If done properly, the process may be used to generate electricity. It is true that the issue of incinerating waste is still a matter of debate because of concerns over its impact on the environment, as well as on the health of the people living in the vicinity of the incineration site; however, new technologies are making the process more and more acceptable (Morselli et al. 2008). The EU has laid down strict guidelines (Saner et al. 2011) for waste incineration; such should be rigorously enforced in any country where waste is incinerated so as to ensure the well-being of its citizens.

Waste decomposition in the absence of air generates considerable amounts of methane gas that is liberated into the air. This gas can be used as a source of energy. Since October 2011, Sotravic, a Mauritian company, has been producing about 2 MW of renewable energy from landfill gas. The company is expecting to increase its energy generation to 3 MW (Sotravic 2012).

The 'Waste-to-Energy' project by the Gamma Coventa company is currently on hold because of protests from the general public. If given the go-ahead, the project is expected to produce 20 MW of energy by combusting solid municipal waste (Central Electricity Board 2009).

Other Energy Sources in Mauritius

The above-mentioned sources of energy would undoubtedly generate a significant amount of renewable energy. However, with increasing demand for electricity, the country needs to tap all the possible resources with a view to becoming totally dependent on its own sources of energy. In this context, another two sources of energy may be considered in Mauritius in the future: geothermal energy and electricity from the movement of vehicles on the Mauritian motorway.

Geothermal Energy

The core of our planet is very hot and at a temperature of around 5000 °C. The heat intensity decreases as we move from the core to the surface. The thermal energy, which can be used for heating or production of electricity, is referred to as geothermal energy (Fridleifsson 2001). In 2010, the world's installed capacity for power generation from geothermal sources stood at 10,000 MW; about 70,000 GWh was produced (International Geothermal Association 2010).

Mauritius, being a volcanic island, may have sources of geothermal energy. According to the Mauritius Research Council, a preliminary study has shown that it is possible to tap geothermal energy in Mauritius. Experts now have to establish the areas where the thermal energy may be tapped (Laurent 2012; Lexpress 2010; Lxrichter 2010). Therefore additional work is needed to determine the feasibility of tapping this source of energy in Mauritius.

Piezoelectric Generators

Piezoelectricity is the ability of a material to produce electric power when a mechanical stress is applied to it (Piezoelectric materials 2007). Tests are being currently carried out in Israel on a roadway that had been embedded with piezoelectric generators (Arjun et al. 2011). It is expected to generate up 400 kW over a stretch of one kilometre (Hanlon 2008).

The technology, developed by Innowattech (2011), should be able to produce 200 kWh, while a four-lane highway would produce about 1 MWh of electricity per kilometre, enough to provide power to 2500 households in Israel (Alternative Energy 2009).

This interesting technology might be of interest to Mauritius, as the country is developing its road infrastructure. However, the feedback from the Israeli experience would indicate whether it is worth conducting any feasibility study for the island.

Conclusion

This paper has highlighted the potential for using RE in Mauritius. While the cost of RE hardware is quite significant, it is falling as more and more efficient technologies enter the market. There will therefore be a lot of opportunities in the future for making the country increasingly reliable on RE sources. Using less fossil fuel means higher savings on foreign currency as well as less air pollution. Mauritius may dream of becoming a 'green destination' for tourists, with a healthier population. It would be interesting to evaluate the savings due to the latter.

Wave energy and energy from animal waste, such as chicken waste, have not been considered in this article, although it is believed there is considerable potential in these areas too. There is an additional opportunity for generating electricity from the sun at hotels that are situated in coastal areas, where more sunlight is usually available.

There is also the opportunity of job creation: SMEs should be encouraged to design, mount and maintain installations such as solar panels, wind turbines and mini and micro hydro plants. With 330,000 households in Mauritius, one can easily imagine the potential for setting up SMEs and creating jobs in the field of energy.

Energy saving should become a habit. Every little gesture counts.

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Chapter 16
The DIREKT Project: An Example of a Technology Transfer Project on Renewable Energy

Veronika Schulte, Walter Leal Filho and Jonathan F. Krink

Abstract This paper presents an example of a technology transfer project on renewable energy undertaken by the Hamburg University of Applied Sciences, namely the Small Developing Island Renewable Energy Knowledge and Technology Transfer Network (DIREKT), a cooperation scheme involving universities from Germany, Fiji, Mauritius, Barbados and Trinidad and Tobago. The overall aim of this project is to strengthen the science and technology capacity in the field of renewable energy of a sample of African, Caribbean and Pacific (ACP) small island developing states, by means of technology transfer, information exchange and networking. The project is funded by the ACP Science and Technology Programme, an EU programme for cooperation between the European Union and the ACP region. This paper introduces the DIREKT project, its aims and the partnership. It presents the methodology and results of a survey that was conducted in work package 2 of the project: the Assessment of Needs for Market-Oriented Research and Technology Transfer, along with a comparison of the results obtained in Fiji, Mauritius and selected Caribbean countries. A comparative analysis of the political and institutional frameworks in the field of renewable energy in the ACP regions and in Germany is presented, along with an assessment of research and innovation needs in science and technology. Finally, the paper summarises the similarities and differences between the surveyed regions regarding the use and promotion of renewable energy, and characterising the role of the DIREKT project as a technology transfer project on renewable energy.

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_16,

Keywords Small developing island states · Renewable energy · Technology transfer

Short introduction

This paper presents an example of a technology transfer project on renewable energy, namely the Small Developing Island Renewable Energy Knowledge and Technology Transfer Network (DIREKT), a cooperation scheme involving universities from Germany, Fiji, Mauritius, Barbados and Trinidad and Tobago. The overall aim of this project is to strengthen science and technology capacity in the field of renewable energy of a sample of African, Caribbean and Pacific (ACP) small island developing states, by means of technology transfer, information exchange and networking.

Introduction

The DIREKT Project

Small island developing states (SIDS) are island nations characterised by low to medium GDP levels, which justify their ranking as developing nations. There are several dozen SIDS distributed across the Caribbean, African and Asia–Pacific regions. Figure 16.1, which illustrates the wide range of SIDS in the Latin American and Caribbean regions, serves the purpose of describing the diversity of shapes and sizes of SIDS in any given region.

Fig. 16.1 Schematic map with an overview of Latin American and Caribbean small island developing states (© Climate Click 2012)

Most SIDS are heavily dependent on increasingly expensive imported fossil fuels to supply their basic energy needs, and are thus exposed to unpredictable price fluctuations. Oil prices have virtually doubled in many countries since the year 2000, hence putting additional pressure on the economies of SIDS. This has led to the diversions of funds, which could be better used in health care or education, towards meeting the costs of imported fuel, a situation which is unsustainable.

Despite the current dependency on imported oil, SIDS have a visible potential for renewable energy generation, especially in respect of solar and wind power, and marine renewable energy technologies. Indeed, as stated by Boyle (2004), renewable energy offers very interesting prospects to developing countries. Global trends in renewable energy as a whole and in sustainable energy investment in particular are on the increase in developing countries (Hohler et al. 2007).

A number of international gatherings have been organised and discussions of the problem have been attempted. For example, the Outcomes Pacific Energy Ministers' Meeting held in Noumea, New Caledonia, in 2011 outlined the potential in the field of renewable energy seen in the Pacific region—according to Singh (2009), only accessible provided adequate infrastructure is in place. In doing so, vulnerable SIDS such as Fiji and Tonga—which have a renewable energy road map (TERM 2010)—may be able to take better advantage of the opportunities renewable energy offers them.

The predominant situation is that these countries suffer a lack of awareness of the role they can play by using renewable energy, have very few experts working in this field and have limited availability of academic programmes in renewable energy, all of which has hindered progress in this field.

In an attempt to address the problems outlined here, the Small Developing Island Renewable Energy Knowledge and Technology Transfer Network (DIREKT) project has been initiated. DIREKT is a university-based project with an emphasis on communication, education and training, aimed at promoting the implementation of renewable energy technologies in selected African, Caribbean and Pacific (ACP) regions. The overall objective of DIREKT is to enable the partners to better exploit their renewable energy resources by means of technology and knowledge transfer, information exchange, capacity building and networking. The partners involved are universities in Germany, Fiji, Mauritius, Barbados and Trinidad and Tobago. The project is funded by the ACP Science and Technology Programme, an EU programme for cooperation between the European Union and the ACP region.

Work Package 2 of the DIREKT Project

The DIREKT project is structured along a set of work packages (WPs), one of which is concerned with the Assessment of Needs for Market-Oriented Research and Technology Transfer (WP2), the subject of this paper.

In order to achieve good and sustainable results through technology and knowledge transfer between the DIREKT partners on the subject of of renewable energy it is first essential to investigate the current situation and to explore existing structures. Therefore, a number of studies which have analysed the status of policy making and the use of renewable energy in small developing island states and which were conducted at different times in the past, have been analysed. Some examples of international studies which are thematically similar to the one presented in this paper are also provided here.

In 1999, the Caribbean Council for Science and Technology published a paper assessing the status of energy sources in the Caribbean and the potential of renewable energy in particular. It provides the outlooks of various possible future scenarios involving renewable energy and suggestions for policy making in this field. An aspect that the paper highlights is the broad spectrum of advantages that are inherent to the use of renewable energy. Accordingly, the implementation of renewable-energy technologies is not only good for meeting energy demands, but also improving resource management, environmental preservation and sustainable development. The paper emphasises the major potential for creating employment opportunities that the development of renewable energy holds. Examples given in the report are the emergence of small and medium-sized businesses in the renewable energy sector in Barbados, St Lucia and Costa Rica. Furthermore the paper stresses that these developments are, if not appropriately supported, in danger of going bankrupt in the competition between renewable and fossil energy sources (Caribbean Council for Science and Technology 1999).

The German Cooperation Agency (GIZ) published a paper in 2004 presenting the current status of renewable energy in Latin America and the Caribbean region with regard to policy making and baseline conditions in these areas. After presenting a background review of past efforts to promote renewable energy in the region, it divides the area into six subregions comprising several neighbouring countries. The subregions are analysed with regard to the current state of renewables in the region. Moreover, obstacles and opportunities for penetrating renewable energy and policy making in this field are described. The paper points out the importance of the sustainability of renewable energy production. This remark relates to the fact that the intensive use of hydroelectric power and power from biomass in some countries is practised without respect to the negative environmental and social effects it generates. Finally, the need for improved cooperation between important governmental, non-governmental and private organisations and institutions is expressed (GTZ and ECLAC 2004).

In the Pacific region, the RECIPES project, a European project promoting renewable energy in developing countries, surveyed selected island states in the region in 2004. The countries chosen to represent the Pacific region were the republics of Fiji, Vanuatu and Kiribati. Among others, the objectives were to provide data on the renewable energy situation and energy policies, and to describe renewable energy projects. The survey is in the form of a data acquisition study. Gathered information is presented in the form of tables or lists of facts with little or no analytical text. It consists of four parts. Part A contains detailed information on the status and potential of all renewable energy technologies and renewable energy policies as well as conventional energy technologies for each of the three states. Part B presents the current policies concerning energy and renewable energy. It identifies the main energy issues of the different countries and describes the present renewable energy programmes and policies as well as institutional policies. Part C contains maps of the region and the single countries. In Part D the most successful renewable energy projects and their outcomes are described in depth. The overall objective of the survey was to provide all stakeholders involved in renewable energy with information and insights and in doing so contribute to the implementation of renewable energies in the Pacific (RECIPES Project 2004).

In 2007 the Australian government organisation AusAID conducted a study involving various Pacific island states, assessing the potential of renewable energy for rural electrification in the region. Initially it gives an overview of the situation of renewable energies in the Pacific in a global context. The study report elaborates on the issues of rural electrification and fossil fuel dependency in the region. With particular regard to the problems caused by the unique geographical situation, the study analyses four rural electrification projects "in order to assess the cost-effectiveness of a particular renewable energy technology option in a rural Pacificisland setting". Using least-cost analysis and benefit-cost analysis, a solar home-systems project, a micro-hydroelectricity project, a wind hybrid system and a biofuel pilot project using coconut oil were assessed and compared to conventional energy production with a diesel generator. Based on the study results, the authors recommended that Pacific governments actively promote the implementation of renewable energies through renewable-energy policy making and renewable-energy projects (Woodruff 2007).

In 1998 the Danish Forum for Energy and Development published a general report on renewable energies on small islands in developed and developing countries, sampling the ACP regions among others. In the South Indian Ocean, Mauritius and Réunion were sampled as well as seven countries in the South Pacific and six in the Caribbean. A second, revised edition of the report was published in 2000. The report's two main objectives were to show the particularly high feasibility of renewable energy on small islands and to develop global renewable-energy cooperation and networking among islands. The report points out the major renewable-energy potential that is inherent to small islands and the fact that this potential remains mainly untapped. The examined islands are categorised according to their actions and ambitions for the use of renewable energies and an overview is given of how progress is distributed globally. The report also shows a link between whether islands have sovereign status and their level of renewable energy implementation, in that more islands with a formal connection to a developed country use renewable energies than islands that are politically independent. Another important aspect the report emphasises is the role that islands can play in fostering renewable energy use worldwide. Due to their limited size, small islands could become the first countries or communities that rely solely on renewable energies for their power generation, and thereby act as an example for the rest of the world (Jensen 2000).

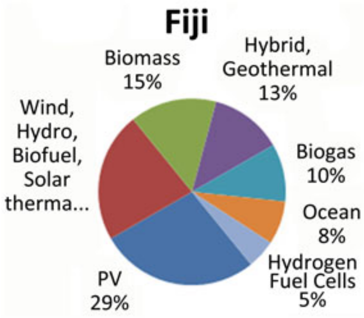


Fig. 16.2 RET preferences in Fiji

Within the framework of work package 2 (WP2) of the DIREKT project, a survey was undertaken in the partner countries. The objectives of the survey were a comparative analysis of political and institutional frameworks in the field of renewable energy in selected ACP regions, and an assessment of research and innovation needs in renewable energy science and technology. The countries sampled were Fiji, Mauritius, Barbados, St Lucia and Trinidad and Tobago. For the survey, 75 businesses, and public and private institutions involved in renewable energy were interviewed in the period from January to June 2010 (Figs. 16.2, 16.3, 16.4, 16.5).

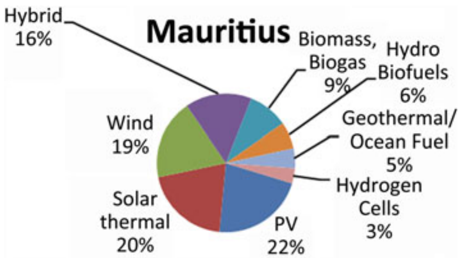


Fig. 16.3 RET preferences in Mauritius

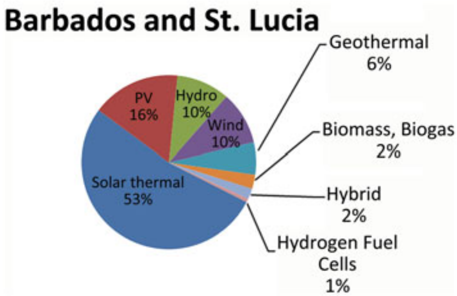
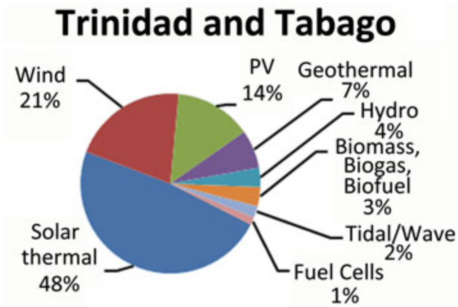


Fig. 16.4 RET preferences in Barbados

Fig. 16.5 RET preferences in Trinidad Tobago and St Lucia



Comparative Analysis of Political and Institutional Frameworks in the Field of Renewable Energy in Selected ACP Regions

Renewable Energy Policy and Institutional Framework

The survey conducted in the context of WP2 shows that all countries perceive renewable energy as an inevitable part of their future energy supply. Efforts are made on national and international levels. Policies and frameworks in the different regions are numerous; however, this paper only describes the outlines of all the efforts made.

Several international energy frameworks exist in the Caribbean region. Trinidad and Tobago, Barbados and the Organisation of Eastern Caribbean States (OECS) are engaged in the Caribbean Renewable Energy Development Programme (CREDP), which is an initiative of the Energy Ministers of the CARICOM (Caribbean Community) region. CREDP mainly strives to remove barriers to renewable energy utilisation in the Caribbean.

In the Pacific region, the Pacific Island Forum (PIF) was founded in 1971 as an umbrella company to attend to general development matters in the Pacific island countries and territories (PICTs). The PIF comprises 16 countries, including Fiji, and oversees the activities of many regional organisations. The first international energy policy was the Pacific Islands Energy Policy PIEP (2004), which was succeeded by the Framework for Action on Energy Security in the Pacific (FAESP). FAESP does not focus on the implementation of renewable energy; however, it does incorporate it [40th Pacific Islands Forum in Cairns (August 2009)].

In the EU, an energy and climate change policy was introduced in 2008. Among other things, the ambitious targets of this policy are the reduction of greenhouse gas emissions by 20 %, increasing the share of renewables in the energy consumption to 20 % and improving energy efficiency/reducing energy consumption by 20 %—all to be accomplished by 2020. These targets are elements of the "EU climate and energy package", which was adopted in June 2009. It is compulsory for EU member states to make efforts to achieve them.

On a national level, Trinidad and Tobago possesses a Ministry of Energy and Energy Industries, which pursues a national energy policy including the use of RE. Furthermore, it formed a renewable energy committee in 2009 to produce a green paper for renewable energy development.

Fiji has a national energy policy that provides support for the development, demonstration and application of renewable energy as well as rural electrification policies. It was formulated as part of the Pacific Island Energy Policy Strategic Action Plan (PIEPSAP) project, as were the national energy policies of several other PIF member countries. Recent analysis conducted by the Asian and Pacific Centre for Transfer of Technology and the United Nations Economic and Social Commission for Asia and the Pacific, has shown the potential of Fiji in this field (APCTT-UNESCAP 2010).

In Mauritius, the Ministry of Renewable Energy has a long-term energy strategy (2009–2025) and action plan dated October 2009 to develop renewable energy, reduce dependence on imported fuel and promote energy efficiency, in line with the vision of Maurice Ile Durable (MID), to promote sustainable development. Its Central Electricity Board enacted the Utility Regulatory Act in 2008 to ensure utilities run more efficiently.

In Germany, extensive measures are being taken to make renewable energy a main component of energy generation. Important measures worth mentioning are:

- The Renewable Energy Sources Act (EEG), which took effect in 2004 and was revised in 2009. The EEG contributes to increasing the percentage of renewable energy sources in the power supply to at least 20 % by 2020.
- The Federal Market Incentive Programme designed to promote renewable energy.
- The Renewable Energies Heat Act (EEWärmeG), which obligates owners of new houses to meet a share of the house's heating demands with RE.
- The National Biomass Action Plan for Germany, which aims to significantly increase the percentage of bioenergy sources in the power supply.

Compared to the international/national efforts made in the ACP regions, the goals aspired to by the EU/Germany are rather ambitious. However, this has to be put into perspective relative to the availability of expertise and technology available in each region. Moreover, this is an indication of the strong potential for beneficial knowledge and technology transfer within the DIREKT network.

Assessment of Research and Innovation Needs in Renewable-Energy Science and Technology

A questionnaire was created to analyse research and innovation needs in renewable energy science and technology. It was submitted to 75 businesses and public and private institutions involved in renewable energy in the surveyed countries,and comprised the following three main aspects:

1. General information about the organisation
2. The organisation's research and innovation needs
3. The organisation's staff and training needs

Table 16.1 shows the distribution of all businesses that participated according to country.

The ratio between the different countries does not directly reflect the ratio between the numbers of organisations involved in renewable energy in those countries because the survey was also dependent on potential participants' the willingness to partake in it.

General Information About the Organisations

Size of the Organisations

As can be seen in Table 16.2, the sizes of the surveyed organisations differ widely.

However, it becomes apparent that ACP businesses and institutions in the renewable energy sector are typically small or medium-sized. Furthermore, it is important to differentiate between organisations that are active solely in the field of renewable energy (e.g. renewable energy service, repair and maintenance businesses) and those that offer renewable energy services as only one of several aspects of their business (e.g. utilities or NGOs for which renewable energy makes up only a small part of their activities).

Table 16.3 provides information about how many employees of the companies in the various locations worked directly with RE.

Table 16.1 Number of organisations surveyed in the different countries

Country/Island	Mauritius	Fiji	Trinidad and Tobago	Barbados and St Lucia
Number	33	20	13	9

Table 16.2 Number of employees in the organisations surveyed

Fiji	16 of the 20 organisations had between zero and 20 employees. One employer in Fiji had $\sim$100 employees
Trinidad and Tobago	Business organisations varied considerably in size, ranging from six to about 700 people. However, the number of people in these organisations directly involved in renewable energy ranged from zero to 80
Barbados and St Lucia	Business organisations varied considerably in size, ranging from four to about 130 people. However, the number of those people directly involved in renewable energy ranged only from zero to 20
Mauritius	Business organisations varied considerably in size, ranging from two to 241. There are two parastatal bodies that employ between 1,500 and 1,800 people

Table 16.3 Percentage ratios of employees engaged in renewable energy in the organisations surveyed in the different countries

Country/Island	Percentage/Range
Fiji	0–100 %
Mauritius	Most had about 30 %
Trinidad and Tobago	0–53 %
Barbados and St Lucia	0–71 %

The results show that companies usually offer renewable energy as one part of their services. Organisations active solely in renewable energy are the exception rather than the rule. This demonstrates that renewable energy technology has not yet become profitable to a desirable extent and is not considered sufficiently profitable for specialisation in the ACP region. However, it is also possible that only companies which have the knowledge required to work in the field of renewable energy are now gradually embracing the renewable energy market.

Generally, the percentage of female staff entrusted with renewable energy tasks was relatively low, roughly amounting to 20 %.

For Trinidad and Tobago, Barbados and St Lucia enough data was available to make a statement about the distribution of employees within the renewable energy sector. Solar-thermal technology, mainly solar water heating (70 %), is the major renewable energy application in those regions, followed by electricity generation through photovoltaics (20 %) and hydropower, wind, biomass, biofuels and fuel cells (10 %).

Types of Renewable Energy of Interest to These Businesses and Institutions

The graphs below show the percentage ratios of the different renewable energy technologies (RETs) in Fiji, Mauritius, Barbados, St Lucia and Trinidad and Tobago.

Photovoltaic, wind and solar thermal energy were the most utilised types of renewable energy in all regions. Pther than this, the trends in the regions differ: Fiji has hydro and biomass as the next two categories. Hydro is the 4th most important in Barbados and St Lucia, the 6th most important in Trinidad and Tobago, and the 6th most important in Mauritius. Also, biofuels are much more important in Fiji than in Mauritius, Trinidad and Tobago, Barbados and St Lucia.

Some of the aspects that might be responsible for this distribution pattern are:

- That electricity generation through photovoltaics and wind does not require much more than basic skills in electric installations because the sunlight and the wind are directly converted into electric potential (voltage) that is ready for consumption.

- Energy production through biomass is very simple (e.g. burning wood for heat), but is always limited to the biomass resources of the region. Fermenting biomass to create gas, on the other hand, requires some education in that field.

Finally, hydro power generation is, in its complexity, comparable to power generation through photovoltaics or wind, but is always limited to the potential of that source of energy that is inherent to the region.

Types of Organisations

The organisations with an interest in renewable energy cover all types of organisations that appeared in the questionnaire. Figure 16.6 illustrates their distribution in the ACP regions included in the survey.

As can clearly be seen in Fig. 16.6, business forms in the field of service, repair and maintenance for renewable energy technology play a key role in all ACP regions. Service, repair and maintenance is the most represented industry in Fiji (60 %), Barbados and St Lucia (50 %) and Trinidad and Tobago (35 %), but is less represented in Mauritius (23 %).

These business forms are followed by education and training, aid and development facilities and governmental organisations in all regions except Fiji. The regional and international organisations come second in Fiji (55 %), but are fourth in Barbados and St Lucia. In Trinidad and Tobago they are an absolute minority and in Mauritius they are completely non-existent. Presumably, these differences partly reflect the geographical circumstances of the different regions. The South Pacific region consists of more than a dozen Pacific island states overseen by the Pacific Island Forum, of which Fiji is a member. Likewise, Barbados and St Lucia are members of a multi-island international area, as is Trinidad and Tobago. Mauritius, on the other hand, is a "stand-alone" country.

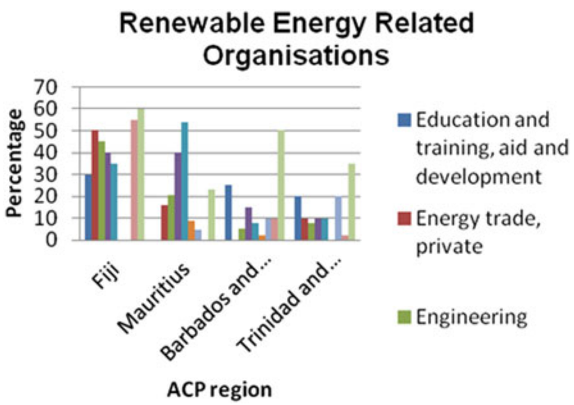


Fig. 16.6 Types of renewable energy related organisations surveyed in the different countries

Research and Innovation Needs

Existing Renewable Energy Abilities Within Organisations

The organisations were surveyed for their abilities in the following categories:

- Producing new renewable energy products
- Carrying out resource assessments
- Obtaining resource data from established sources
- Evaluating the economics of RETs
- Managing renewable energy projects
- Writing funding proposals

The majority listed their performance in these categories as excellent, good or satisfactory. Altogether the performance ratings for Mauritius were slightly lower.

Knowledge of Government Incentive Schemes

The results of the survey indicate that government incentive schemes are well known in most organisations. Particularly in the Caribbean region, information about government incentive schemes was well distributed: 80 % of the organisations surveyed in Barbados and St Lucia and 100 % in Trinidad and Tobago are aware of them.

Information Services, Provided by Tertiary Education Institutions, of Value to Organisations

Tertiary education institutions provide various services in the field of renewable energy such as research and development, renewable energy resource assessment, seminars and workshops, training in project management and design, and RET installation. The services tertiary education institutions provide to businesses and organisations include joint research, consultancy, monitoring and evaluation of renewable energy projects, networking with businesses, and database services for RE.

Organisations in Fiji, Barbados, St Lucia and Trinidad and Tobago—but not Mauritius—listed these in the same order of importance. Research and development for instance was viewed as the most important service in Fiji, Barbados, St Lucia and Trinidad and Tobago, but not in Mauritius. Consultancy on the other hand was second in Mauritius but of lower priority in the other countries. These are shown in Table 16.4.

Furthermore, monitoring and evaluation of renewable energy projects was viewed as an important service (first in Mauritius and second in the other countries).

The questionnaire distributed for this study also enquired about market-oriented services that tertiary education institutions could provide in the organisations' opinion. Table 16.5 shows those services most frequently named by the institutions in the different regions.

Staff Training Needs in Business Organisations

Types of Renewable Energy Knowledge Staff Already Have

Based on the answers to this question, it can be deduced that the staff's degree of knowledge and the management's notion of what is needed vary. The major conclusions are as follows:

1. Most said their managers had general awareness of renewable energy.
2. Staff generally lacked academic training in renewable energy.
3. Managers generally had adequate abilities in renewable energy management.
4. In all countries surveyed, organisations said their finance staff lacked academic training in renewable energy finance.

Table 16.4 Shows the need for services offered by tertiary institutions in detail

Preference	Fiji	Mauritius	Barbados and St Lucia	Trinidad and Tobago
1st	Joint research and development, consultancy and advisory services (45 %)	Monitoring and evaluation of projects (36 %)	Joint research and development (30 %)	Joint research and development (25 %)
2nd	Monitoring and evaluation of projects and database services (40 %)	Consultancy (32 %)	Monitoring and evaluation of projects (25 %)	Monitoring and evaluation of projects (20 %)
3rd	Networking with business or research partners (35 %)	Joint research and development (28 %)	Database services (25 %)	Networking with businesses (15 %)
4th		Networking, database services (20 %)	Consultancy (25 %)	Consultancy (12 %)
5th		Database services (20 %)	Networking with business (20 %)	

Table 16.5 Market-oriented services that tertiary institutions could provide

Fiji	Mauritius	Barbados and St Lucia	Trinidad and Tobago
Reports on suitability of renewable energy projects in areas of the Pacific	Training in construction and installation of renewable energy products	Training in different types of renewable energy technologies for staff	Training and capacity building for all categories of workers, especially technicians
R&D training	Funding information	R&D training	R&D training
Feasibility studies	Partnerships with private companies	Feasibility studies	Consultancy services
Energy audits	Energy audits	Energy audits	Energy audits
Monitoring and evaluation of renewable energy and energy efficiency projects		Funding information and consultancy services	Partnerships with private companies

5. Staff had previous work experience in renewable energy.
6. Staff had acquired knowledge and skills through on-the-job training

The high percentage of staff lacking academic knowledge in RE is surprising. Figure 16.7 shows the deficit in academic knowledge for each country.

Types of Training Required by Staff in Business Organisations

- In Fiji, renewable energy awareness was mostly required by clerks/sales people (50 %), followed by finance and middle managers (45 %). In Mauritius, 10 % of all staff require renewable energy awareness training. In Barbados and St Lucia and in Trinidad and Tobago, it was felt that most staff in all categories could benefit from further training in renewable energy awareness.
- In Fiji, academic training in management and finance was required by finance and middle managers (60 %), managers (40 %) and clerks/sales people (25 %). In Mauritius, it was most important for finance and middle managers (30 %) and clerks (20 %). Further academic training in management and finance was considered valuable by all organisations in Trinidad and Tobago and in Barbados and St Lucia.
- Essentially all categories in Fiji, Trinidad and Tobago, Barbados and St Lucia required academic training in renewable energy science and technology (all staff categories above 30 %). In Mauritius, this was most important for finance and middle managers (35 %), managers (25 %) and clerks/sales persons (25 %).

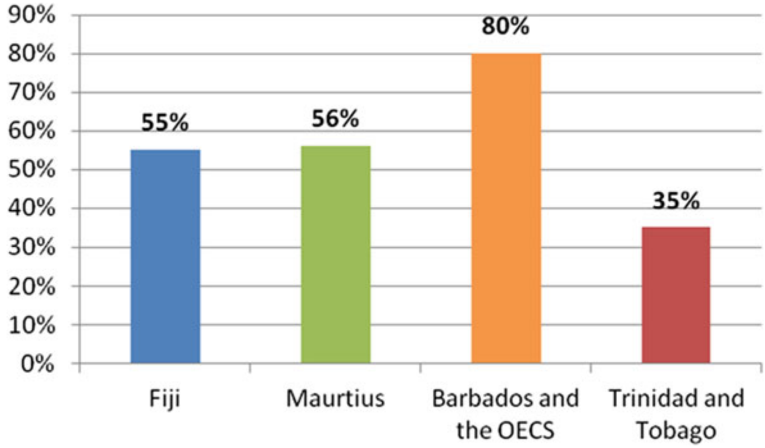


Fig. 16.7 The percentage of staff lacking academic training in RE

What Type of Training is Most Appropriate for Staff?

Generally, the most applicable training for staff was considered to be learning on the job or through in-house training. In Fiji 50 % view learning on the job as important, whilst 60 % viewed in-house training as important too. In Mauritius 56 % said in-house training was important. In Barbados and St Lucia, the need for training in practical skills such as installation and sizing was emphasised. In Trinidad and Tobago the organisations expressed the need for training in design and in research and development abilities (about 70 % of organisations), as well as for better understanding of renewable energy policies (about 30 % of organisations).

In all the tertiary institutions surveyed in Barbados, St Lucia and Trinidad and Tobago, the need for more staff in renewable energy across a wide range of renewable energy technologies and capabilities (such as wind, solar, ocean, geothermal, hydro, biofuels, and energy management and efficiency) was emphasised.

Conclusions

The survey showed the existence of similarities and differences between Fiji, Mauritius, Barbados, St Lucia and Trinidad and Tobago. As mentioned earlier in the paper, this is probably partly due to the level of complexity that is inherent to the different RETs. But a lack of appropriate technology transfer may also be a reason.

When comparing Fiji, Trinidad and Tobago, Barbados and St Lucia on the one hand and Mauritius on the other, one key difference lies in the geographical circumstances and their implications. Fiji is one of the island countries in the South

Pacific region, and thus enjoys the presence of various international bodies and NGOs, many aid and development-related. The same applies to Barbados, St Lucia and Trinidad and Tobagoin a Caribbean context. Mauritius on the other hand does not appear to belong to any such groups.

Even though Trinidad and Tobago is the most industrialised of all surveyed ACP countries, this fact does not seem to make a big difference in terms of the utilisation and development of RE. This is presumably due to Trinidad and Tobago's acute awareness that their oil resources are finite and the considerable emphasis they therefore place on the development of renewable energy technologies.

All in all,the survey conducted in WP2 shows that all the DIREKT countries perceive renewable energy to be an inevitable part of their future energy supply. It is now crucial that these efforts are duly supported by means of appropriate knowledge and technology transfer. Best practices are shown so that the degree of preparedness to engage in further actions in this field may be increased.

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Chapter 17
Strategies Developed by DIREKT for the Small Island Developing States to Enhance Renewable Energy Utilisation

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Abstract Given the current global situation of scarce energy resources, rapidly rising fossil-fuel prices and drastic climate changes, it is recognised that the promotion and application of Renewable Energy (RE) and Energy Efficient (EE) technologies is of vital importance for sustainable socioeconomic development in the Small Island Developing States (SIDS). The DIREKT network (Small Developing Island Renewable Energy Knowledge and Technology Transfer) is a teamwork scheme that involves the participation and collaboration of various universities from Germany, Fiji, Mauritius, Barbados and Trinidad and Tobago. The aim of the DIREKT project is to reinforce science and technology competency in the domain of renewable energy through technology transfer, information exchange and networking, targeting ACP (Africa, Caribbean, Pacific) SIDS as they are more vulnerable to problems associated with climate change. The overall objectives of the DIREKT project consist, basically, of enhancing sustainable

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Climate Change Management, DOI: 10.1007/978-3-642-37753-2_17,

collaboration between the participant countries and the EU, and transferring research results on the key topic of renewable energies, by putting into operation "technology transfer centres" in the participant countries. To help in achieving these aims, the partners of the DIREKT project have set up short-term, medium-term and long-term strategies to be applied to SIDS.

Keywords Strategy · Small island developing states

Short Introduction

This paper presents the strategies developed by DIREKT for the Small Island Developing States (SIDS) to enhance renewable energy utilisation. The DIREKT network (Small Developing Island Renewable Energy Knowledge and Technology Transfer) is a teamwork scheme that involves the participation and collaboration of various universities from Germany, Fiji, Mauritius, Barbados and Trinidad and Tobago. The overall objectives of the DIREKT project consist, basically, of enhancing sustainable collaboration between the participant countries and the EU, and transferring research results on the key topic of renewable energies, by putting into operation "technology transfer centres" in the participant countries.

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Introduction

The DIREKT network (Small Developing Island Renewable Energy Knowledge and Technology Transfer) is a teamwork scheme that involves the participation and collaboration of various universities from Germany, Fiji, Mauritius, Barbados and Trinidad and Tobago. It is a three-year project begun in 2010 and expected to end in 2012. During these three years, the aim of the DIREKT project is to reinforce science and technology competency in the domain of renewable energy through technology transfer, information exchange and networking, targeting ACP (Africa, Caribbean, Pacific) Small Island Developing States, as they are more vulnerable to problems associated with climate change. The overall objectives of the DIREKT project consist, basically, of enhancing sustainable collaboration between the participant countries and the EU, and transferring research results on the key topic of renewable energies, by putting into operation "technology transfer centres" in the participant countries. Finally, the specific objective of DIREKT is to establish a long-term EU-ACP Small Island Developing States science and technology network. To help in achieving the set aims and objectives, the ACP Science and Technology Programme, which is an EU programme for cooperation between the European Union and ACP region (Africa, Caribbean, Pacific), is funding the project.

Given the current global situation of scarce energy resources, rapidly rising fossil-fuel prices and the potential exacerbation of these problems by climate change, it is recognised that the promotion and application of Renewable Energy (RE) and Energy Efficient (EE) technologies is of vital importance for sustainable socioeconomic development in the Small Island Developing States that constitute the Caribbean. Taking all these problems into consideration, the DIREKT team has developed a strategic plan for short-term and long-term applications.

Strategy

Strategy refers to a plan of action designed to determine basic objectives and the allocation of resources towards the accomplishment of these objectives. It determines the direction in which a set project needs to move to fulfil its mission. A strategic plan acts as a road map for carrying out the strategy and achieving long-term results, that is, its end vision.

Strategic planning implies short-term to longer-term planning, which is allied to the institution or project's vision, values and goals. Short-term planning normally looks at projected goals over at least a three to six-month period. Medium-term planning is probably a year to eighteen months. Long-term planning would look at a very long-term goal—say over five or ten years. Thus, to ensure all the goals and objectives set by the DIREKT project are achieved within the three-year time frame, each partner involved in the DIREKT scheme has come up with a *strategic plan consisting of short, medium and long-term strategies to be implemented in their respective countries. This paper provides a summary of the strategic plans of the partner countries.*

The general goal of the technology transfer strategy is to stimulate greater awareness of the potential of renewable energy by demonstrating to the public the available RE technologies, and providing training in such technologies. It is anticipated that, with this exposure, knowledge and increased capacity, individuals will be motivated to engage in innovative technologies that have the potential to unfold new economic development opportunities and promote a clean environment and a sustainable future.

Barbados's Strategy

The specific objectives of the Barbadian team consist of setting up a technology transfer centre that will act as a hub for the dissemination of RE material and RE technologies to the wider community. This will be done primarily through a "Renewable Energy Demonstration Facility", which in the first instance will be a pilot project at the University of the West Indies. Further objectives are: to promote the use of RE technology by providing awareness and training in RE technologies through workshops, seminars and networking events; to strengthen the capacity of research staff by providing them with the necessary knowledge and resources; to provide closer links between research institutions and the public sector in order to better cater for the needs of the market; and to enhance the capacity of businesses to use renewable energy and to develop new and innovative RE products.

Main Activities

Aprincipal activity required in order to execute this strategy is training, capacity development and the dissemination of public awareness materials through workshops, short courses, seminars and networking events. Training will be provided to administrative staff, businesses and research staff, with an emphasis on gender balance, in the following technological areas:

- the application of photovoltaic technology
- the maintenance of photovoltaic systems
- geothermal and wind technology
- writing grant and project proposals for RE projects

There will also be networking events to disseminate information about the DIREKT project and available RE technologies. A second principal activity required to execute the strategy is a technology transfer centre, which will be run as a pilot project at the University of the West Indies entitled the "Renewable

Energy Demonstration Facility”. The mission of the Renewable Energy Demonstration Facility will be to transfer innovative knowledge on renewable energy technologies to the University community, schools and wider society, including the business sector and policymakers.

The renewable energy technologies to be displayed, tested and compared will initially be: a fixed solar photovoltaic system, a single-axis tracking photovoltaic system, a vertical axis wind turbine, and simpler renewable energy technologies such as solar cookers and dryers, stills, solar water heaters, and solar mobile generators. A major focus in terms of display will be models to demonstrate the potential of marine power technologies, given the significant role they could play in the future Caribbean energy profile. These would include sea_water air conditioning, wave power (onshore and offshore), and ocean thermal energy conversion (OTEC).

Fiji’s Strategy

A strategy that provides solutions to these problems while contributing to the socio-economic development of the region consists of facilitating the training of businesses and decisionmakers through short courses/workshops, and engaging both research institutes and businesses in a project that identifies potential RE resources for remote rural communities; a learning opportunity should also be provided to businesses by demonstrating to them how the appropriate Renewable Energy Technologies (RETs) are designed using readily available software.

Apart from producing the intended outcomes, such an interactive project will have hidden benefits. An important example is the opportunity to demonstrate to businesses and decision makers the resources and the capacity available within the region (and especially within the research institutes) to carry out feasibility studies and to develop RET design models.

Main Activities

The key elements of the overall strategy consist of establishing a research and technology transfer centre, strengthening the link between research institutions and the RE-related market in the Pacific, combining the capacity building of the RE business sector with the socio-economic development of the region, and using a pilot project to demonstrate the efficacy of the chosen strategy.

These projects will require ongoing data collection and analysis, and the installation of RETs. To ensure the sustainability of these projects, there is a need for skilled local expertise (within both the government and private sectors). Businesses need a range of expertise (from how to install masts and equipment to predicting wind-energy regimes in selected regions using appropriate software).

The Fiji partner is already working closely with a number of regional energy agencies in the Pacific. These relations will be further enhanced, in keeping with the "many partners, one team" motto adopted by the framework partners.

An implementation plan that provides for all requirements has been suggested as follows:

(a) *A research and technology transfer centre*

This will be a virtual centre, and will consist of a physical office (with the appropriate communications and data-storage capacity) from where all the research and technology-transfer actions of this project will be coordinated. It will be an information hub which businesses, NGOs, other government and private sector organisations, as well as research institutes, can access for information on all RE activities in the region. It will store information on the plans and activities of the DIREKT project's Fijian partner in the Pacific region. A website, linked to the parent DIREKT website maintained by the lead partners in Hamburg, will be created to provide an effective communication instrument and to assist in the visibility of the actions of DIREKT's Pacific network.

(b) *Capacity building for businesses and decisionmakers*

This goal will be best achieved via a two-day workshop which will include regional research institutions as active partners in the organisation and conducting of the activities, provide capacity building through a series of seminars, combined with hands-on learning opportunities and local field trips, and endeavour to involve other regional energy agencies through co-financing.

(c) *Pilot project*

The Pilot Project will act as a "proof of concept" for the R&TT Strategy. It will combine the capacity building of the RE business sector with the socio-economic development of the region, and will also involve regional research institutions in its actual action plan. The elements of this Pilot Project are outlined in a separate document.

Mauritius's Strategy

The strategy developed by the Department of Chemical and Environmental Engineering at the University of Mauritius is the roadmap for Mauritius to address the energy and environmental challenges lying ahead, which depends on innovation through science-driven development of new technologies. This plan renews and extends the commitment of our island to the environment, both resolving and supporting a future using cleaner energy.

Main Activities

Therefore, the main objectives of the department are:

- to promote more efficient use of energy and increase the use of renewable energy;
- to embark on projects to explore and harness all potential for local sources of renewable energy and to reduce dependency on imported fossil fuels;
- to support programmes to reduce the consumption of fossil fuels, achieve greater efficiency in the use of energy in enterprises, offices, homes, the public sector, the transportation sector and in hotels;
- to support programmes for research and analysis pertaining to the development of renewable sources of energy and consumption trends, and to ensure environmental sustainability;
- to embark on energy-management programmes through networking with local and international partners;
- to create awareness campaigns on energy saving and the use of renewable energy sources.

Moreover, to propagate the notion and implementation of renewable energies throughout the island, the university will target the following:

- the availability, security and diversity of supply, with particular focus on renewable energy;
- affordability, with a view to ensuring socio-economic development of the country, taking into account the financial sustainability of the utility;
- energy efficiency and conservation, given the high volatility of the price of fossil fuels, in particular oil;
- targets for efficiency in the electricity sector;
- the introduction of sustainable energy topics in all programmes at tertiary level;
- the running of programmes as a permanent activity to create awareness of the benefits of energy efficiency, renewable energy and sustainable living, including information on incentives/deterrents and rights/obligations for consumers.

However, the development of a sustainable energy economy affects people's way of life, so it is important to develop not only a broad appreciation of sustainable energy and the resulting environmental benefits, but also to transfer expertise and skills, including practical engineering skills in areas such as energy efficiency and renewable-energy technologies. Thus, relevant educational materials on sustainable energy will be developed by the department, and the transfer of expertise will be achieved through:

- knowledge creation to boost pure and applied research and the development and building of a platform for innovative ideas;

- knowledge diffusion by promoting emerging sectors, inculcating industrial skills, promoting life-long learning and continuous professional development, and promoting innovative e-learning systems;
- investing in resources by recruiting, retaining and rewarding quality people, ensuring sustainable professional development for staff, enhancing provision for modern high technologies, developing and optimising infrastructure and equipment, exploring sources of funding through national, regional and international collaboration, and strengthening its networking role nationally and internationally;
- community outreach by assisting communities in developing, monitoring and enhancing renewable energies and by promoting civic engagement.

Trinidad and Tobago's Strategy

Trinidad and Tobago is the most industrialised of the Caribbean Community (CARICOM) countries and its energy requirements are among the highest in the region. One current challenge is that, due to an increasing population size and industrialisation, Trinidad and Tobago's energy needs are increasing. The government of Trinidad and Tobago has expressed a commitment to the development of an energy policy that includes renewable energy.

National Renewable Energy Strategies will have to be developed to meet the objectives of an Energy Mix Policy, as outlined in the Framework for Development of a Renewable Energy Policy for Trinidad and Tobago. To be effective, these strategies must clearly be developed as a step-wise process, and must also be implemented within the broader framework of carbon reduction strategies, consistent with the draft National Climate Change Policy that is presently being developed in the context of the global objective of reducing emissions of greenhouse gases, as outlined in the Kyoto Protocol, of which Trinidad and Tobago is a signatory.

Main Activities

In its budget of 2010–2011, the government of Trinidad and Tobago introduced tax measures to support opportunities for small-scale, low-cost applications of renewable energy in residential, commercial and other institutional sectors. To maximise the effectiveness of energy use, appropriate measures for energy efficiency and conservation must also be undertaken. It is expected that this knowledge will have a significant impact on capacity building, awareness creation, public outreach, and market growth and expansion in renewable energy in Trinidad and Tobago.

Medium and long-term strategies identified by the government of Trinidad and Tobago are:

- carbon reduction;
- mass transportation;

- green buildings;
- education through capacity building and awareness creation;
- research and development;
- the creation of an enabling environment;
- energy efficiency and conservation;
- appropriate institutional arrangements.

The Trinidad component of the DIREKT project will effectively contribute to the development of the renewable-energy sector in Trinidad and Tobago in a manner that is entirely consistent with the regional and national strategies for renewable energy. The first is the organisation and delivery of seminars designed to increase public awareness of renewable energy technologies, and to provide training and capacity development in RE. The second is the establishment of a technology transfer centre, which will essentially be a database and e-platform, which can bring together information relevant to RE technologies and facilitate the interaction of RE stakeholders, e.g. researchers, businesses, students and the general public. The third is the pilot project proposed for the Trinidad component of the DIREKT project—essentially the establishment, operation and display of a renewable energy powered laboratory at the University of the West Indies.

Germany's Strategy

The long-term goal of the Research and Transfer Centre—"Application of Life Sciences" (RTC-ALS) is to be the leading renewable energy technology transfer centre for developing countries in northern Germany, and to become well-known internationally. The RTC-ALS will make use of its strengths to promote the centre, and will not focus on engineering solutions for energy-related topics. Consequently, the general direction of the RTC-ALS should be to strategically make use of its strengths to take advantage of opportunities. Besides this general approach, weaknesses as regards in-depth knowledge of circumstances within developing countries should be dealt with on an appropriate timescale. The general direction will take advantage of a multidisciplinary approach, by combining inputs from various partners on a national and international level. Furthermore, all results will be specifically published for the various target groups to make sure that the RTC-ALS will become a widely known partner.

Main Activities

To reach this overall goal, various sub-goals were created with different timelines, which involved the following activities:

- as the leading renewable energy technology transfer centre for developing countries in northern Germany, to determine indicators for goal achievement;

- establishing a second pillar, next to the RE research topic, which might be of additional use (e.g. capacity building for energy-related jobs) and establishing contacts/access to networks;
- publishing articles related to RE in developing countries on a national and international level;
- promoting cooperation with partners in developing countries for knowledge-oriented proposal writing;
- support for orientation of local actors;
- application-oriented proposals;
- establishing contact with national and international organisations present in developing countries;
- observing the national development of the RE activities of other organisations (HEIs, NGOs, foundations) to find out who is active in the field of RE transfer/projects in developing countries;
- positioning and marketing of RTC within the HAW (Hamburg University of Applied Sciences) and adjoining events/publications;
- settingup the concept of the technology transfer hub (according to the DIREKT proposal) and its implementation plans.

Conclusion

With the development of a strategic plan by each partner involved in the DIREKT project, it is certain that the specific aims and objectives set up for the promotion of renewable energies in developing countries will be met, and that the same principle can be extended for other developing countries to enjoy a safe and clean future.

Acknowledgments We would like to express our thanks to all the partners of the DIREKT team for providing information on their strategic plans.

Chapter 18
Past and Present Green Economy Initiatives and Capacity Building and Financial Mechanisms for the Future Development of the Barbados Energy Sector

Tom Rogers and Ksenia Chmutina

Abstract As with most Small Island Developing States (SIDS), imported fossil fuels make up the majority of Barbados' primary energy requirements, including electricity generation. As well as using up valuable foreign exchange, this import bill makes the island highly vulnerable to the ever more volatile international energy market. Sustainable development has long been present in the island's ideological mindset and in 2010 the government of Barbados signalled its commitment towards becoming "the most environmentally advanced green country in Latin America and the Caribbean". This paper first describes the island's present fossilfuel-dominated energy sector, as well as past and present green economy-related initiatives. It then discusses two key areas of energy sector reform necessary to promote sustainable development: capacity building and finance, highlighting the role that innovative financing mechanisms could play in decreasing the country's reliance on fossil fuel imports.

Keywords Small island developing states · Green economy · Renewable energy · Financing mechanisms

Short Introduction

Import of fossil fuels makes Barbados, as many other countries in Latin America and the Caribbean, highly vulnerable when fulfilling its energy requirements. In order to mitigate its reliance on fossilfuel imports, this paper first describes the

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_18,

island's present fossil fuel-dominated energy sector, as well as past and present green economy-related initiatives. Further on, it discusses two key areas of energy sector reform necessary to promote sustainable development: capacity building and finance, highlighting the role that innovative financing mechanisms could play in decreasing the country's reliance on fossil fuel imports.

Introduction

Imported fossil fuels (~9,000 barrels/day) cover most of Barbados' primary energy requirements, including electricity generation. This import bill makes the island highly sensitive to the volatile international energy market (Fig. 18.1). In 2010 imported oil for electricity generation cost the country some US $300 million (7.5 % of GDP). With few possibilities of expanding its own limited production of fossil fuels (the Barbados National Oil Company extracts ~1000 barrels/day), the most effective method of increasing energy security is to:

1. contain demand growth by increasing energy efficiency, and
2. expand production from alternative energy sources (Green Economy Scoping Study 2012).

Although much progress is now being made, neither of these two areas has an established policy/regulatory framework for the promotion of public or private investments (Sustainable Energy Framework for Barbados 2012).

The share of renewable energies in total primary energy supply has remained constant at slightly over 7 % over the last decade (Schlegelmilch 2009). The

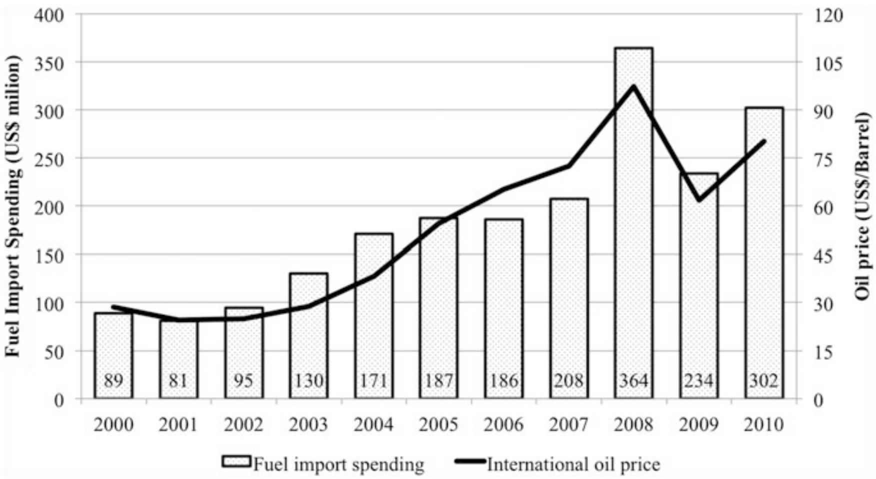

Fig. 18.1 Fuel import spending for electricity generation (ministry of finance and economic affairs)

sources of renewable energy in the primary energy mix originate mainly from the use of solar water heaters and bagasse cogeneration during the sugarcane-harvesting period (approximately 50:50 share between the two). The electricity generated from bagasse cogeneration is all used in the sugar refining process/ factories and there is currently no utility-scale renewable energy on the island. However, a 10 MW wind farm has been held at the planning stage for over six years with installation now expected by 2014. There are also plans for a 13.5 MW waste-to-energy plant, and a 17.5 MW biomass cogeneration plant.

The two largest consumers by far of the fuel imported onto the island, are electricity generation (50 %) and transport (33 %). Of the total electrical energy generated in 2010 (1,036 GWh), domestic consumption was the major user at 31 % (see Fig. 18.2). The commercial sector was the second largest consumer at 22 %. Tourism, which includes hotels and numerous tourist attractions, was a close third at 17 %. In addition, a notable user of electricity is the water sector, with most potable and irrigation water being either pumped from aquifers or via a 30,000 m^3/day reverse osmosis desalination plant. Barbados is classed as a water-scarce island due to it being a relatively flat island with few rivers, thanks to it consisting of predominantly permeable coral limestone.

Figure 18.3 shows that there has been a steady increase in electricity generation in recent years, with an average annual increase of 2.7 % over the last 11 years. However, the electricity consumption per customer (commercial and residential) peaked in 2007 and has been slowly decreasing since. When consumption is broken down between commercial and domestic customers (see Fig. 18.4). It is clear that the commercial customers are the main cause of this decrease. A steep increase in domestic electricity consumption was seen up until around 2005, since then consumption per customer has levelled. This levelling off coincides with the

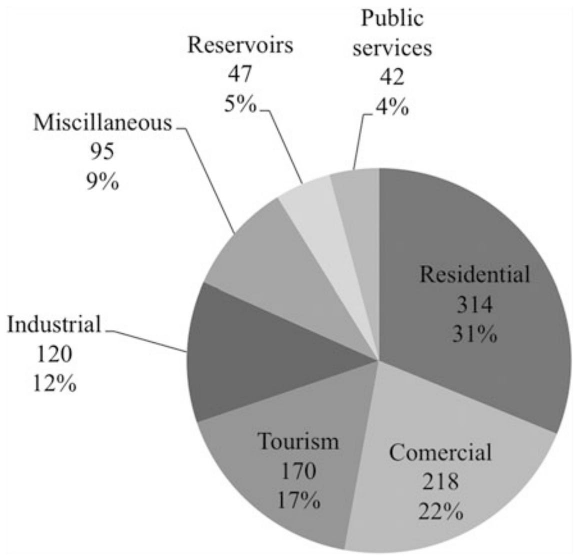

Fig. 18.2 Electricity consumption by sector for 2010 (GWh)

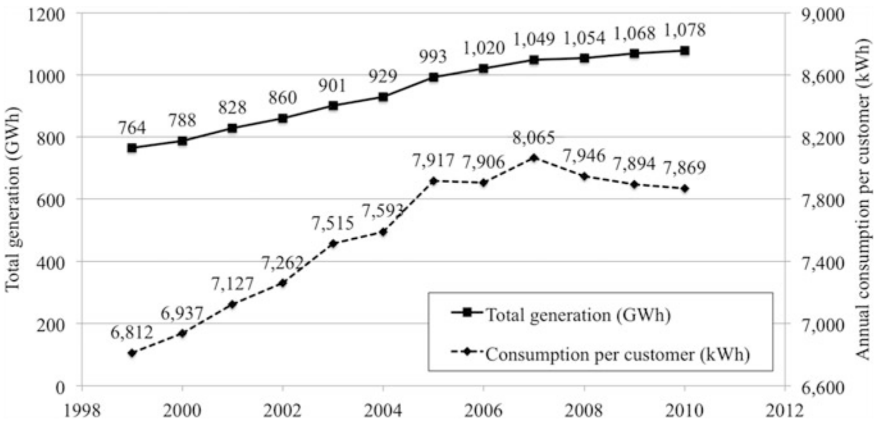

Fig. 18.3 Electricity generation and consumption per customer (BL&P 2010)

increase in energy prices, which occurred at the same time. The number of customers has increased by 19 % since 1999 levels.

Electricity generation on the island is by Barbados Light & Power (BL&P). Most of the generators they use for producing the islands electricity are diesel-electric units that run on heavy fuel oil. Some gas turbines are kept in reserve for peak loads and emergencies. Total installed capacity for the island is 240 MW whilst the peak load for 2010 was 168 MW.

Green Economy

The transition of Barbados towards a green economy was first proposed in the 2007 Statement of Economic and Financial Polices (Arthur 2007). The Statement describes the green economy:

> The practice of green economics recognises that because everything on earth is connected, synergies and linkages can be created within and between sectors often with resulting substantial increases in efficiency and productivity.

Past and present green economy initiatives for Barbados are described in the following sections.

Past Green Economy Initiatives

With the exception of the widely acknowledged success of the Barbados solar hot water heating industry (Headley 1998), which originated and grew from the 1970s global energy crisis, green economy related initiatives in Barbados are mainly

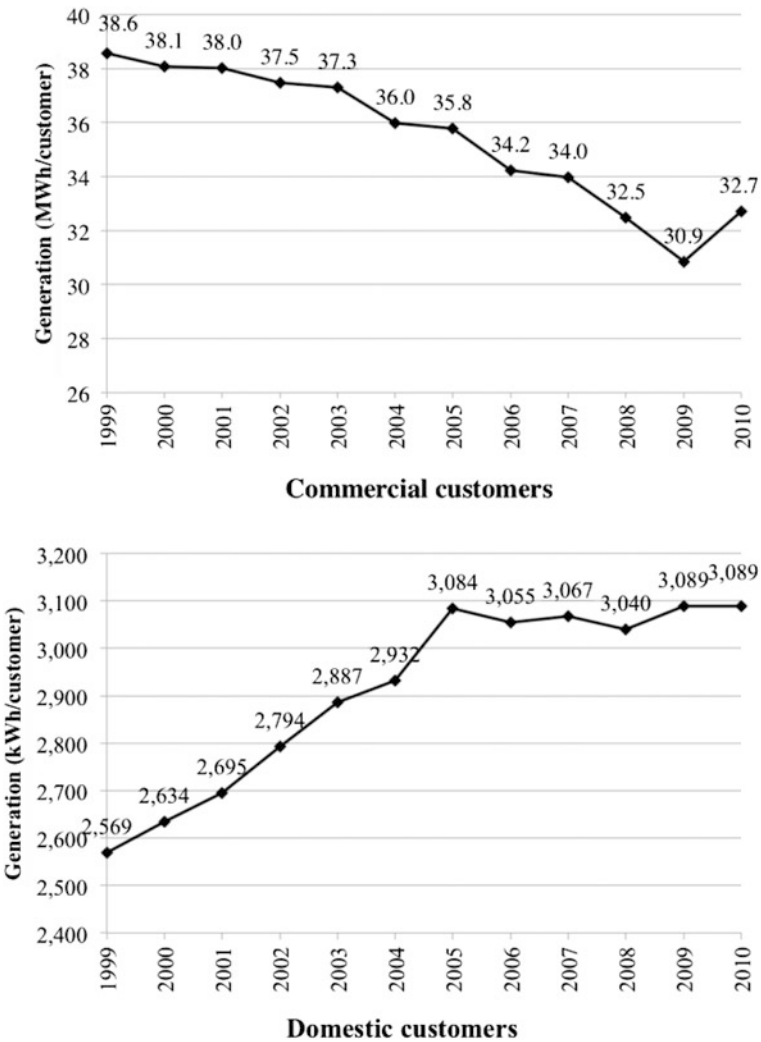

Fig. 18.4 Electricity consumption for commercial and domestic customers [4]

confined to recent history. The National Sustainable Development Policy (NSD Policy) was published in 2004 with the aim of providing a clear outline as to what would be required in order to make the island more sustainable (Barbados Sustainable development Policy 2004). The policy is targeted at all persons, corporations and decision-makers. Its recommendations to the energy sector focus on energy conservation, as well as the promotion of alternative renewable energy sources, in particular: support for Independent Power Producers (IPPs); the articulation of standards for energy efficient technologies; the encouragement of utility-scale use of renewable energy technologies; capacity building in education establishments (primary, secondary, tertiary and vocational establishments); and cooperation with the wider Caribbean region. Following this report various administrations adopted a number of green economy-related initiatives. The 2007 Statement of Economic and Financial Policies was the most broad-based to date, outlining initiatives in the areas of energy, water, waste management, coastline protection and other policies to elicit behavioural change. For example, all businesses in Barbados can now writeoff 150 % of the cost incurred in obtaining international environmental certification. Since the 2007 budget, most public policy initiatives focused on energy, largely due to the impact that high oil prices have on the economies of small states. For example, all alternative energy systems are now exempt from import duty, and households and businesses are allowed to writeoff the costs of conducting energy audits and retrofitting their homes/ buildings. A detailed list of some of the main historical green economy-related initiatives can be found in the Green Economy Scoping Study (GESS) (2012) and the Sustainable Energy Framework for Barbados (SEFB) (2010).

Present Initiatives

The Government of Barbados (GoB) has begun to introduce measures designed to increase the share of renewable energy supply and energy conservation measures, reflecting concerns about the GHG emissions and the terms-of-trade risks from fuel import costs. In an effort to utilise the island's favourable wind and solar resources, BL&P, together with the island's independent regulator, the Fair Trading Commission (FTC), introduced a two-year trial known as the Renewable Energy Rider (which is effectively a Feed-in-Tariff) to lower the costs of renewable generation. The current payment is 1.8 times the fuel related element of the electricity tariff (currently US $0.24 per kWh) or US $0.158 per kWh, whichever is higher. This measure has no direct fiscal impact, since the costs are passed on to consumers by BL&P (although there may be indirect effects, for example on receipts from income and profit taxes). If this system were continued and expanded, then the increased cost passed onto the consumer could eventually have repercussions on poorer sections of society; options would need to be explored to ensure that this does not occur.

To improve energy Demand Side Management (DSM), BL&P are trialling a time-of-use tariff, whereby commercial customers can benefit from a lower electricity price during off-peak hours, and an Interruptible Service Rider for commercial customers who agree to have their supply interrupted, thus reducing the reserve generating capacity required (BL&P 2010).

In addition, a Smart Energy Fund, financed through a loan from the Inter-American Development Bank, has been established to promote renewable energy and energy conservation: of the US $10 million total funding envelope, US $6 million is set to be allocated to loans for energy auditing, energy conservation programmes and renewable energy technologies, while the remainder is to be used for grant finance, including for LED light bulbs and more efficient air-conditioning units.

The 2011 Statement of Economic Policies continued to promote the use of energy conservation and alternative energy with initiatives aimed at helping homeowners, businesses, farmers and the vulnerable groups of society. The budget also included the submission of draft RE and EE policies, as well as draft legislation to facilitate the generation of RE systems and the sale of electricity to the grid.

Discussion

Although the nation of Barbados has made progress in transitioning towards becoming a greener economy, there are still obstacles to its continued transition, in particular in the areas of financial and capacity enhancement. These obstacles are discussed in this section.

Capacity Enhancement

As suggested in the 2007 Statement of Economic and Financial Polices (Arthur 2007) (see section introduction), the importance of education, training, research, communication and sensitisation to the green economy is paramount. The principals and benefits of a green economy need to be understood and practiced by all sectors of society in order to ensure its success.

To date, the sentiment often found in Barbados among businesses, farmers, householders and hotel owners, is that there is a willingness to explore green economy initiatives (increasingly so, as the cost of energy rises), however there is a significant 'skills gap' in meeting the needs of the green economy (Green Economy Scoping Study 2012). There is a need to put appropriate education and training arrangements into place. Training would need to focus on trade schools, universities, and on-the-job training in the workplace (DRAFT (2012). Solid R&D, engineering, and manufacturing capacities are a critical aspect of building green industries and jobs. Indeed, some occupations in the renewables sector or in energy efficiency require highly educated and even quite specialised personnel, including a variety of technicians, engineers, and skilled trades. Green employment is not limited to high-end skills. There are many positions that demand a broad array of skills and experience levels, especially in installation, operations and maintenance.

There is evidence that this process has already begun; with solar PV installation courses taught by experts, being arranged by BNOC and the GoB's Energy Division, renewable energy modules and programmes are now being offered at undergraduate and postgraduate level at the University of the West Indies, and the

DIREKT (2012) and INEES (2012) projects at the UWI are encouraging renewable energy knowledge transfer between other SIDS and developed countries.

Elsewhere, evidence of private sector capacity building is evident, the Barbados Renewable Energy Association (BREA) was formed in the spring of 2011, and is a non-governmental association, promoting the application of RE and EE technologies in Barbados. There are currently around twenty companies offering RE and EE solutions on Barbados. They serve both the public and private sector, and their activities include: energy auditing; solar PV and solar thermal installation; small-scale wind installation; system design; biodiesel production and consultancy. The association is committed to national development through ongoing lobbying for appropriate alternative energy policies and frameworks that benefit all energy users in Barbados, and it will provide a collective voice to these RE and EE companies.

While access to RE and EE training has developed considerably in recent years, it is still a fundamental component of sustainable development and capacity-building for the long term, and would need to continue to expand, both in the current channels mentioned in the previous paragraph, and also in the area of public awareness and the workplace. As noted in the Barbados National Assessment Report (2010):

> communicating sustainable development to the general population is a challenge. For effective education, a variety of messages have to be transmitted to a number of different publics in differing formats. The resources required to adequately provide the volume of information required in the appropriate format have been ad hoc and information is usually provided in response to various situations. The approach to public education and information requires streamlining and coordination and will be bolstered by the requisite information for decisionmaking.

There are still more areas that require urgent capacity enhancement. There is a requirement to increase the amount of renewable energy positions in key areas, most notably the energy division's renewable energy unit. Given the importance that renewable energy and energy efficiency will have in energy policy for a green economy, the employment of additional renewable-energy qualified staff is required. Another sector requiring capacity enhancement is the Government Electrical and Engineering Department (GEED), here the current requirement is the training and certification of existing employees in the installation of renewable energy technologies (namely solar PV and wind), rather than an increase in staff numbers (Green Economy Scoping Study 2012).

Options for Financial Incentives

Although the cost of technical components has been declining, investing in RE and some EE technologies is still expensive and, to date, this has discouraged their deployment. High costs limit diffusion and create a negative reinforcing effect, which prevents the economies of scale that are needed to generate cost decreases. In addition, most RE technologies are new and not market-mature in Barbados, which creates high risks for investors, as their performance cannot be guaranteed. Nonetheless, due to the high cost of electricity on the island, some forms of renewable energy technology are already economically viable. The SEFB highlights wind energy, waste-to-energy, solar water heating, hybrid PV/Thermal and biomass cogeneration as RE technologies that are already commercially viable, with several other technologies close to becoming viable if oil prices continue to rise (Sustainable Energy Framework for Barbados 2010).

Although many technologies are already viable, financial constraints (i.e. limited access to capital) are currently limiting the uptake of RE technologies, and this issue is being experienced across the private, public, and third sectors (i.e. voluntary, non-governmental and community sectors). Particular aspects of this barrier are the timescales of securing funding; the risks for investors, particularly with regard to the timescales involved; the difficulty of finding funding for the feasibility and bidding stages of projects; and the lack of funding for paying person hours (revenue as opposed to capital). These constraints, particularly in the public sector, also include the issues of what they can borrow and whom they can lend to. Possible financing solutions to reduce this financial burden are the subject of the remainder of this discussion section and concentrate on innovative hybrid Private–Public Partnerships (PPP) and Energy Performance Contracting (EPC).

Hybrid Private–Public Partnerships

Usually, governments have two ways of financing a solar programme: either with tax-exempt bonds (government-owned approach), or by entering into turnkey relationships with private solar developers. In the case of the local government-owned approach, government issues debt that typically has to be repaid over the useful life of the project. Also under this approach, the government owns the system as well as retains all the benefits of the ownership other than the federal tax benefits; however, the debt adds to the burden of government and requires a procurement process to design, acquire and install the solar project. In this case the financing can be obtained at tax-exempt rates, and the government could receive revenue from selling the electricity to the power utility in order to lower the overall costs of the solar project (Pearlman and Scerbo 2010a, 2010b).

The turnkey solar developer-owned approach is typically used when the government lacks knowledge or experience in solar project development. In this case the government engages a private developer to build and own the project: the private developer gains access to the roof of the local government buildings through a license and access agreement. The private developer designs, finances, installs, operates, and maintains the solar system and then sells the renewable energy back to the local government through a Power Purchase Agreement (PPA) (Barbados national Assesment Report 2010; Pearlman and Scerbo 2010a).

These two approaches can be incorporated together; by doing so, the PPP takes advantages of both options, while minimising drawbacks (Chegwidden et al.

2010). The idea of the hybrid approach is that the government provides the financing by issuing a bond. Normally a third party—such as an Energy Agency or an Improvement Authority—is introduced in order to act as a facilitator between the government, the solar developer and the sites where the technology is to be installed. This third party issues bonds supported by the credit of the government and, therefore, significantly lowers the cost of capital for the projects. The project then uses a turnkey approach, with the difference that the financing being provided at the lower cost of capital is obtained by the government. This allows cheaper financing for the solar development community as well as preserving the developer's capacity to borrow from the private capital lending sources for other projects (Pearlman and Scerbo 2010a).

One example of this approach is the Morris Model implemented in New Jersey, USA (Chmutina and Goodier 2012). The programme started in 2009 and the Local Financial Board approved the Morris County Improvement Authority (MCIA) bonds of up to US \$30 million (Pearlman and Scerbo 2010b). The MCIA issued US \$21.6 million of debt at a 4.46 % net interest cost, with a county guarantee to fund 3.2 MW of solar projects. The MCIA has completed the first phase of its award-winning renewable energy project, installing 13,629 solar panels at locations in five school districts and several county government facilities throughout the county. These installations provide the county with 3.1 MW of clean energy and around US \$3.8 million in energy savings, and approximately 7,000 t of carbon dioxide equivalent (CO_2e) emissions.

Energy Performance Contracting

While PPPs are used for financing renewable energy technologies, EPC can be used for energy efficiency projects, such as building retrofits. EPC, or energy service performance contracting, is a mechanism to deliver energy efficiency products. It is a financing mechanism that includes energy savings guarantees and associated design and installation services provided by the Energy Service Companies (ESCOs) (Xu et al. 2011). EPC can be broadly defined as a contract between ESCO and a client involving an energy efficiency investment at the client's facility, the performance of which is guaranteed by the ESCO, with financial consequences for the ESCO (Taylor et al. 2007). Under EPC, ESCO provides finance for a specific set of measures for energy efficiency retrofits, such as planning, building, operation and maintenance, optimisation, fuel purchase, (co-)financing and user behaviour motivation.

The contract between the ESCO and the building owner contains guarantees for cost savings and takes over financial and technical risks of the implementation and operation for the entire project duration (typically 5–15 years). The EPC service is paid by realised energy cost savings (European Energy Service Initiative 2009).

EPCs were originally introduced in the 1970s in North America due to the oil crisis. Currently ESCOs have successfully been implemented in many countries, such as Chile, China, the UK and almost all other EU countries. One of the most well-known programmes is the Berlin Energy Saving Partnership (BESP) (Chegwidden et al. 2010), which is described in detail here. The State of Berlin first introduced the BESP in 1995. The concept is based on transferring energy management of state-owned properties to a partner, who uses private capital to self-finance the modernisation of a building's infrastructure necessary to cut energy use and CO_2e emissions. In return, the partner guarantees annual energy cost savings for the state (Siemenes 2011).

Among refurbished buildings under the current BESP there are schools, nurseries, office buildings, leisure centres, theatres, universities and other municipal buildings. The general details of current contracts are presented in Table 18.1. To date, implemented energy efficiency measures include refurbishment of heating and illumination, energy management as well as user motivation. User motivation is particularly important in this programme as building energy consumption often rises again once the projects are finished, therefore it is important to make building users aware of the energy consumption patterns and affect their energy use, so that the efficiency becomes habitual rather than behavioural.

The process of the BESP is the following: firstly, the Berlin Energy Agency confirms a building pool (the client). Buildings willing to take part in the programme have to fulfil the following criteria (Schlopsines 2009):

- secured ownership for at least 10 years;
- steady use of the building and constant energy consumption in the past 3 years;
- consumption of connected buildings (under-supply) is measurable;
- modernisation and replacement of the central heating, ventilation and cooling devices are possible (no restrictions in supply contracts, devices owned by building owner);
- minimum project size (baseline);

If parts of the building are rented to third parties—allocation of the costs/savings has to be checked.

The client is responsible for the uptake of various buildings and is bound by contract to the utility company. In order to reduce its energy consumption, the client runs a competitive tendering process to transfer the financing, planning, implementation, and monitoring of energy-saving measures to a private energy-saving partner—the contractor. The main criteria for the contractor are specialist know-how (references), effectiveness and creditworthiness. The successful contractor undergoes a tendering process. While the contract between the client and the utility

Table 18.1 BESP results

Number of contracts	24 pools (~1,400 buildings)
Guaranteed savings (all contracts)	US $14.9 million/year (including US $3.6 million/year savings in Berlin public budget)
CO_2 reduction	67,900 t/a
Investment (all contracts)	US $64.6 million

company is not affected by the project, the contractor, however, agrees on the necessary technology and supply with the energy supplier. When signing a contract with the client, the contractor guarantees a minimum level of energy savings—around 25 %. The contractor only receives his/her agreed earnings if the stated savings have been reached. At the same time, the client is able to save money through reducing heating and electricity consumption, achieved through energy efficiency measures. The investment carried out by the contractor is also refinanced through these savings. Any remaining savings are shared by the partners according to a ratio system agreed in the contract. The contractor is responsible for the maintenance and servicing of his/her system upgrades for the duration of the project (5–15 years), and the client fully profits from the full savings once the contract has expired (Schlopsines 2009). This programme is not limited to large buildings with highenergy consumption: a group of smaller buildings can create 'a building pool' which allows less unprofitable buildings to be integrated in the project.

Conclusions

This paper has outlined the current status of Barbados' energy sector, highlighting the green economy related initiatives that are currently being explored. Building capacity in the RE and EE sector will continue to play a vital role in the island's transition towards a green economy. For a country such as Barbados, which has limited access to funding and is 'lockedin' to a fossil fuel-based energy economy, financing mechanisms such as the hybrid Private–Public Partnerships and Energy Performance Contracting offer realistic opportunities for increasing its RE and EE capacity. Barbados has a number of energy use sectors that could significantly benefit from the financial initiatives described here. In particular Energy Performance Contracting is capable of providing substantial energy and emissions savings in its hotel and tourism sector, its governmental sector (including the Barbados Water Authority), the island's educational establishments and its manufacturing sector.

Acknowledgments The authors gratefully acknowledge the Green Economy Scoping Study team at The University of the West Indies, Cave Hill campus, along with all those involved in the Green Economy Scoping Study.

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Chapter 19
Project Funding for Innovative Research and Development Projects: A Practical Example in the Field of Renewable Energy

Jochen Selle and Stefan Franzke

Abstract In order to guarantee sustainable economic growth and future-oriented jobs, governments are in charge of providing the right framework conditions. An important lever is to support inventions as well as innovations all along the value chain. That applies to all fields of technology, and to the field of renewable energy in particular. Besides various national and regional specific funding programmes the Federal State of Lower Saxony (Niedersachsen), Germany, established a subsidisation guideline mainly targeted at small and medium-sized companies (SME) to enable the implementation of research and development projects. Provided that the content-related and formal criteria of a project proposal meet the requirements of the guidelines, the applicant may receive up to 50 % sponsorship of the total project costs. This paper focusses on the process of project funding with respect to a practical example in the field of renewable energy, beginning with the relevant network activities and ending with the evaluation scheme applied to decide whether the proposal qualifies or not. The practical example chosen deals with the application of a PEM fuel-cell system to be installed in a wind energy plant in order to maintain emergency functions during power failure or while the assembly phase is still ongoing.

Keywords Innovation framework · Evaluation scheme · Technology transfer · Renewable energy

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_19,

Short Introduction

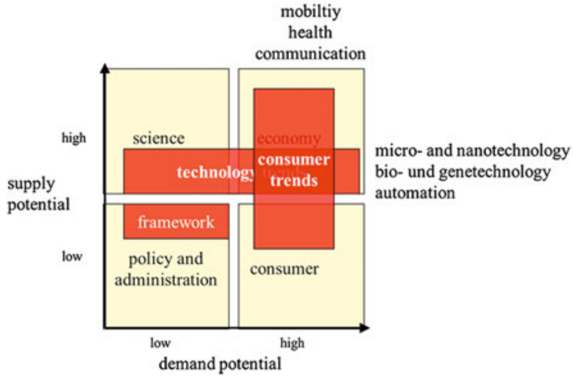
The Federal State of Lower Saxony (Germany) established a subsidisation guideline mainly targeted at small and medium-sized companies, to enable the implementation of research and development projects. This paper focusses on the process of project funding with respect to a practical example in the field of renewable energy, beginning with the relevant network activities and ending with the evaluation scheme applied to decide whether the proposal qualifies or not. The specific example of this paper focusses on the application of a PEM fuel-cell system to be installed in a wind energy plant in order to maintain emergency functions during power failure.

Introduction

Drivers of innovation processes can mainly be divided into four groups: science, economy, consumer and policy. The interaction of these groups can be illustrated by considering the innovation supply potential over the innovation demand potential (Fig. 19.1). Evidently, the supply potential of science and economy is high as well as economy and consumers providing a high demand potential. This way two driving trends can be observed: one is the technology trend with its origin in science and moving towards economy (e.g. micro and nanotechnology, bio and gene technology, automation), and the second one is the consumer trend (e.g. mobility, health, communication). Consequently, new, innovative products are being introduced to the market for the benefit of the consumer.

Unfortunately, the introduction of clean energy technologies to the market is the best example that the economic system does not always work this way. Even if there is a certain interest in a product on the demand side, there might still be too many obstacles that prevent development on the supply side. The exceptions to the rule can often be subsumed by market failures. If desirable products within the

Fig. 19.1 Drivers of innovation



range of clean technology on the one hand, show outstanding figures on the carbon footprint but on the other hand, cannot guarantee functionality to a reasonable price that is already state of the art in comparable products, they will not find many customers. High technological and economic risks very often keep the industry from making further progress despite promising market situations, so that only innovations would change this attitude. In order to enable the development of these products, the fourth driver of innovation—policy—should therefore set up appropriate framework conditions.

Framework for Innovation and Technology Transfer

There is no patent solution regarding a framework for innovation. The policy of any country or region is responsible for setting up a system that fits to its individual requirements.

Niedersachsen as a Site for Technology

This paper reflects on the individual requirements of Niedersachsen (Lower Saxony), a federal state of Germany. Its technology site status remains a key priority for adjusting a framework for innovation and technology transfer, by taking into account that strengthening the virtues of a site eventually leads to its future prospects. Regarding companies and research institutes that belong to leading entities with respect to a certain field of technology, an overview of Niedersachsen as a site for technology is derived (Fig. 19.2). Three classifications can be made to distinguish the level of a branch of technology from its national and international competitors. Focussing on wind energy and vehicle manufacturing, the economy in Niedersachsen belongs to the top few worldwide. Therefore, a practical example of supporting the innovation process within the framework was chosen from the interaction between renewable energy (wind energy) and drive technology (fuel cell).

Niedersachsen has installed 6.8 GW of wind energy (June 2011) which is approximately one quarter of current installed capacity in Germany. Germany's energy strategy aims to source at least 80 % of gross electricity consumption from renewable energy sources by 2050, while simultaneously taking offline nuclear power plants by 2022 (Bundesministerium für Wirtschaft und Technologie, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 2010). Despite the high number of wind turbines in Niedersachsen, the expansion and implementation of wind energy is still ongoing. The importance of the energy issue has lead to the decision to create a specific energy strategy for Niedersachsen (Niedersächsisches Ministerium für Umwelt und Klimaschutz 2011).

Fig. 19.2 Technology site of Niedersachsen

Aligning to milestones, Niedersachsen plans to source 80 % of gross power consumption from renewable energy—including offshore wind energy—roughly 140 % of consumption is theoretically possible. Wind energy is, therefore, a key factor in meeting the targets. Niedersachsen's energy strategy proposes the following regulatory framework concerning onshore and offshore activities (Table 19.1).

Table 19.1 Regulatory framework for wind energy in Niedersachsen

Onshore wind energy	Offshore wind energy
Reducing the regulatory limitation of height of the wind turbine	Enabling port infrastructure
Instead of setting up strict distance limits, individual decisions on appropriate areas are allowed	Defining areas for required power lines for connecting offshore wind farm
Simplifying the admission of wind turbines	Initiating part-time degree courses for employees
Repowering	Defining test areas to study wind energy within the 12 mile zone
Establishing a repowering platform for owners of old wind turbines and investors	
Regional policy supports the activities on a national level	

Nevertheless, apart from a regulatory framework, there are still several technological challenges that need to be solved by interaction between science and companies, such as increasing power output per asset, fluctuating electricity input, setting up load-bearing structures, improving weather forecasts, grid expansion and European integration of energy markets.

Volkswagen, as one of the world's largest vehicle manufacturers, is making great efforts in the research and development of low-carbon drive technologies on the basis of biomass and synthetic fuels, as well as electric mobility. The development of next generation batteries and fuel cells is still subject to national and international research. Just considering the broad field of fuel cells, there is an enormous need for development concerning all components, in terms of reducing costs, extending lifetime and simplifying the system, meaning an intensive level of innovative activity is required (Table 19.2).

Innovation Framework of Niedersachsen

A sustainable climate and energy policy and the competitiveness of the companies at the site are both decisive factors for an innovation framework in Niedersachsen. The next section provides the means of knowledge and technology transfer in order to introduce innovations despite the technological challenges named above, and refers to the actors that contribute to the value added chain of innovation (Fig. 19.3).

Institutional funding of universities and scientific research institutions provides a basis guaranteeing the interaction of several faculties, which is necessary for investigating the complex subjects of climate change and energy topics. Therefore, the government of Niedersachsen established research institutes that work together

Table 19.2 Technological challenges for developing fuel cells

Material technology of stack components	MEA technology (MEA = diaphragm electrode unit)	Fuel/air-supply
Bipolar plate	New coatings	Integration of motor, motor driver electronic and compressor
Resistivity against corrosive media, high temperature and mechanical load	Zero-carbon electrode substrates	Process stability for vehicle-specific features during operating conditions
Sufficiently high electric potential and conductivity	Platinum free catalytic converter	Design and production of pressure regulation
Cost-effective materials and automated manufacturing	Proton-conducting membrane electrolytes	Investigation of life cycle and corrosion
Power electronics and control systems		
Test engineering		

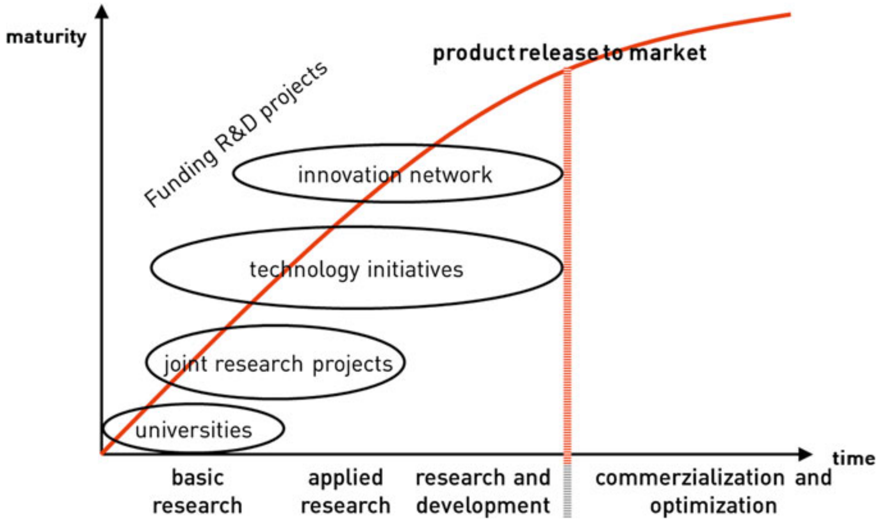


Fig. 19.3 Partners in the value added chain of innovation

across locations. The energy research centre of Niedersachsen (EFZN) was founded to ensure interdisciplinary analysis of the complete energy chain. Furthermore, the centre for wind energy research (ForWind) includes wind energy research activities from the universities Oldenburg, Hannover and Bremen in a broad spectrum within the areas of physics and engineering. The German wind energy institute (DEWI) is one of the leading international consultants in the field of wind energy, offers all kinds of wind energy-related analysis for industry, wind farm developers, banks, governments and public administration.

Funding joint research projects on energy topics enables knowledge transfer mainly between different areas of research. The second task is to provide a competent contact point for companies that are already interested in the basic research. At this stage, the cooperation between areas of research, namely researchers and companies, not only increases the quality of research and teaching, but may also result in far advanced products or services. There are presently three joint research projects in Niedersachsen dealing with decentralised energy systems: sustainable use of biomass energy between conflicting priorities of climate protection, landscape and society, and the consequences of climate change for costal protection, animal and crop production, forestry and land-use planning.

The further research and development advances on the time scale, the higher the product maturity achieved. Technology initiatives aim at intensifying the knowledge and technology exchange between companies, respectively companies and research institutes. Technology initiatives set up networks providing a trans-technological and interdisciplinary communication platform. This network supports research institutes and companies (preferably SME) in order to develop innovative products, processes and services, resulting in increasing innovation capabilities within the companies, and contributing to increasing the number of or

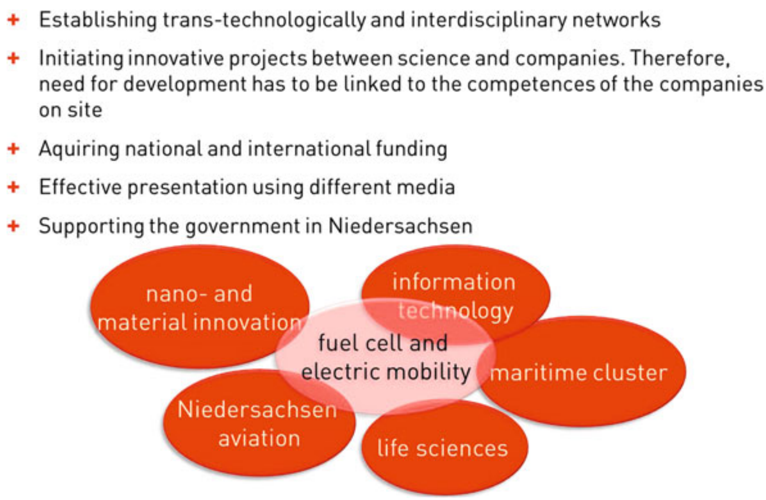


Fig. 19.4 Main tasks of technology initiatives in Niedersachsen

securing existing jobs. Currently, the technology initiatives nano and material innovations, life science, aviation, maritime cluster, information technology and fuel cell/electric mobility, convey innovations. The main tasks of a technology initiative are described in Fig. 19.4

Funding Research and Development

Along the value added chain of innovation, different guidelines support the funding of research and development. The guidelines set up rules that have to be followed by the project partners in order to receive non-repayable subsidies. The following section shows the subsidisation guidelines developed especially for Niedersachsen, along with the evaluation scheme for independent experts, and ends with a practical application of the guidelines to a research and development project in the intersection fuel cells and wind energy.

Niedersachsen's Innovation Guidelines

After all relevant players were brought together on the technical side, suitable national and international funding programs have to be considered. Niedersachsen offers guidelines open to all types of technology, with the specific aim of supporting research and development by small to medium enterprises dealing with high technological targets and risks (Investitions- und Förderbank Niedersachsen—Nbank 2011).

Table 19.3 Quality criteria for innovation funding based on Niedersachsen's guidelines

Features	Guideline for innovation funding
Quality criteria	Derived product, process or service is either new or a significant improvement to the German market
	Project approach is clarified in detail
	Project approach promises success
	Derived product, process or service is marketable
	Project contributes to the performance of industry situated in Niedersachsen
	Jobs are ensured or created
	Project contains high technical risk
	Project contains high economic risk
	Use of resources is as efficient as possible
	Environment and sustainability are taken into account
	Gender aspects are guaranteed
General notice	All quality criteria have to be fulfilled
	Evaluation of quality criteria is carried out by independent experts
Deadline	None
Rejection	In case of rejection the applicant receives the negative evaluation

Before the project is notified of their grant, so that the project can start, certain steps have to be carried out carefully.

First of all, the project consortium has to prove that formal aspects such as liquidity and solvency are sufficient for the proposed project. Then, an evaluation of the quality, according to the innovative topics, is matched with the criteria of the guidelines. The guidelines are certified by the European Union. Table 19.3 shows the criteria that have to be evaluated by the expert committee.

Evaluation Scheme

In order to evaluate the quality criteria, a scheme has to be applied to enable a comprehensible and reproducible assessment for the expert. Table 19.4 shows a scheme that is used to evaluate research and development projects based on Niedersachsen's guidelines.

Initiating a Research Project Crossing Over Between Fuel Cells and Wind Energy

The application of the Niedersachsen guidelines can be illustrated using a research and development project at the intersection of fuel cells and wind energy. As the first step, the technology initiative for fuel cell and electric mobility created these issues and passed them to the suppliers.

Table 19.4 Evaluating scheme

Features	Evaluating scheme
Innovation	Product, process or service has a definable task. Compared to other products this task is achieved with a higher ideality:
	A higher ideality results from dissolving the connection between added functionality and added disadvantages (major restraint of growth)
	The connection between added functionality and added disadvantages is dissolved by the application of at least one of one of the following: miniaturisation, automation, integration, and/or self-organisation
	Product, process or service:
	Improves functionality
	Introduces new technologies from other disciplines
	Increases possible applications by integrating new functions
	Increases possible applications by integrating formerly unknown functions
	Consists of a new technical system
	Product, process or service:
	Is new to the German market
	Is an adaptive development
Market	Target market
	Commercial customers [B2B, customer (B2C), public sector]
	State of development
	Mature market, growing market, future market
	Consumer trend
	Mobility, communication, health, sustainability
	Number of target industries
	Benefit for the customer
	Usability, time to market, anticipated price
Resources	Knowledge resources
	Within project consortium, external service supply, network, applied research, basic research
	Personnel resources
	No change, safe jobs on a long-term scale, creates new jobs
	Added value in Niedersachsen
Competence	Degree of competency within the consortium
Overall impression	Technical risk
	Economic risk

The suppliers confirmed that all relevant components of forced-air ventilated, low temperature PEM fuel cells are already on the market. The suitable configuration is still to be determined and optimised for industrial application. Then, the technology initiative for fuel cell/electric mobility put the producer of fuel cells in touch with with several potential users on the industrial side. Finally, a producer of wind turbines agreed to participate in a combined project. The application of PEM fuel cells within a wind turbine could be a new and innovative solution to maintain important emergency functions during power failure, or while the assembly phase is still ongoing.

An application was submitted on the basis of the Niedersachsen guidelines. The common factor shared by all research and development projects is that the project must be ready to start as soon as possible after the application. Therefore, the evaluation of the formal and innovation criteria has to compromise between accuracy and a short processing time. With respect to the practical example, independent experts stated that all quality criteria were fulfilled, and in case there is a liquidity problem,a grant could be delivered to the consortium.

Conclusion

Innovation guidelines should take into account the individual structure and potential of the local companies and research institutes in an area. This paper illustrated the means for a regulatory and innovative framework according to a practical example at the intersection of two areas of clean-energy technology. Focussing on the process of initiating and funding a research and development project, the Niedersachsen subsidisation guidelines and their evaluation scheme were taken as a basis. Funding innovative projects that would not otherwise be considered by industry is one measure against market failure, and one step towards sustainable economic growth with future-oriented jobs in the field of renewable energy.

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Chapter 20
Modern Technologies of Biomass Combustion and Pre-treatment for more Efficient Electricity Production: Review and Case Analysis

Wlodzimierz Blasiak

Abstract Biomass combustion and biomass–coal cofiring represents a near-term, low-risk, low-cost, sustainable, renewable energy option that offers reduction in effective CO_2 emissions, reduction in SO_x and NO_x emissions. However, untreated, woody biomass has a relatively low energy density, low bulk density, high moisture content and is difficult to comminute into small particles. As a matter of fact, these properties make biomass preparation and conversion to electricity expensive. Moreover, biomass can absorb moisture during storage and may rot as well. These properties have negative impacts during energy conversion such as lower combustion and electricity generation efficiencies. Therefore, enhancement of biomass properties is advisable not only to improve its inferior characteristics, but also to make it a suitable alternative to fossil fuels. In order to address these problems, biomass is required to be pretreated to improve its quality.

Keywords Volumetric combustion · ROFA · Biomass · Biomass pre-treatment

Short Introduction

Although biomass coal has many advantages and much potential as a renewable-energy option (reduction in CO_2, SO_x and NO_x emissions), there are still many inconveniences attached to its usage. For this reason, there is a need to study more in detail how to overcome those issues. As the price of fossil fuels is going to increase and their availability on the market decrease, modern power plants must now use different coals, biomass or even waste fuel. Thus, modern combustion processes must be fuel flexible and must be able to accommodate changing fuel supplies.

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*, Climate Change Management, DOI: 10.1007/978-3-642-37753-2_20,

Introduction

At present very well known and established combustion technologies are used to burn fossil fuels. For example, combustion technology to burn coal was the subject of more than a hundred years of development. Coal, depending on its properties and quality, can be burned efficiently using well-known technologies: grate combustion technology, fluidised-bed combustion technology and pulverised-fuel combustion technology. Using already well-known, in-furnace combustion techniques it is possible to make combustion complete (low CO, low LOI) and clean (low NO_x combustion, in-furnace SO_x reduction) as well as maintaining the boiler's very high efficiency. Using end-of-tubes reduction methods, it is possible to obtain even lower emissions of NO_x and of So_x, as well as maintaining very low emissions of dusts. These technologies developed for coal are now used to burn biomass. Since biomass has very different properties from coal, there are many differences in the physics and chemistry of coal and biomass combustion. The main differences between biomass and coal which influence the combustion process and boiler performance are:

- the higher calorific value of coal comparing to biomass,
- the higher content of volatiles in biomass comparing to coal,
- the higher content of alkali metals and chlorine in biomass resulting in a higher risk of slagging,
- higher corrosion when burning biomass.

Consequently, there are the following technical problems to be solved when boilers designed to burn coal are to be used to burn biomass:

- combustion process modernisation,
- anti-slagging, anti-fouling and anti-corrosion measures,
- fuel preparation and fuel pretreatment.

Depending on the combustion technology, different solutions are applied. This work focuses on the technology of pulverised and dried biomass combustion. Fluidised-bed combustion of wet biomass is not discussed in this work. The main reason for this decision is the fact that the combustion of dry, pulverised biomass is of a higher efficiency, and, in the case of conversion from coal to biomass, improves chances of achieving the same capacity from the boiler.

Combustion Process Modernisation

Although there are many ways to modify a combustion process, there are only a few which modify the combustion process and can still guarantee minimum emissions, complete combustion, maximum boiler efficiency, and low operational and maintenance costs. Modern power plants must now use different coals, biomass or even waste fuel. Thus, modern combustion processes must be fuel flexible and must be able to accommodate changing fuel supplies. It has also to be able to utilise difficult fuels and reduce the negative effects of fuel blends by enabling direct, large percentage co-firing and a 100 % fuel switch. Traditional air-staging systems are not uncommon in utility and district-heating boilers, independent of firing configuration or combustion technology. However, the ability of traditional systems to accommodate different fuels and NO_x reduction for is limited. The typical organisation of staged combustion is shown in Fig. 20.1. In order to prevent the formation of nitrogen oxides from fuel-bound nitrogen, the primary combustion zone is operated under sub-stoichiometric conditions with excess air number (λ) less than one. To complete combustion, a secondary air is introduced into the upper furnace by means of an air supply system called Over-Fire Air (OFA). The secondary combustion zone is operated with excess air number (λ) above one. Interaction between the two separated combustion zones is difficult to control in large scale combustion chambers particularly when the boiler's load and operational parameters change. Negative effects of such staged combustion can be seen clearly when large percentage co-firing (above 40 % of coal replaced by renewable fuels) or 100 % fuel switch are introduced. Common negative effects of biomass combustion are:

- incomplete combustion (CO, unburned volatiles, carbon in fly and bottom ash),
- wrong temperature distribution along the height of boiler's combustion chamber (thus too high a use of spray water),
- slagging, corrosion and wastage of water walls inside the boiler's combustion chamber, as well as the steam preheater,
- dropin steam temperature and steam production rate, resulting in a reduction of boiler capacity of up to 20 %.

ROFA (Rotating Opposed Fired Air) (Moberg et al. 1999; Crilley et al. 2004; Higgins et al. 2010) is a boosted over-fire air system that includes a patented rotation process. With ROFA, the gas in the furnace is set in rotation via special asymmetrically placed, high velocity air nozzles. ROFA promotes intensive internal recirculation of flue gases from the level of secondary air injection, down to the primary combustion zone. This is particularly important when burning biomass

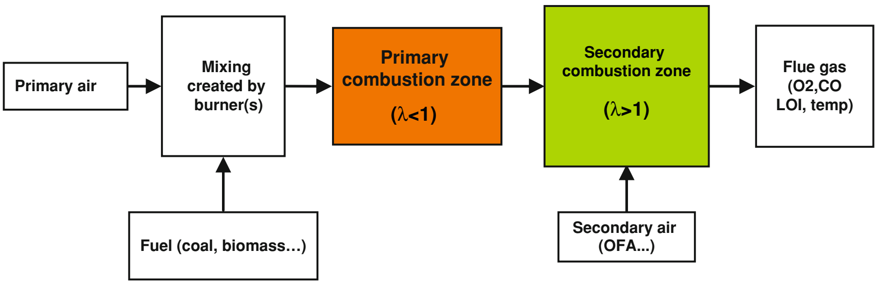

Fig. 20.1 Conventional staged combustion concept

with a high content of volatiles. Combination of air staging and internal flue gas recirculation changes not only in-furnace flow, but also affects combustion.

Due to intensive recirculation and good mixing between secondary air and flue gas, the combustion volume is larger than with conventional staged combustion. Such combustion is termed a Volumetric Combustion System (Fig. 20.2). With ROFA, volumetric combustion is created by very intensive mixing and recirculation of hot, reacting flue gases. Volumetric combustion is stabilised by the uniform temperature of the circulating flow field. The main advantage of applying this type of combustion is a very deep air staging and consequently a reduction in the formation of nitrogen oxides (NO_x), (Higgins et al. 2010). With ROFA the flue gas is well mixed with the available air in the entire upper furnace. This improves particle burnout and volatiles burnout. ROFA also increases particle residence time by changing their trajectories to utilise more of the volume of the furnace, thus reducing carbon content in the fly ash (LOI). The highly turbulent mixing and rotation prevent the formation of stratified flow, which enables the entire furnace volume to be used more effectively for the combustion process. Existence of the stratified flow, called also a “chimney” flow is a common phenomenon in the case of conventional air staging. It is often accompanied by non-uniform, and too high a temperature and CO concentration at the upper furnace outlet. Application of volumetric combustion changes the flow pattern of flue gases and eliminates these negative effects. More efficient mixing of the combustion air can also reduce the need for surplus excess air and also reduces CO emissions.

Slagging, Fouling and Corosion

Negative consequences of co-firing coal with biomass have already been reported in literature. Ash-forming elements like potassium, sodium, calcium, magnesium, silicon and aluminium are present in biomass and can cause slagging, fouling and high temperature corrosion. Mixing of ash from two fuels during direct co-firing enhances the negative effects because of the typically lower ash melting temperature of biomass ash.

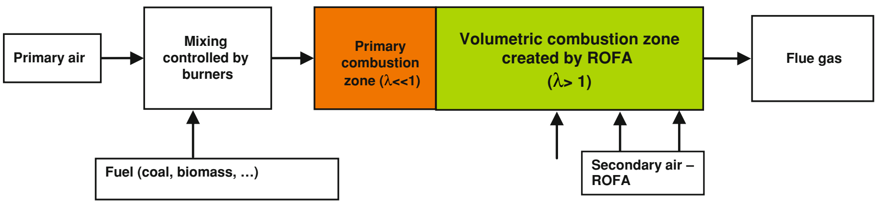

Fig. 20.2 ROFA influence on the staged combustion process creating the volumetric combustion system

Mixing of biomass ash with coal ash can negatively influence the performance of the electrostatic precipitator and can cause deactivation of the SCR (Selective Catalytic Reduction) catalysts used for nitrogen oxide reduction.

Mixing of ash can create problems with the ash used by the cement and building industry. High alkali and/or chlorine content can lead to excessive ash deposition and can cause corrosion of heat-transfer surfaces as well as flue-gas cleaning equipment. At lower percentages of co-firing, there are no major problems related to slagging, fouling, or corrosion. However, there are problems at a high percentage of co-firing, or when 100 % biomass is fired. Substantial deposits of fly ash on heat-transfer furnaces are often observed, and an example of this is shown in Fig. 20.3. Deposits in the lower part of furnace (around the burners) and in the upper part of the furnaceare also often a problem. Ash distributed uniformly is quite easy to remove, but requires more frequent use of so-called soot blowers. Thickness of deposition on walls can be between 5 and 30 mm. At the superheater, the thickness of ash deposits can be between 15 and 50 mm (Fig. 20.3).

Removal of chlorides is a way to avoid these negative effects and to protect heat-transfer surfaces. After the installation of a volumetric combustion zone, the application of a chemical-injection system allows for the efficient and cost-effective reduction in this problem. Ammonium sulfate, $(NH_4)_2SO_4$ reduces the KCl levels in the flue gas and consequently reduces the level of deposits and rate of corrosion of the heat-transfer surfaces which fire the biomass. Roughly 80 % of the potassium chloride, KCl, is converted into the much less corrosive potassium sulfate, K_2SO_4.

Fig. 20.3 Photo of superheater with deposits accumulated as a result of biomass combustion

Conventional Cofiring and Biomass Preparation Systems

Forced by new European Community legislation to reduce emissions, many power plants now plan to burn biomass, instead of coal, to produce electricity. There are few big boilers in the order of 200 MWel capacity where 100 % fuel switch from coal to biomass is going to be introduced. Some smaller boilers (in the order of 50–70 MWel capacity) are already fully converted from coal to biomass. However, the most common way of burning biomass is still the co-firing of coal with biomass. Here are the types of cofiring:

- Low percentage co-firing is when a maximum of 10 % of coal (by energy fraction) is replaced by biomass,
- Intermediate percentage co-firing is when up to 40 % of coal is replaced by biomass,
- Large percentage co-firing is when more than 40 % of coal is replaced by biomass.

In the case of low percentage co-firing, only a few percent of dry biomass (max. 10 %) is burned together with the coal. Raw biomass is mixed with coal before it is fed into the existing coal mills. Existing coal mills dry and pulverise biomass together with coal, producing a pulverised coal-biomass mixture. This mixture is burned in existing boilers without any substantial modernisation of the combustion system or of the boiler itself. Low percentage co-firing is used mainly because of the very low investment cost and high profit when burning biomass. Existing boilers are able to accommodate this coal-biomass mixture without any serious modernisation of the combustion system. There were some safety problems with milling biomass together with coal. However, after a few years of adaptation of coal mills to low percentage co-firing was carried out. At present, this rather safe, reliable operation is possible with a satisfactory rate of distribution of the coal-biomass mixture.

Intermediate percentage co-firing (up to 40 %) requires feeding the pulverised, dry biomass directly into the boiler's combustion chamber. Biomass is injected via separate nozzles or via burners. The number of nozzles, as well as their location, depends on the amount of biomass and its properties, but mainly on the combustion system used. Biomass can also be injected via new biomass burners or via existing, modified coal burners (dual fuel burners). Intermediate percentage co-firing requires a much greater modification of the air combustion system and some modification of the heat-transfer surfaces.

Large percentage co-firing, as well as complete fuel switch, (Blasiak et al. 2007, Blasiak 2008; Higgins et al. 2009) also requires feeding the pulverised, dry biomass through modified burners. Coal burners must be modified to handle higher mass-flow rates of fuel, and to guarantee complete, stable combustion throughout the operation. Full modernisation of the combustion system is necessary if the same capacity and steam parameters are to be kept. This would include, for example, the application of volumetric combustion, as well as substantial modernisation of the boiler heat transfer surfaces.

Biomass has a higher volatile content than coal, creating potential for a combustible environment. Therefore, the handling and processing of dry biomass must be performed safely. To ensure plant safety and operational reliability, the biomass handling system has to be designed to avoid and eliminate possible combustion during biomass storage, transport, and in the milling systems. The standard dry-biomass feeding system [*Wroclaw paper*] is comprised of the following main components:

- a biomass conveyance line from the fuel yard,
- a biomass (pellet, wood chips…) storage silo,
- hammer mills,
- dust separation cyclone filters,
- a powder silo,
- a biomass injection system (nozzles or burners).

Dimensions of the feeding system, (size and number of biomass storage silos, number of hammer mills, size of filters, size of powder silo, size and number of burners) and thus also the amount of investment necessary, depends on the capacity of the boiler and the amount of biomass replacing coal.

Conventional biomass feeding systems are commonly used although there are well known problems and disadvantages. The main problem is that even dried biomass has a relatively low energy density, low bulk density and is difficult to comminute into small particles. Moreover, it can absorb moisture during storage and may rot as well. This makes biomass transportation unsustainable and very expensive, as well as the negative impacts it can have during energy conversion, for example, lowering combustion efficiency. Therefore, enhancement of these properties is advisable to achieve the following benefits:

- reduced fuel transportation costs,
- reduced operational costs of fuel preparation and milling,
- an improved combustion process and boiler efficiency,
- reduced risk of slagging, fouling and corrosion, thus decreasing the boiler's downtime,
- reduced investment costs into the fuel-feeding system.

Biomass Pretreatmant Technologies

To achieve the benefits listed above, biomass must be pretreated to have a higher calorific value, grindibility and resistance to moisture. In recent times, the wood pellet industry has experienced rapid expansion into the energy market. Global wood-pellet production in the year 2009 was 13 and 8 million tons/year of this was consumed by European countries. It is predicted by the European Biomass Association that a consumption of 50 million tons/year will be reached in European countries by 2020. However, conventional wood pellets present problems such as low hardness, low specific weight, high sensitivity to moisture and low heat content. Moreover, the cost of transport is considered to play an important role in the wood pellet industry. Biomass is improved density can save transport and handling costs. Therefore, the improvement of wood-pellet quality, both in terms of fuel quality and density, seems indispensable. Currently, different approaches have been considered to improve the quality of the wood pellet, for example, torrefaction and fast pyrolysis. Another promising technology is the steam-explosion pretreatment process. Previously, application of the biomass steam-explosion process was limited to ethanol, and composite panel production. Both concepts are applied together with pelletisation of pretreated biomass to reduce transportation costs and the risk of explosion.

Recently, this concept has been brought into the spotlight to improve wood pellets, in order to produce high quality and high density pellets called “black pellets” as a biomass fuel to replace fossil fuels like coal and oil.

Steam Explosion

Woody biomass is made of cell wall with polysaccharides (cellulose and hemicelluloses) and an aromatic polymer named lignin. Cellulose and hemicelluloses are considered to be strongly bonded with lignin in wood. In the steam-explosion process, saturated steam ranging from 453 to 513 K in temperature is used to disrupt different components of biomass. The steam-explosion process involves the separation of the main components of woody biomass (lignin, cellulose and hemicelluloses) by both chemical degradation and mechanical deformation. The process involves adiabatic expansion of water inside the pores of the wood tissue and the auto hydrolysis of cell components. The steam-explosion pretreatment process can be divided into three different sub-steps. Initially, biomass is fed into the reactor and the vessel pressurised with steam until the desirable pressure and temperature are reached. Afterwards, sudden decompression is achieved by releasing pressure from the reactor. Later on, the slurry produced is passed through a filtration unit to separate the solids from the liquids.

Steam explosion pretreatment is striking in the context of the alteration of the elementary composition of fuel. A greater degree of carbonisation and the removal of oxygenated compounds leads to an increase in the heat content of the fuel. Moreover, the total amount of ash is also reduced in the residue from pretreated biomass. The removal of ash content can be attributed to the combination of water leaching and the disrupted cell structure. Although steam pretreatment shows promising results in terms of reducing the alkali and heavy metal components of biomass, degradation in ash fusibility was observed in the residue from steam-treated biomass.

Pellets produced from steam treated residue showed an increment in certain physical properties of the pellets such as density, impact resistance, and abrasive resistance. The higher density of the pellets can be attributed to the greater proportion of fine particles produced during the process. On the other hand, higher impact and abrasive resistance can be attributed to the melting of lignin, which has a low molecular weight, on the surface of the pellets during pelletisation (Sassner 2006).

Biomass Torrefaction

Torrefaction (Bergman and Kiel 2005; Bergman et al. 2005) is a thermal pre-treatment process applied to enhance the quality of biomass fuel. In process of torrefaction, numerous products are formed, such as a solid and some liquids and gases. The solid is rich in carbon in comparison with oxygen. As a result, a significant improvement in the heat content of the biomass (solid) can be achieved (20–23 MJ/kg). The heating value of torrefaction gas can vary from 5.3 to 16.2 MJ/Nm^3. Therefore, torrefaction gas can be combusted to generate heat. Although the torrefaction process has been validated in the laboratory and on the scale of a pilot, there are many issues that need to be addressed before it can be used on a commercial scale. These include safety issues, fouling and corrosion when using it in co-firing. In addition, the choice of an appropriate reactor for torrefaction is considered decisive in plant performance.

Several reactor technologies are available nowadays. With the choice of appropriate technology, torrefaction can be proven beneficial for biomass chain supply. It is expected that the torrefaction process will provide an important contribution to biomass chain supply in the near future. The concept of the torrefaction process is shown in Fig. 20.4 (Biswas and Yang 2011). Initially, wet biomass is dried in a dryer with flue gas to reach the desired moisture content: to 10 % from 20 %. The drying temperature is 135 °C to provide sufficient energy for drying and avoiding saturation of the gases and volatilisation of the biomass. The dried biomass is torrefied under certain process conditions by using a majority of torrefaction gas. The reason for using torrefied gas is to ensure an inert atmosphere for the torrefaction process. Torrefaction gas is used as the main source of energy for the process. If the process requires additional energy, due to higher moisture content, part of the torrefied biomass is used as an energy source.

Biomass type has a significant effect on product yield, the energy retained in product (Fig. 20.5) and the efficiency of the torrefaction process (Fig. 20.6). Softwood tends to provide higher process efficiency in comparison with hardwood and agricultural residue. On the other hand, the choice of process conditions has great importance when considering process efficiency. Extreme process conditions may lead to excessive loss of mass and hence reduction in the efficiency of the process. Therefore, it is advisable to operate the process under less severe conditions, i.e. below auto-thermal point, to maximize process efficiency. Although

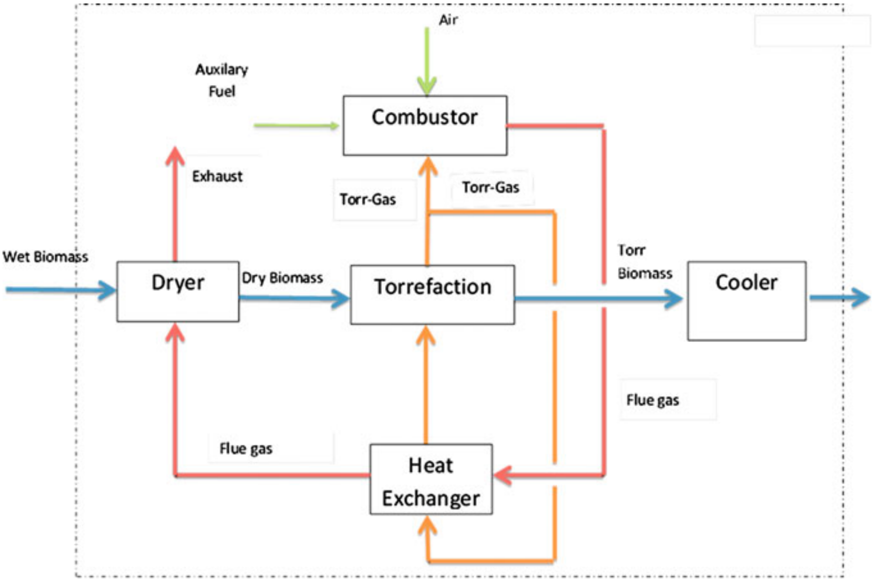

Fig. 20.4 Process flow diagram for the torrefaction process

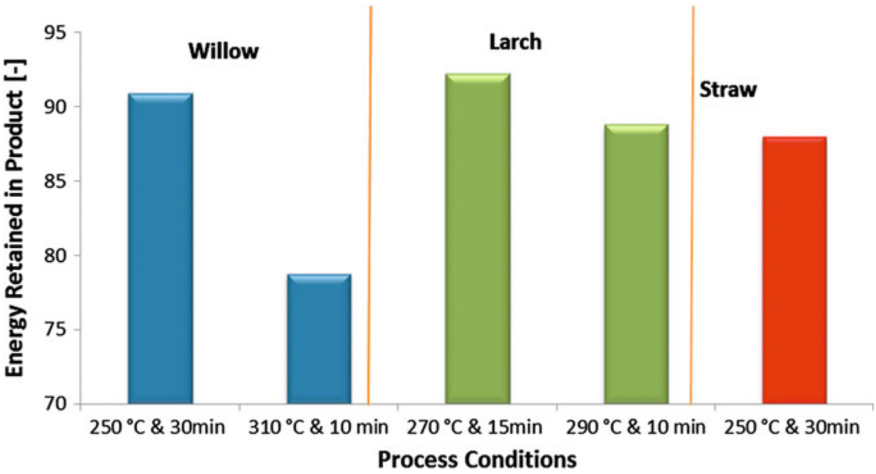

Fig. 20.5 Energy retained in product (torrefied biomass) after the torrefaction process versus the process conditions

process efficiency is observed to be around 80–90 %, it can be significantly improved by recovering heat from the cooling water used for the solid, which can be used as preheated water for district heating systems. Therefore, desirable process performance can be achieved by the correct choice of biomass, process conditions and an effective way of using the low quality heat of the system

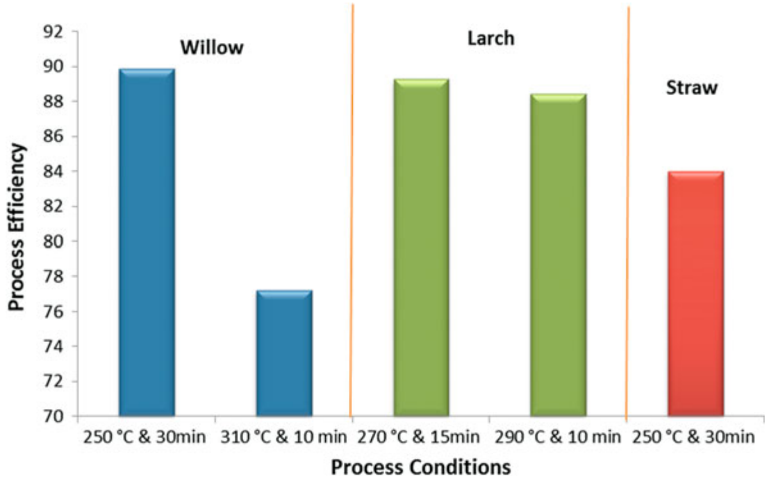

Fig. 20.6 Overall torrefaction process efficiency versus the process conditions

Influence of Biomass Pretreatment on Boiler Modernisation

It is a known and common practice, that even moderate percentage co-firing of pulverised, dried biomass requires modification of the air-supply system in order to secure better mixing inside the combustion chamber. The combustion of pulverised, torrefied biomass also requires the modernisation of the combustion process and combustion air-supply system. It is particularly necessary when large-percentage co-firing of torrefied biomass and coal, or a complete fuel switch, is to be performed. Applying conventional combustion technologies in such cases will encounter such difficulties as a fall in boiler efficiency, reduced steam production, a drop in steam parameters, increased fouling and corrosion of heat transfer surfaces inside the boiler.

Biomass, as well as torrefied biomass, has a much higher content of volatiles. A large fraction of torrefied biomass is released as volatiles (up to 65–75 % of mass) therefore gas-phase temperature distribution will be different compared to that of pulverised coal combustion or standard biomass. Modified combustion systems must be flexible and secure complete and clean combustion of volatiles, as well as particulates, but also must secure the performance of the boiler; that is the same steam flow rate and steam parameters.

It is known that the change from coal to co-firing significantly influences temperature distribution along the height of the boiler. When firing coal, the area of highest temperature is located just above the burner zone. When co-firing, there are two zones of high temperature: one zone just above the burners and a second zone much higher in the upper furnace. The reason for this bi-modal temperature distribution is a lack of good mixing. In order to improve and control the temperature in the upper furnace, and at the inlet to the superheater, much better mixing must be introduced.

The highly turbulent mixing and rotation prevent the formation of stratified flow, which enables the entire furnace volume to be used more effectively for the combustion process. Existence of the stratified flow, called also a "chimney" flow, is a common phenomenon in conventional boilers. It is often accompanied by a non-uniform and too high a temperature and CO concentration at the upper furnace outlet.

Figure 20.7 shows temperature distribution in a vertical cross-section of a steam utility boiler fired with different pulverised fuels. In all three cases the firing capacity is the same, as well as having a similar size distribution. The combustion system used is the same as that traditionally used for the combustion of pulverised coal. It can be easily observed that torrefied biomass with the same calorific value as bituminous coal creates a much higher temperature at superheater level. In the case of this combustion process and a fuel switch from coal to torrefied biomass, the boiler will not work properly. Therefore, the above mentioned modernisation of the air supply system, as well as the introduction of much intensive mixing, seems necessary.

Application of a proper air supply and mixing system will result in much more uniform temperature distribution, complete combustion, better operation, boiler load flexibility and better steam parameters. Because of better mixing, modification of burners is often not required and existing burners can be used to burn pulverised coal or pulverised, torrefied biomass with good flame stability.

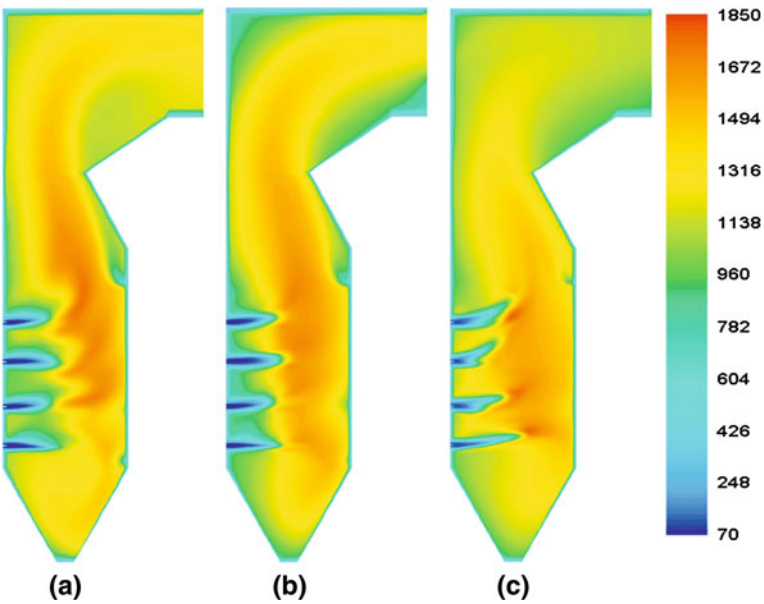

Fig. 20.7 Temperature distribution in a vertical cross-section of a steam boiler fired with pulverised **a** torrefied biomass no. 1, **b** torrefied biomass no. 2, **c** bituminous coal

Because of differences in the chemical composition of biomass and the coal-firing system, boiler modifications and equipment additions are also required. Extra heat transfer surfaces at convective part of the boiler must be analysed and, most probably, additionally installed when 100 % of torrefied biomass is fired. This decision must, of course, be based on the thermal calculations of the boiler.

Slagging, Fouling and Corrosion When Firing Torrefied Biomass

Negative consequences of co-firing coal with biomass have already been reported in literature. Ash-forming elements like potassium, sodium, calcium, magnesium, silicon and aluminium are present in biomass and can cause slagging, fouling, and high temperature corrosion. Mixing of ash from two fuels during direct co-firing enhances the negative effects because of the typically lower ash-melting temperature for biomass ash. Mixing of biomass ash with coal ash can negatively influence the performance of the electrostatic precipitator and can cause deactivation of the SCR catalysts used for nitrogen oxide reduction. Mixing of ash can create problems with the ash used by the cement and building industry. High alkali or chlorine content can lead to excessive ash deposits and can cause corrosion of heat transfer surfaces, as well as of flue gas cleaning equipment. In order to avoid all these negative effects, an anti-slagging chemical injection system must be installed.

Summation

Volumetric combustion created by Rotating Opposed Fired Air (ROFA) is a very effective method to perform large percentage direct co-firing of pretreated biomass and coal, and offers the possibility to utilise a large quantity of biomass at low investment cost.

Biomass pretreatment combined with modern combustion technology offers a new, effective way of using biomass for efficient, clean and low cost electricity production.

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Chapter 21
Remote Sensing and GIS Techniques for the Assessment of Biofuel and Biomass Energy Resources

Lalit Kumar and Anirudh Singh

Abstract The Pacific Island Countries (PICs) are faced with energy challenges arising from the lack of availability of fossil fuel sources in the region. Renewable energy has been identified as a primary means by which these challenges could be met. The successful utilization of renewable energy resources of the region will, however, depend on several factors. Among these are the availability of the relevant resources, and the political and legal framework, human capacity, and institutional mechanisms required to develop and implement renewable energy projects. Biomass and biofuels are two important resources available to many of the PICs. However, before these forms of renewable energy can be used, a necessary first step is the assessment of the availability of these resources, and the land area required to produce them. Remote sensing and GIS are two important techniques that can be employed for this purpose. In the technique of remote sensing, satellite imagery is used to quantitatively assess the biomass cover and available land area over large areas of a country. The information thus collected is conveniently stored in GIS systems which can be used for decision-making. This paper begins by showing why there is a need for a quantitative assessment of the biomass and biofuel resource potentials of the region before decisions about the use of such resources can be made. The techniques of remote sensing and GIS are then introduced, and examples of their potential application in the assessment of biomass and biofuel resources provided. The need for a biofuel resource assessment for Fiji is then considered in detail. Finally, recommendations are made for a biomass and biofuel assessment strategy for the Pacific region.

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_21,

Keywords Remote sensing · GIS · Pacific island countries (PICs) · Resource assessment · Biofuel resources · Biomass resources

Short Introduction

The Pacific Island Countries (PICs), as many other countries nowadays, are trying to replace the fossil fuel produced energy with renewable sources. In the lack of fossil fuel sources in the region, biomass and biofuels showed to be two important potential renewable resources available to many of the PICs. In this paper, the techniques of remote sensing and GIS are used in order to test their potential application in the assessment of biomass and biofuel resources provided. Analyzing the results, the final recommendations are made for a biomass and biofuel assessment strategy for the Pacific region.

Need for Biomass/Biofuel Resource Assessment

Biomass and biofuels are important renewable energy options for the PICs in their endeavor to reduce their dependence on imported fossil fuels. While biomass is used traditionally as cooking fuel, it also provides the feedstock for biogasification plants and biomass-fired thermal power plants. Biofuels can be used either directly, or after conversion to biodiesel, for transportation and power generation.

An assessment of the biomass and biofuel resources of a PIC is therefore an important pre-requisite to the development of an effective national energy strategy for the country. These resources are, however, determined by the geography and geology of the country. While the rich alluvial soils which are often characteristic of volcanic islands are capable of supporting a variety of biomass and vegetation providing feedstocks for biofuels, the same cannot be said of the coral atoll states.

As the geography of the PICs vary widely, ranging from volcanic islands such as PNG, Solomon Islands, Vanuatu, Fiji and Samoa to coral atolls such as Kiribati. RMI and Tuvalu, the potential within these states for these resources will vary. It is therefore necessary to carry out quantitative measurements to ascertain the extent of these resources in these countries (Fig. 21.1).

Two important biofuels that can be produced from indigenously-derived feedstock in the PICs are coconut oil and ethanol. The former is derived on commercial scales from coconut plantations. The latter can be obtained either from sugar or molasses produced from sugarcane plantations, or from root crops such as cassava. It is therefore of interest to determine the extent of the existing crops of such feedstock, and to assess the potential for expanding these stocks further.

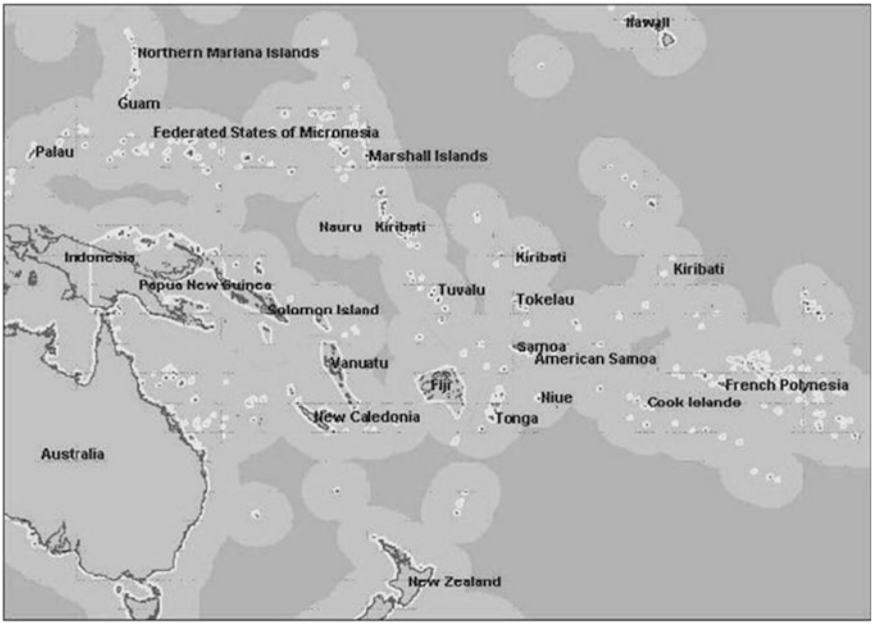

Fig. 21.1 Map of the Pacific, indicating the volcanic chain of islands to the West and the coral atoll nations to the North East

Some data for the quantities of these biofuel feedstock already exists (Key statistics 2011a, b; Krishna et al. 2009; Report on Fiji National Agricultural Census 2009) (Table 21.1).

However, additional information is needed for the further development of these resources. For instance, one requires an assessment of the land resources and their distribution. Further information needed to inform the process of the energy strategy development, includes

- How much land area is available for further biofuel feedstock development
- The suitability of such land for biofuel feedstock crops
- Other issues, including land availability and access.

Not all of such information is currently available. There is therefore a need to collect the additional data to better inform the biofuels development program for the region.

Table 21.1 Data on available or proposed biofuel feedstock crops in Fiji

Feedstock or crop	Land area (ha)	Volume harvested p.a.(t) (2010)
Sugarcane	45,000 (2010) [1]	132,000 [1]
Cassava	2,600 [2]	34,500 [2]
Coconut	15,000 (2009) [3]	4,977 (2009) [4]

Much of such data can be obtained through Remote Sensing (RS). This data can then be combined with the other forms of information mentioned above in the layers of Geographical Information System (GIS) models.

GIS and Remote Sensing Technologies

Introduction

Timely data at appropriate scales is critical for the management of natural resources. Remote Sensing provides the means to collect data at broad scales and at variable resolutions for input into GIS based models so that the satellite data can be integrated with other ancillary data for modelling purposes.

A thorough knowledge of the spatial distribution and quantity of resources is critical to any decision making process. In regions with limited resources, there is always competition between interested groups for the utilisation of such resources. In the Pacific Islands there is the added problem of the geographic spread of such resources and their accessibility.

Remote Sensing, which uses satellites or other airborne sensors is a technology that has made great strides in the last 20 years in terms of resolution and repeatability. There are many more satellites from which data can be obtained, and the spatial resolutions are much better than when the first environmental satellites were launched. The repeat cycles (i.e. number of days to repeat capture) have also improved greatly.

In areas with limited resources there is always competition between interested groups for food and resources. Timely data at appropriate scales is critical for conflict resolution and management of the resources. Remote Sensing (RS) provides the means to collect data at broad scales and at variable resolutions for input into GIS-based models so that the satellite data can be integrated with other ancillary data for modelling purposes.

Biomass Estimation

Methods of Biomass Estimation

In general, biomass includes both the aboveground and below-ground living mass, but due to the difficulty in field data collection of below-ground biomass, RS researchers mainly focus on aboveground biomass (Burton et al. 1991; Brown 1997; Drake et al. 2002).

Biomass can be measured using 3 different methods: (a) direct methods (destructive sampling), (b) indirect methods (tree measurements and models), and

(c) remote sensing approaches. To reduce the need of destructive sampling and develop a rapid and relatively accurate method, non-destructive approaches are usually used. Houghton et al. (2001) compared different estimation biomass methods in the Brazilian Amazon. The methods included three field measurements, two environmental gradients methods, and two remote sensing techniques. The results indicated that, among the 3 methods, the Olsen method (Olson et al. 1983) estimated the lowest and the Fearnside method (Fearnside 1997) the highest rank of total biomass, but they concluded that a combination of satellite data together with field measurement could have better results for above ground biomass.

A stand growth model, called the 3-PG (use of Physiological Principles in Predicting Growth), have been used in a number of studies. This model can calculate the total carbon from different factors such as solar radiation, temperature and rainfall and converts the carbon to total biomass (Landsberg and Waring 1997). Biomass can also be calculated by generalized biomass expansion factors (expanding the total stem volume to total biomass). The expansion factors vary depending on tree species, wood density, site fertility, and climate conditions (Lehtonen et al. 2004). Under fieldwork conditions, the diameter at breast height (DBH) and total height, are the most common variables for measuring biomass because of their estimation reliability (Popescu 2007). Some studies have shown correlation between tree height and stem diameter variables (Nilsson 1996).

Biomass Prediction with Remote Sensing Approaches

A number of studies have used the remote sensing techniques for estimating the aboveground biomass (De Jong et al. 2003a, b; Drake et al. 2003; Lefsky et al. 2001; Lefsky et al. 2005; Nelson et al. 1988; Roy and Ravan 1996; Strahler et al. 1986). Different approaches such as multiple regression analysis, neural network, and K nearest-neighbour have been used for estimating above ground biomass by remote sensing data (Nelson et al. 2000; Zheng et al. 2004).

The aboveground biomass mapping of the Mediterranean oak forest was done by De Jong et al. (2003a, b) by using digital airborne imaging spectrometer (DAIS7915), for collecting and analysing data; and spectral indices and multiple regression, for biomass prediction. The biomass map of the Wisconsin national forest was created by Zheng et al. (2004) by using various vegetation indices from Landsat 7 ETM+ and regression analyses. They concluded that forests stand age map, together with above ground biomass map, could help forest classification and further help to quantify carbon budget, to construct fire modelling and to determine fuel accumulation.

Jatropha: Yield Prediction with Remote Sensing and GIS

Many countries have established or are in the process of establishing Jatropha (*Jatropha curcus Linnaeus*) plantations as an alternative source of energy. The Fiji Department of Energy (FDoE) has a biofuel development program that will access the productivity of this crop as feedstock for Fiji's biofuel industry.

Jatropha has several advantages as an alternative energy crop:

1. it has a high yield content (Achten et al. 2008; Azam et al. 2005; Tiwari et al. 2007),
2. it is drought tolerant,
3. it requires only low levels of nutrients (Francis et al. 2005),
4. is highly adaptable to marginal lands (Francis et al. 2005) and
5. emits very low levels of greenhouse gases (Prueksakorn and Gheewala 2008).

The techniques of Remote Sensing and GIS can be used to obtain, store and analyse critical information on the viability of such crops over regions of the globe. Li et al. (2010) have used GIS to estimate the biological productivity and potential dry seed yield of Jatropha. They used a number of GIS layers to further classify yield according to levels of water and nutrient supply. To identify the spatial locations of future plantations, the yield levels were overlaid with global land cover types (data routinely generated from remote sensing). They then summed the potential area and production in each zone at the national, regional and global scales. The results are presented in Fig. 21.2.

Figure 21.3 shows the dry seed yield of Jatropha based on latitude, annual mean temperature and annual mean precipitation, found by the above workers. An

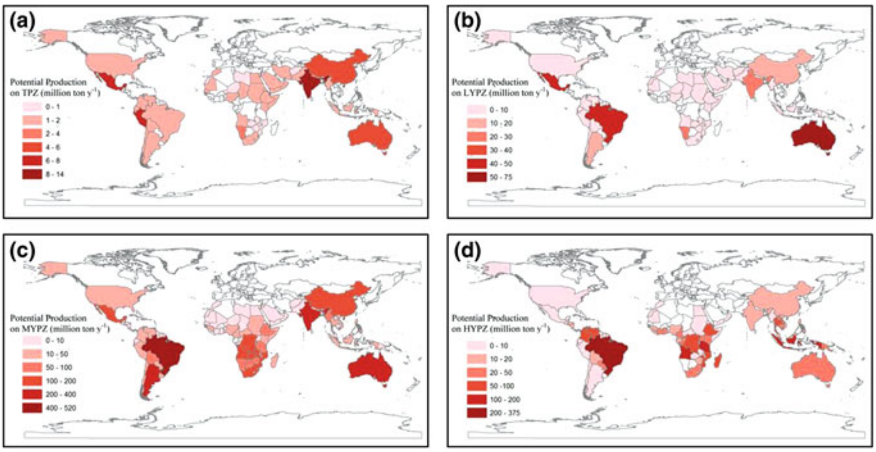

Fig. 21.2 Jatropha dry seed production potential at different zones at a national level. **a** Potential production on a tentative plantation zone. **b** Potential production on a low-yield plantation zone. **c** Potential production of a medium-yield plantation zone. **d** Potential production of a high-yield plantation zone (*Source* Li et al. 2010)

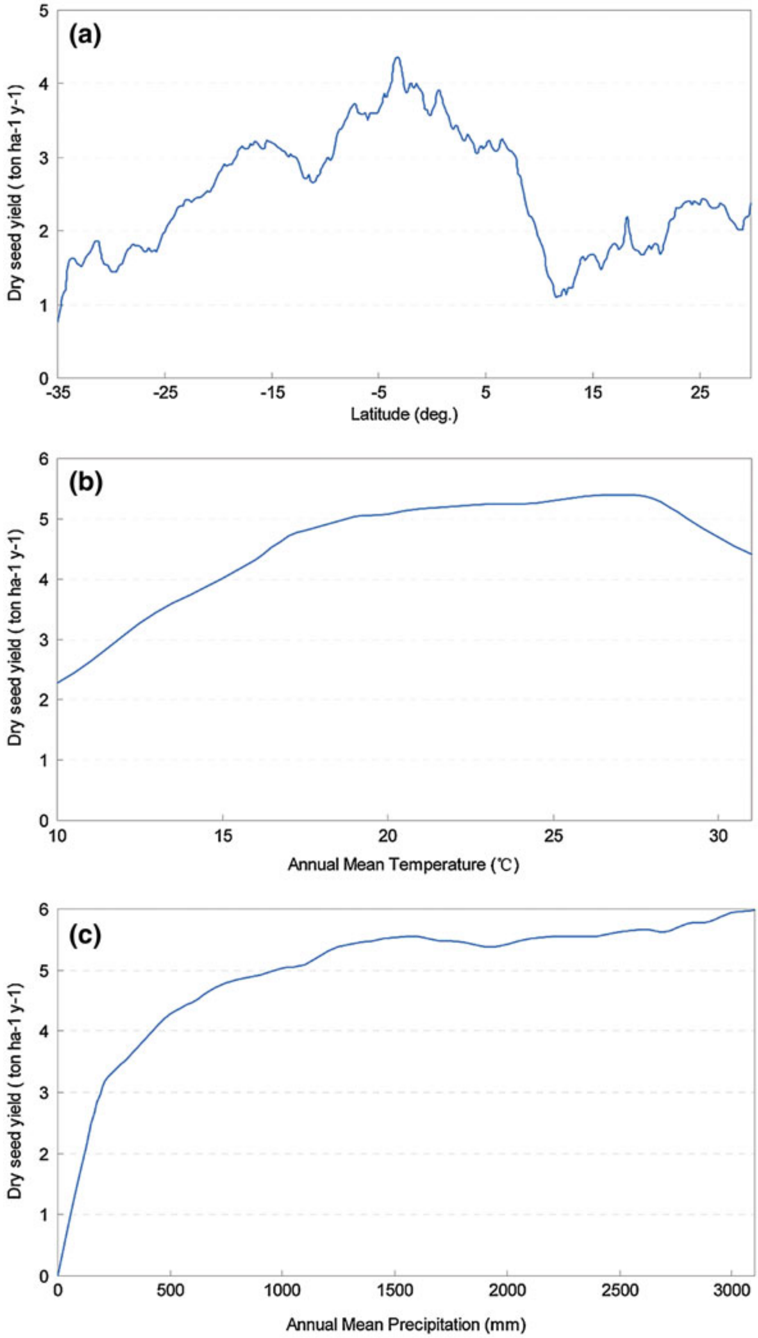

Fig. 21.3 Estimated *Jatropha* dry seed yield depending on the latitude (**a**), annual mean air temperature (**b**), and annual mean precipitation (**c**) (*Source* Li et al. 2010)

analysis of the location, temperature range and rainfall zones of the Pacific Island Countries shows that most of them would be ideal for Jatropha production. This however has to be linked to current land use and opportunities for conversion of this land for biomass plantations.

Assessing Fiji's Biofuel Resources

Introduction

Interest in biofuels as renewable energy alternatives to fossil fuels in the Pacific is currently confined to the r first generation biofuel feedstocks. These include sugarcane derived sugar and molasses, and cassava for the production of ethanol, and a range of existing or potential vegetable oils including coconut oil (CNO), jatropha, pongamia and castor oil for the production of biodiesel.

Ample data is available on the potential for producing ethanol from sugarcane-derived feedstocks. Information on sugarcane plantations and the tonnage of cane, sugar and molasses produced has been carefully maintained by the Fiji Sugar Corporation since the beginning of the industry nearly a hundred years ago. Summaries of such data is available from the Fiji Bureau of Statistics (Key statistics 2011a).

The annual national production of cassava (an ethanol feedstock) is also available (Key statistics Key Statistics 2011c). However there is little documentation of the location of the plantations and other details affecting the productivity of these farms.

While the sizes (areas) of CNO plantations as well as their productivity are known, there is a need to determine regions of plantations and scattered trees and road access to these. Information is also required on suitable land for further development of such plantations. In the case of new crops such as jatropha, a complete resource assessment will have to be undertaken starting from land availability, soil type and climatic conditions, as well as ownership and access issues.

Applcation of RS and GIS to Biofuel Resource Assessment

The techniques of remote sensing and GIS are useful devices for the assessment, storage and analysis of data on biofuel crops and a range of parameters that determine their productive yields. Table 21.2 exemplifies the utility of these techniques in the case of indigenous biofuel feedstock of the Pacific Island Countries (PICs).

Table 21.2 Application of RS and GIS to the determination and analysis of biofuel feedstock data

Feedstock	Location, terrain and land area	Soil type	Rainfall, temperature	Land ownership, road access
Ethanol feedstock				
Sugar	Known	Known	Known	Known
Cassava	New areas (RS)	(GIS)	(GIS)	(GIS)
Biodiesel feedstock				
Coconut	Area, no. of trees (RS)	GIS	GIS	GIS
New vegetable oil crops	RS	GIS	GIS	GIS

Sugarcane, which produces molasses as a feedstock for ethanol production, is only cultivated in Fiji and information on its production details is well documented by the Fiji Sugar Corporation. In the case of cassava, while summary data on the total amount of production is available for the whole region [Krishna], little is known about the geographical distribution of the plantations. In addition, no information is available on possible new areas where this crop could be grown. Remote Sensing will be instrumental in providing data for the further investigation of such new sites, while GIS provides a suitable technology for the storage and analysis of information on the soil types, rainfall, temperature and land ownership and road access details. Both these techniques can complement each other in the acquisition and analysis of data required for the production of new vegetable oil crops such as jatropha, pongamia and castor throughout the region.

Jatropha Cursis: Fiji Government Development Programme

The Fiji government has an ambitious programme for the trialing and cultivation of Jatropha as a potential feedstock for biodiesel production (Singh 2011).

The program will include the

- establishment of germplasm
- collection of promising progenies as future seed source
- establishment of nurseries for growing jatropha seedlings
- identification of suitable locations for jatropha plantations
- documentation of agri-techniques for the jatropha cultivation
- establishment of demo plots
- production of bodiesel, and the
- evaluation of the economics of the whole program.

The following data can be provided and managed through RS-GIS for this proposed program:

- Identification of suitable location, including terrain and soil types

- Rainfall data
- Road access and land ownership

The simple examples presented above illustrate the significant utility of RS-GIS techniques in the assessment of biofuel resources in the PICs.

A Strategy for Regional Biomass/Biofuel Resource Assessment

It is clear from the above examples that RS-GIS techniques can play a pivotal role in the resource analysis of existing or proposed biofuel crops in Fiji. A similar need exists for the rest of the region, as exemplified by the Samoan interest in biogasification (Ministry of Natural Resources, and Environment 2011), and the proposed use of CNO by the Tongan government in their energy roadmap (TERM 2011). A region-wide assessment of biomass and biofuel resources is thus in order.

A regional resource assessment strategy can use either a broad spectrum approach or a focused approach. In the former, a systematic assessment is carried out of all potential resources in all PICs, whereas in the focused approach, a selective assessment is considered, based on the stated requirements of the individual PICs. These requirements can be obtained from the individual National Energy Roadmaps of the PICs. If budget considerations are kept in mind, the latter approach is clearly a more viable alternative.

A suitable methodology will involve

- Determining the assessment requirements of each PIC through actual consultation
- Collecting initial data from individual lands departments
- Planning detailed satellite imagery based on the above information
- Looking for funding from, e.g. from regional development partners
- Preparing funding proposal (with, if possible, the involvement of trainee students), and
- Project implementation

Whatever the method adopted, the value of such a resource assessment to the development of energy policies in the region cannot be under-estimated.

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Chapter 22
A Method for Mapping Monthly Solar Irradiation Over Complex Areas of Topography: Réunion Island's Case Study

Miloud Bessafi, Béatrice Morel, Jean-Daniel Lan-Sun-Luk, Jean-Pierre Chabriat and Patrick Jeanty

Abstract The aim of this study is to build a high-resolution mapping model for Réunion, a mountainous island with highly complex terrain. The dataset used here, which consists of solar irradiation, is not available from the regular weather station network over the island. This network is relatively dense and includes quality-monitoring stations, thus providing enough information to tackle the problem of climate data interpolation over the complex terrain. A model for mapping the monthly means of such variables is presented. It combines Partial Least Squares (PLS) regression with kriging interpolation of residuals. For all the variables, the same set of nine predictors, including altitude, geographical and topographical features, was selected for PLS regression. The regression model gives statistically good estimates of monthly solar irradiation. Accuracy improves significantly using solar radiation mapping built with regression+kriging than for mapping built with regression only.

Keywords Solar irradiation · Spatial distribution · Partial least squares regression · Kriging

Short Introduction

Réunion is a small, hotspot volcano island located 800 km off the east coast of Madagascar and recognised as vulnerable to climate change. The observation network in its mountainous and complex terrain is irregularly spatially distributed. In order to capture meteorological spatial variability, the setting up of a high-resolution regular grid (<1 km) is needed due to the small size of the island. This

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_22,

study offers a model that combines Partial Least Squares (PLS) regression with kriging interpolation of residuals, which proved to be more efficient than geostatistical mapping based only on statistical interpolation of observational data.

Introduction

The last decade has seen the development of much high-resolution spatially -distributed climate data for use in various fields. Many long-term time-mean meteorologically-gridded datasets have then been developed (Brunetti et al. 2009; Chen et al. 2007; Efthymiadis et al. 2006; Gyalistras 2003; Hirabayasi et al. 2008; Mitchell and Jones 2005). Moreover, several authors have pointed out that high-resolution mapping (<1 km) is often required to take into account high topographic variability (Daly et al. 2007; Pape et al. 2009). Thus, geostatistical mapping based only on statistical interpolation of observational data is not sufficiently accurate to estimate spatial climate patterns, as explained by topographic variables, in complex terrain (McKenney et al. 2006).

Réunion (a French overseas *département*) is a small island located in the south–west Indian Ocean (55°E–21°S) and 800 km off the east coast of Madagascar. It is a hotspot volcano with three calderas (Mafate, Salazie, Cilaos). Moreover, the observation network in this mountainous and complex terrain is irregularly spatially distributed. In order to capture this meteorological spatial variability, the setting up of a high-resolution regular grid (<1 km) is needed due to the small size (2,512 km^2) of the island and its topographical context. In addition, Réunion has been recognised as vulnerable to climate change. High-resolution gridded climate data should be used, then, as a complementary tool for assessing energy resources and meeting insular requirements and policies for renewable energy.

This paper addresses the issue of improving the spatial coverage of monthly solar irradiation over Réunion, which is a mountainous small island with very complex terrain (Fig. 22.1a).

A multivariate approach is used here to include elevation and additional topographical and geographical parameters, which are expected to reflect the effects of local topography and weather patterns on global solar radiation. The dataset consists of ground-based observations from the Météo-France network. This network, which is a relatively dense network of quality-monitoring stations, provides enough information to tackle the problem of solar-data interpolation over complex terrain, and in this regard, makes Réunion a privileged area. Few islands, especially in the tropics, are as well documented.

The main objective of this study was to compute a regression law using a specific set of predictors. Some of them are linked to orographic pattern (height, slope), others to the tropical marine environment and weather (the distance between the recording stations and the sea, temperature inversion altitude, latitude, longitude).

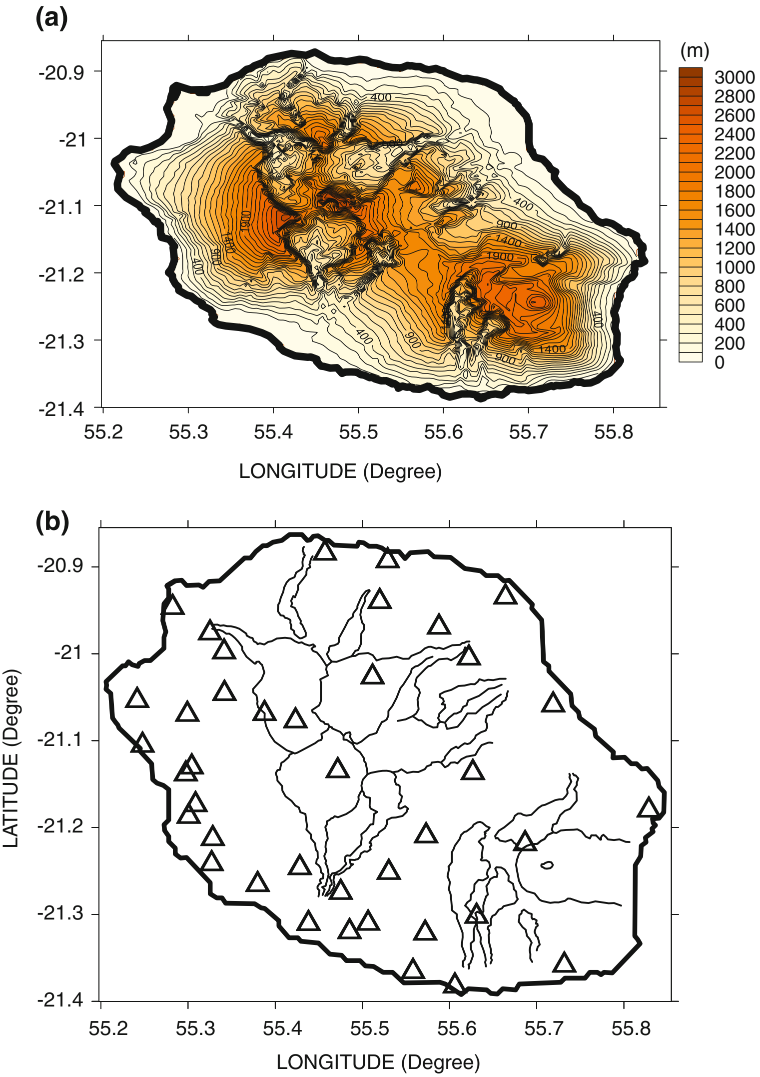

Fig. 22.1 **a** 250 m DEM topographic data for Reunion. **b** Solar radiation observing station network over Reunion provided by Météo-France

For each month, a regression law was built for the whole island. Finally, a residual kriging was applied to improve the mapping. In this work, this regression method has been applied to solar irradiation in the same way. This takes into account the slope aspect and orientation which is assumed to be important to solar irradiation (McCune and Keon 2002); (1) to compute the distance to the sea with real coastlines from a Digital Elevation Model (DEM); (2) to compute a regression equation with the Partial Least Squares (PLS) procedure in order to handle collinearities among the predictors, and to set up the model to have the best correlation between the predictors and the predictand.

In Data, we describe Météo-France's station data and the DEM used to generate high-resolution gridded maps of monthly global solar irradiation for Réunion. In Methodology, we present the mapping methodology based on PLS regression and residual kriging interpolation. Regression focuses on the obtained results and discusses the efficiency of the model to produce a suitably high spatial resolution solar radiation dataset for Réunion. In the last instance, some conclusions are highlighted.

Data

The original dataset consists of daily time series of solar irradiation over a period of 10 years, for a total of 40 individual Météo-France meteorological recording stations (Table 22.1). These stations did not take regular measurements over time, so quality check control and a homogenisation process were required. These two procedures were performed by the French Meteorological Service (Météo-France 2000). The stations are irregularly spatially distributed over the island (Fig. 22.1b) with about 80 % of them being situated below 1,000 m.

In this study, we propose the interpolation of the station data on a regular grid with higher resolution. The spatial interpolation algorithm is based on regression and employs a DEM provided by the French National Geographical Institute (IGN) to describe the relief of Réunion. We used the IGN-BD ALTI® 250 m product on a regular grid of 250 m resolution. This product is a matrix of size 267 × 160 (42,720 pixels). Elevations measured in situ at each recording station and elevations predicted by the DEM for the same locations can vary substantially according to the model's resolution (Goodale et al. 1998). For each of the 40 individual recording stations, we then compared the nearest pixel elevation, as given by the model, to the corresponding measurement point.

Table 22.1 Features of the solar irradiation observational network

Solar radiation	
No. of sites in data set	40
Mean duration of records (year)	10
Minimum elevation (m)	5
Mean elevation (m)	549
Median elevation (m)	379
Maximum elevation (m)	2,245
Standard deviation (m)	576
1st quartile (m)	119
3rd quartile (m)	806
No. of sites with elevation >500 m	17

Methodology

In this paper, the daily station observations were used to produce monthly grids. The daily time series of the climate variables provided by Météo-France were thus transformed into monthly averages prior to the gridding process. Daily solar-irradiation data records collected from 40 stations were averaged by month over the period 1998–2008 (Table 22.2).

The methodology in this study is a two-stage process of multiple regression of the monthly climate variable (which may first be normalised) with an extended set of predictors, followed by interpolation of the model residuals on a grid.

Regression

An exploratory analysis shows that the meteorological elements to be modeled over the study domain (Fig. 22.1b) exhibit dependencies on geographical features, especially topography. The summary statistics associated with the monthly solar irradiation at the stations, are presented in Table 22.2. This parameter fluctuates significantly over the year. There is a noticeable contrast between the monthly means for summer and winter. As mentioned previously, this feature is mainly due to large-scale tropical seasonal patterns like the ITCZ and the trade winds (Météo-France and Atlas climatique de La Réunion 2000; Taupin et al. 1999) and the associated trade-wind inversion. As far as solar irradiation is concerned, a minimum value of $971 \times 1e^{-4}$ J/m^2 was observed in July at Petite France (1,200 m asl.) over the north–west inland side of the island and also in June at Le Baril station (115 m asl.) in the south of the island. A maximum solar irradiation of $2{,}536 \times 1e^{-4}$ J/m^2 was observed in November, again at Bellecombe station. The preceding analysis shows different features from one place to another in the spatial patterns, thus revealing the complexity of the effects of mountainous orography, as well as of tropical weather, on a mesoscale.

As shown in Fig. 22.2, solar irradiation is not linearly distributed as compared to temperature, and it is difficult to extract any linear pattern. The spatial distribution of solar irradiation seems to be additionally influenced, throughout the year, by the meteorological conditions over the island, like the trade winds and the wind and temperature inversion. In a tropical, marine boundary layer, the low-level temperature inversion is generally located at the top of this layer, typically at an

Table 22.2 Climatological characteristics of solar irradiation over Réunion island

($1e^{-4}$ J/m^2)	Min.	Mean	Median	Max.	St. dev.	1st quartile	3rd quartile
Year	971	1,665	1,629	2,536	333	1,403	1,938
Summer (November to April)	1,101	1,816	1,794	2,536	301	1,577	1,315
Winter (April to October)	971	1,514	1,452	2,484	294	1,315	1,693

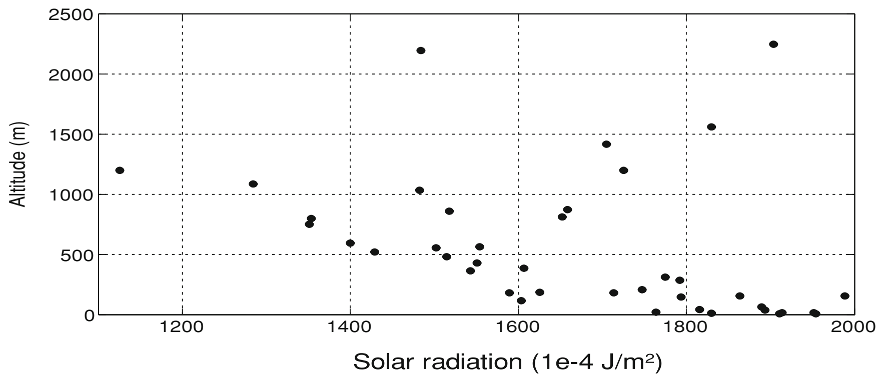

Fig. 22.2 Solar radiation averages from Météo-France recording stations at different altitudes over Réunion

altitude of 1,000–2,000 m, and corresponds to the large-scale pattern of the Hadley-Walker cell circulation (Zeng et al. 2004). The results in Fig. 22.2 thus show that simple dependence on parameters such as elevation cannot explain the observed variability in solar irradiation, thus justifying the extension of the predictor set as follows.

Nine predictors are used in this study namely: altitude; minimum distance from the station to the coastline; four altitude threshold criteria as defined by Douville (1992); slope; latitude and longitude. These predictors are commonly used for mapping climate variables (Abdi 2010; Goodale et al. 1998; Guan et al. 2005; Gyalistras 2003; Hunter and Meentemeyer 2005; Kyriakidis et al. 2001; Portalés et al. 2009).

For the regression model, we combine Principal Component Regression (PCR) and Multi Linear Regression (MLR) approaches to capture the maximum variance of the predictor set, and to maximize the correlation between the predictor set and the predictand. Thus, to establish a relationship between the monthly mean of the selected solar irradiation parameter and the predictor set, we have chosen to perform a PLS Regression (PLS-R), which would be a more suitable approach for mapping solar irradiation at Reunion. PLS was developed in the 1960s by Herman Wold in the scientific field of econometry (Wold 1966). PLS-R is used to describe the relationship between multiple-response variables and predictors through latent variables (Abdi 2010; Goyal and Ojha 2010; Tootle et al. 2007). It seeks to extract a set of mutually orthogonal components from independent variables that maximises the predictive power for one or more dependent variables. Moreover, PLS is a particularly useful method when predictors are cross-correlated (D'ambra and Sarnacchiaro 2010; Tan et al. 2008; Yeniay and Göktas 2002). In order to achieve the most accurate predictive equations, we have used a cross-validation procedure to identify the most appropriate dimension for the regression models (Abdi 2010). For more details, readers can refer to reviews from Höskuldsson (1988) and Wold et al. (2001).

Residual Kriging

In this study, solar irradiation is related to some elevation and terrain morphology-derived parameters via PLS regression analysis to create a gridded dataset of the climate variables. Over a highly mountainous and complex terrain like Réunion Island, solar irradiation highly depends on the local meteorological conditions caused by the relief. As mentioned previously, this effect cannot be fully explained using only linear regression. The idea here is to extract additional information, as contained in the part left unexplained by the PLS model, using ordinary kriging of the regression residuals over a regular grid (Issaks and Srivastava 1989; Matheron 1971). PLS residuals refer to the difference between predicted values from the PLS model, and the observed values at all measurement sites. In this case, the final maps of the monthly means for each climate variable are derived by adding the interpolated residuals to the initial regression-based field.

Results

The quality of the PLS regression model was tested using a leave-one-out cross-validation (LOOCV) procedure. For each month, a model was fitted to all stations except the first one, and the climate variable estimate for this station was computed. It should be noted that the PLS model was run twice. In the first run, all predictors (nine) defined in the last Section were considered in its modeling; while in the second run, after finding the estimated number of significant components that minimise the Predictive Residual Sum of Squares (PRESS) (e.g., Wold et al. 2001), only these components were considered in the modeling procedure. The LOOCV procedure was repeated by successively dropping each station, one at a time. Predicted values for all stations were then compared to the observed ones. For that purpose, two classical criteria were used here: Root Mean Square Error (RMSE), and average Skill [SK; Ward and Folland (1991)].

Figure 22.3, which shows the results of the LOOCV procedure for monthly solar irradiation, indicates that the model achieves satisfactory predictive performance on average, except for certain respects. Even if the average skill is very high (SK $\sim$80 %) and the statistical error is low, the scattering of points about the line of best fit increases. Moreover, Fig. 22.4 reveals that the model overestimates low solar irradiation values. The model overestimates the observations by 10 % at values less than 1,500 J/cm^2. On average, the model was run with two PLS components. Based on these two components, percentage variance captured by the predictors is 54 %, explaining 18 % of the variation in solar irradiation during June and July. For the other months, proportion of explained variance is higher (from 61 % for the predictors to 31 % for the predictand).

In this work, fit quality of the PLS regression model was assessed in cross-validation mode. To calculate skill scores of the model in prediction mode, it is usually necessary to apply the model to a testing dataset different from the training

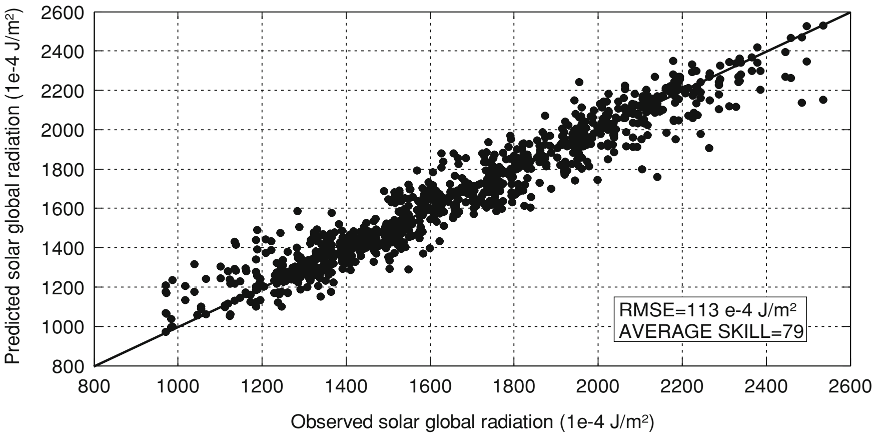

Fig. 22.3 Observed versus predicted values of solar irradiation

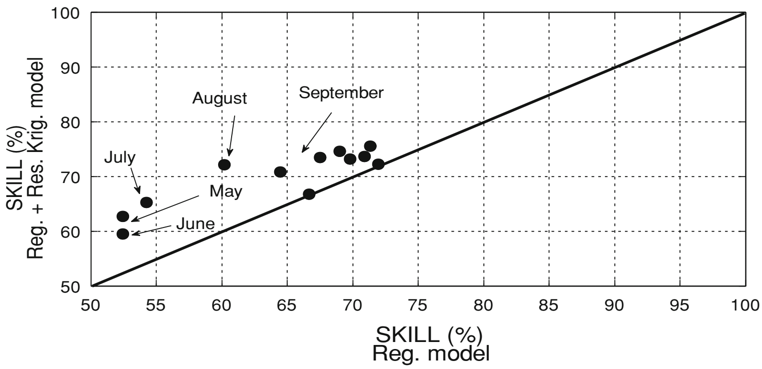

Fig. 22.4 Comparison of the predictive capability of the pure regression model and the regression+kriging model, for solar irradiation

dataset used to compute the model. In our case, such an approach would have some drastic limitations as: (1) the sample size is small with sparse data over the island, so that subdividing the sample data into training and test sets would not provide a sufficient sample size to assess the statistical significance of regression; (2) the spatial patterns of solar irradiation over the island are so complex that the regression equation would very much depend on the way the dataset is partitioned into training and test sets. It is important to have both a training dataset and a separate, spatially well-distributed, dataset if we want these datasets to be representative of the prevailing patterns of solar irradiation over the island. In this work, the performance of the model in prediction mode was thus tested in the following way: (1) define a regression model based on a subset of observations from the available meteorological stations; (2) apply this model to predict values at the

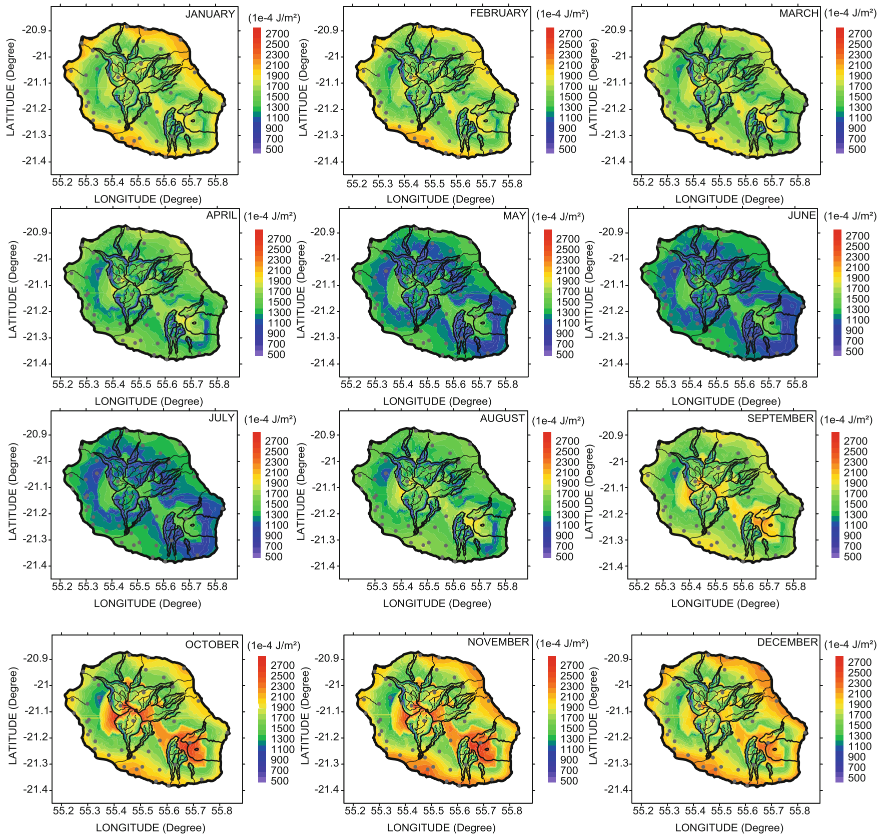

Fig. 22.5 Monthly mean solar irradiation mapping of La Réunion. Station locations are displayed with *grey dots*

remaining meteorological stations considered as an independent test dataset. At Step (1), observations were randomly excluded from the original dataset using Monte Carlo (MC) simulations. Each MC simulation consisted firstly of generating a random number of stations to be extracted, and secondly of randomly extracting the number of stations from the available stations. The size of the extracted sample was limited arbitrarily in such a way that it did not exceed 20 % of the available stations at the most. At Step (2), predicted values for the remaining stations were compared to the corresponding, observed ones. In this work, Step (1) was repeated 5,000 times. Information on prediction error statistics for the entire year is retrieved from the preceding procedure. Note that the performance of the model is slightly different over the year. A good level of accuracy is also obtained, however, the model appears to be less efficient at predicting solar irradiation in May to August, especially in May to July when the lowest scores are found (SK <55 %).

One possible way to improve the predictive performance of the model for solar irradiation in May to August is to explore and fit the spatial residual error. Modeling and taking into account the residual error in regression is a well-known technique in mapping, known as residual kriging. Several studies have been conducted to map solar irradiation (Alsamamra et al. 2009) using residual kriging. Figure 22.4 shows that adding kriged residuals to the PLS regression estimates leads to significant improvement in predicting solar irradiation especially during the winter season.

Figure 22.5 displays the results of mapping processes presented here for each month of the year. We can see the impact of both the altitude and the topography of the terrain through the year.

Conclusion

In this study, a multivariate prediction model, using only topographic and geographic parameters as predictors, was defined to estimate the spatial distribution of monthly maximum and minimum solar irradiation over Réunion, a mountainous island with highly complex terrain. The weather prevailing over the island is dominated by both synoptic tropical weather (ITCZ, trade winds) and orographic effects. Such a configuration leads to a seasonal contrast throughout the year with roughly a windward-leeward regime along a south–east–north–west axis on the island. In addition, the presence of the calderas and the volcano, and the marine conditions make the spatial weather pattern over Réunion more complex. The predictor set in the regression model was built up using geomorphological information (elevation, slope, geographical location) available at the stations, along with the minimum distance of these stations to the sea as computed using a DEM model and altitude threshold criteria. A model based on Partial Least Squares regression was chosen so as to deal with correlated predictors and maximise the correlation between the independent variables (predictors) and the dependent variables (predictands). Combination of the DEM model and information from stations to define the predictor set, together with PLS regression, produced good results. A good level of accuracy was also obtained for solar irradiation. Residual kriging significantly improved accuracy in solar irradiation prediction during austral winter. Thus, this model is found to be relevant for high-resolution mapping of solar irradiation over complex terrain like that of Réunion.

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Chapter 23
Case Study Analysis of Urban Decentralised Energy Systems

Ksenia Chmutina and Chris I. Goodier

Abstract The UK has set an ambitious plan to substantially cut its carbon emissions. In order to meet this 2050 target of 80 % reduction, the UK is facing a significant challenge of restructuring its energy system, currently characterised by lock-into centralisation. There is however, potential to challenge this lock-in through the development of more decentralised energy systems—based not only on technological, but also on more innovative political, social and economic approaches. Examples of these unique approaches have already been successfully implemented in many cities worldwide, demonstrating that more decentralised energy systems can lead to enhanced carbon emissions reductions. Using a multi-disciplinary framework, this work critically assesses several urban decentralised energy systems around the world through the assessment of exemplar international case studies. Following semi-structured interviews, this work compares and critiques four diverse international case studies in order to demonstrate and contrast a variety of decentralised approaches. It emphasises the variety and inter-relationships of barriers and drivers involved in the implementation of such projects. Although it is believed that regulations heavily influence the implementation of decentralised energy projects, these projects are frequently driven and motivated by other factors such as reputation, profitability and the opportunity to show that "we can do it". The main non-technical barriers are not necessarily financial, as is often believed. Governance barriers—such as out-of-date regulations or unreliable partners—also play an important role in the success or failure of a project. Social barriers in the form of public apathy and misinformation regarding energy consumption can also be significant, which often affects the operation on the project.

Keywords Decentralization · Energy systems · Lock-in · Renewable energy · Carbon reduction · Future scenarios · Case study

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_23,

Short Introduction

The UK is facing a significant challenge of restructuring its energy system in order to meet the 2050 target of 80 % reduction, by focusing more on decentralised energy systems. Following semi-structured interviews, this work compares and critiques four diverse international case studies in order to demonstrate and contrast a variety of decentralised approaches. Although it is often believed that the main non-technical barriers are mostly financial, this paper argues that governance barriers (out-of-date regulations or unreliable partners) and social barriers (public apathy and misinformation regarding energy consumption) can also be significant.

Introduction

The urban environment is responsible for significant amounts of greenhouse gas (GHG) emissions; at the same time, urban population and infrastructure are vulnerable to the effects of climate change, such as heat waves, sea level rises, and catastrophic climate event (Carbon Disclosure Project 2011). In order to reduce GHG emissions and save energy, the urban environment worldwide faces the challenge of transforming established energy systems based traditionally on the use of fossil fuels. A shift has to be made towards more sustainable and renewable forms of energy (Government Office for Science 2008; Rydin et al. 2012; Walker et al. 2007) and a number of towns, cities and communities are moving successfully towards those new models of energy generation and supply.

The UK has set an ambitious target of 80 % carbon emission reductions by 2050, but to reach this target the significant challenge of restructuring the energy system has to be addressed. Currently, the UK energy system is characterised by a lock-into centralisation (Bergman and Eyre 2011; Walker et al. 2007). There is, however, a potential to challenge this lock-in through the development of more decentralised energy systems based not only on technological but also on more innovative political, social and economic approaches. Indeed, many cities worldwide have already pioneered unique and effective approaches to more decentralised energy systems leading to enhanced carbon emissions reductions. This paper critiques and compares some of these approaches in order to demonstrate a variety of potential decentralisation approaches.

In this paper, none of the case studies contain a thorough evaluation of the project impact and effectiveness with regards to their UK implementation; however, the diversity of the projects provides valuable information regarding decentralised urban energy systems and their ability to help address climate change and challenge urban energy systems lock-in. The case studies presented here cover only a small proportion of the decentralised urban energy projects that currently exist. The focus and motivation for selection of these case studies was their unique and original approach, together with their potential, yet unrealised, applicability within the UK context. To exemplify the multiplicity of pathways that potentially exist towards decarbonisation, it was intentional to present a range of energy resources, technologies, end users and types of project intervention.

Decentralised Urban Energy Systems

The shift towards more sustainable energy systems is extremely challenging and involves a range of complexities, choices and strategic decisions: there are various renewable energy technologies with different applications, technological and infrastructural needs and degrees of maturity; there are different scales at which technologies can be implemented; there are also issues of environmental impact and social acceptance, as well as powerful commercial and political lobbies (Walker et al. 2007).

Many European and other countries are beginning a transition from a centralized and largely fossil-fuel and nuclear-based power systems toward a more decentralized power system relying to a larger extent on small-scale generation from renewable energy sources and Combined Heat and Power (CHP) units, allowing greater active participation of consumers by becoming producers themselves and/or by smarter demand response management of their own energy use (European Parliament's Committee on Industry, Research and Energy 2010). The main drivers for this transition are not only the necessity to reduce GHG emissions, but also to increase the share of renewables in the energy mix and to make the use of energy more efficient. Rising electricity demand and the price of fuel, liberalisation of the markets and increasing concern over energy security also play important roles in encouraging decentralisation of energy systems (European Parliament's Committee on Industry, Research and Energy 2010).

Various schemes exist which prove that it is possible to challenge lock-in in different economic, political and social contexts. One example is Barcelona's innovative policy framework—Solar Renewable Ordinance that started as a support tool for solar thermal and has now been extended to photovoltaic (PV). China also encourages the use of solar energy: according to Rizhao solar policy, it is mandatory for all retrofit programmes to install solar water heaters, while almost all the traffic and street lights and park illuminations are powered by PV cells (Kwan 2010). Other examples include sustainable communities such as the Sustainable Urban District Vauban in Freiburg, Germany and Fossil Fuel Free Växjö in Sweden. The USA also encourages a variety of renewable energy projects from community-led wind farms to green gyms heated by the power created by gym users.

The concept of lock-in has originally been used as a characteristic of an economical assumption but is now frequently discussed in the context of high carbon energy systems (Unruh 2000). The notion of lock-in does not just include technological aspects, but also includes financial (e.g. market rules), governance (e.g.

institutional arrangements) and social aspects (e.g. social norms), all of which can present barriers to the changing of an energy system (Turcu et al. 2011).

Decentralised energy systems are frequently claimed to be more resilient, reliable, efficient and environmental friendly, as well as more affordable and accessible whilst offering greater levels of energy security (Alanne and Saari 2006; Coaffe 2008; Roberts 2008; Turcu et al. 2011). An emphasis on the potential benefits of a more localised and distributed pattern of energy generation and on the involvement of the community emerged in the UK in the late 1990s (Walker et al. 2007). For example, Local Agenda 21 principles were called to be applied to local energy planning in 1999 by the Local Government Association (1999). Various parts of the 2003 White Energy Paper also relate to 'local' and 'community', stating for the first time in official energy policy a future of energy generation in a more local mode (Department of Trade and Industry 2003). The UK is making efforts regards introducing policies that encourage new initiatives which may effectively challenge current lock-in (Turcu et al. 2011), as well as contributing towards its energy targets. The UK has legally binding targets of delivering 15 % of all energy from renewable sources by 2020, and reducing GHG emission by 80 % by 2050, with a reduction of at least 34 % by 2020 and a target to achieve 9 % energy savings by 2016 (Department of Energy and Climate Change 2008). A variety of policies have been introduced in recent years ranging from financial tools such as the Low Carbon Building Programme and Carbon Emission Reduction Target (CERT) to local innovative planning policies and subsidies for the installation of new technologies such as the Feed-in Tariff. A good example of policies that may help drive decentralisation is declaring that all new built residential and non-residential properties must be 'zero carbon' by 2016 and 2019, accordingly, thus require some way of generating energy on-site (Government Office for Science 2008).

However, the development of decentralised systems in the UK is much slower when compared to similar developed countries such as Denmark, Germany, Sweden and others, partly explained by the fact that most of the UK policies are aimed at energy generation rather than demand (i.e. user-behaviour) (Bergman and Eyre 2011). In addition, there is frequently a lack of direct connection between personal behaviour and energy consumption: there is a mixture of economic, technical, cultural, behavioural and institutional barriers that often slow down the uptake of the installed technologies and the potential maximisation of energy savings and emissions reduction.

Challenging Lock-in Through Urban Energy Systems (CLUES) Project

In order to critically evaluate the pursuit of decentralised urban energy systems in the light of carbon reduction targets in the UK, the CLUES project began in 2010, focusing on the potential scope for scaling up various individual examples of decentralised urban energy projects to a national level. One of the specific objectives is to undertake a comparative analysis of urban energy initiatives in the UK and internationally in order to understand the processes involved in transforming local exemplar cases to practices replicable at different scales and in different local contexts (Rydin et al. 2012).

This paper discusses the international initiatives only: with the UK initiatives being discussed elsewhere (Wiersma and Devine-Wright 2012). As well as gathering and analysing the information regarding these innovative international urban decentralised energy projects, it is also important and valuable to identify the potential possibilities of their application and scaling up in the UK.

The four case studies discussed here are from the USA, the Netherlands, Germany and Sweden with the focus on the experience of the project's development, rather than on a critical evaluation of policy or the technical efficiencies of the projects. Indeed, these countries have already successfully pioneered a variety of unique and effective approaches to more decentralised energy systems leading to enhanced carbon emissions reductions. It could be hypothesised that some of the best practices of decentralised urban energy systems implemented in Europe and worldwide are potentially replicable in the UK. However, when discussing replicability, it is important to consider that together with available natural resources and the access to technology, aspects such as social and cultural embeddedness and political and financial context also need to be considered. The definition of decentralised energy is much wider than just the physical technologies of heating, cooling and electricity generation; it is a concept that encompasses energy systems at different scales, with different institutional, policy, environmental, economic and social contemplations (Watson and Devine-Wright 2011).

International Case Studies

The four case studies presented in Table 23.1 were chosen due to their geographic diversity and their variety of financial and technical approaches, together with their potential, yet unrealised, applicability within the UK context.

Seawater District Heating System: An Example of the Hague (Scheveningen/Duindorp)

The City of The Hague and Vestia Housing Corporation partnered with Deerns Engineering Consultancy to implement this energy source in the reconstruction of 800 highly energy efficient houses located within Duindorp—an area along the North Sea Coast.

Table 23.1 Comparison summary of four case studies

	Seawater district heating	Morris model	Energy saving partnership	Kungsbrohuset office building
Location	The Hague, Netherlands	Morris county, New Jersey, USA	Berlin, Germany	Stockholm, Sweden
Technology/area	Seawater heating	PV	Building retrofit	Eco-smart building
Focus	Heating and cooling	Financing	Financing	Profit
Date started	1999	2009	1997	2010
Scale	750 houses	19 municipal buildings; 3.2 MW	1,400 buildings	1 building, 27,000 m^2
Investment	€10 m	$30 m (in bonds)	No initial investment	€120 m
Funding body and instigating party	Vestia (housing corporation)	Morris county Improvement authority (MCIA)	Berlin energy agency	Jernhusen
Energy/CO_2 reduction	50 % of CO_2 reduction	51,500 MWh over 15 years	60,400 t of CO_2/year	50 % of energy consumption reduction
Aim	Sustainability	Financial savings		Profitability

The technologies involved are not new: the innovation lies in their combination that allows constructing a very efficient system for making seawater or surface water the source of energy for heating and cooling homes as well as heating water all year round (Goodier et al. 2012). The overall efficiency of the heat generation process with this system is more than 50 % greater than conventional high-efficiency boilers, while the cost to the residents is the same (The City of The Hague 2009).

The sea water heating plant is part of the city's plan to use more sustainable energy and is one of the steps being taken towards making the area 'climate neutral'. In 2009, the plant was awarded a Climate Star for their climate protection activities (The City of The Hague 2009).

Morris Model: A New way of Financing PV for Municipal Buildings

The Morris Model is a unique and cost effective method of financing municipal renewable energy projects for public facilities through low-interest bonds, traditional Power Purchase Agreements and federal tax. It allows local government to receive access to renewable energy at a price lower than they currently do, without any debt obligation. The Local Financial Board approved the MCIA bonds of up to $30 m. The MCIA issued $21.6 m of debt at a 4.46 % net interest cost with a county guarantee to fund 19 solar projects with 3.2 MW capacities (Chegwidden et al. 2010).

Traditionally, local governments had two ways of financing solar programmes: either with tax exempt bonds (local government-owned approach), or by entering into turnkey relationships with private solar developers. The Morris Model is a hybrid that incorporates these two approaches and takes advantages of both options, whilst minimizing drawbacks (Chegwidden et al. 2010). The project uses a turnkey approach but financing is provided at the lower cost of capital is obtained by government. This allows a cheaper financing for the solar development as well as preserving the utilities capacity to borrow from the private capital lending sources for other projects (Pearlman and Scerbo 2010).

The MCIA has completed the first phase of its award winning renewable energy project, providing the County with 3.2 MW in clean energy and around $3.8 m in annual savings (Chegwidden et al. 2010). The model has been replicated in Somerset and Union counties in New Jersey with several other counties in various stages of programmatic review (Chegwidden et al. 2010).

Berlin Energy Saving Partnership (BESP): An Innovative Approach to Commercial Buildings Retrofit

The BESP was first introduced by the State of Berlin in 1995. The concept was based on transferring energy management of state-owned properties to a partner, who uses private capital to self-finance the modernization of building infrastructure necessary to cut energy use and CO_2 emissions. In return, the partner guarantees annual energy cost savings for the state (Chmutina et al. 2012). Implemented energy efficiency measures include refurbishment of heating and illumination, energy management as well as user motivation.

This model has proved to be a success in Germany and is now widely replicated in other European countries, such as Slovenia, Estonia, Bulgaria, Romania, as well as in China, Chile and other countries (Chmutina et al. 2012). The next step in the development of BESP is "Energy Saving Partnership Plus": its aim is to extend the focus of the partnership on insulation and windows replacement.

Kungsbrohuset Office Building: Eco-Smart Office Approach

Kungsbrohuset is a 27,000 m^2 property in the centre of Stockholm, near the Stockholm Central Station. The owner of the building—Jernhusen—wanted to prove that it is possible to build a sustainable office building using available market materials and mature technologies rather than sophisticated but—in their opinion—'risky' innovations. The objective of the project was to create a development where the environment and energy-efficiency are central considerations. The building is advertised as being 'eco-smart', which includes three characteristics (Jernhusen 2012):

- Eco-smart building: The building with energy efficient façade and environmentally adapted materials, combined with other innovative solutions that lead to three environmental certifications.
- Eco-everyday: Services and technical solutions that enable users to operate in an eco-friendly way.
- Eco-location: The building's proximity to public transport makes travelling and transports easier and contributes to lower CO_2 emissions.

Discussion

Rather than discussing drivers and barriers separately, this paper presents an aspect based analysis that reflects the variety of interconnections influencing the outcomes of the projects. Governance aspects include both structure and process, and involve public, public–private and private activities. By social aspects we understand not only the end-users in the discussed cases, but also those 'affected' by these project, such as communities living around schools, people living in the area where the construction takes place and those engaged in public consultations.

Governance Aspect

The case studies represent three types of governance: The Hague system was initiated by a private company and was supported by the local government, Kungsbrohuset is fully run by a private company, and both Morris Model and BESP were initiated by local governments and implemented through a third party.

The Hague system was initiated by a combination of stakeholders—local government, the housing corporation, the engineering consultancy and the utility company—who wanted to prove that a 'carbon neutral future is possible'. Vestia originated the idea of the district heating system for their newly renovated housing development, and the Deerns engineering company developed the innovative concept of seawater district heating:

> We have the sea here and there's a lot of energy in it and we can try to get this energy out of the sea and bring it into the houses so that we can reduce CO_2.

This decision, however, led to the dropout of one of the initial stakeholders—the utility company—which did not believe that the proposed system would work; this undermined the success of the project. Vestia therefore took all the financial risks thereon in and the project was thus completed. Vestia's policy has always been aimed at energy waste reduction and sustainability:

> Vestia had the initiative to be energy efficient. They were miles ahead of regulations, miles ahead of what the municipality asked then and actually wanted.

This initiative was supported by the City of The Hague, although at the time of the project introduction (1999) the City of The Hague had not yet developed their plan to become carbon neutral by 2050. The City of The Hague, Deerns and Vestia had previously been partners on a variety of projects such as housing renovation and ground source heat pump district heating systems. The City of The Hague supported Vestia's request for the planning permission to use Scheveningen Harbour since it was free after the container transporter moved to another harbour. This however, was not straight forward: the harbour is a part of the coastal defence system against flooding, so the construction could not take place between October and April, as sand is not allowed to be moved over this period of time. It is also a nature reserve that attracts tourism from May to September, which again restricted and slowed construction of the houses and piping infrastructure. Planning permissions also greatly delayed the timing of the project.

The Morris Model has a very different governance approach. Due to the nature of the public–private partnership, governance is closely intertwined with the financial aspect of the model. Morris County is an AAA rated local government and one of the wealthiest counties in the USA. This is very important when implementing a programme like the Morris Model, as the low cost bonds issued by the MCIA are guaranteed by the County. New Jersey is one of 38 states that have introduced a Renewable Portfolio Standard (RPS) according to which energy producers have to produce a share of their energy from renewable energy sources. The Morris Model is also triggered by the national regulation: Washington's tax code gives 30 % investment tax credit for PV along with 5 years accelerated depreciation. From 2009 the developer can also get a cheque for 30 % from the US treasury—this is a stimulus bill which was introduced to boost the economy and which expires in the end of 2011.

The idea of a hybrid funding mechanism was proposed by the MCIA in order to lower energy costs for the local government. This was possible by bringing together ('pooling') municipal buildings, as when pooled together, these buildings had enhanced purchasing power and were able to obtain an enhanced energy price from solar developers due to the increased scale:

> […] if you're a solar developer and you're looking at where I'm going to deploy my assets and wares, I'm much more interested in an 8 MW project than I am in a 250 KW project.

Choosing a pool, however, was not very straightforward due to the costs of site pre-screening until the developer is chosen:

> they[developers] do a preliminary look. They look at the sites, but they don't do a true engineering test and notwithstanding the screen[ing] that we do, there have been in each of these deals typically some change in the final makeup of the sites.

This financial model lowered the costs of energy dramatically and these savings were passed onto schools and municipalities. As one of the initiators of the project stated,

> everyone seems very happy with the final product. All of the stakeholders seem very happy. The developers make some money, the County has helped its local governments, the towns and schools have gotten renewable energy at a lower cost, so it truly has been so far a win–win for everyone.

The reason for developing BESP was to reach Germany's ambitious climate protection objectives, as well as to reduce energy costs. Its basic principle is simple: a private specialized energy service company (ESCO)—the contractor—brings its expertise and financial capacity into the project. The responsibility of the contractor is to ensure that by making adequate investments, the energy savings can be guaranteed. Both partners then share the cost reductions; profits are also shared between the client and the contractor, while energy consumption is reduced. BESP was initiated by the City of Berlin:

> …Berlin decided "Yeah, this is the right way for us to do energy refurbishment on buildings." And they were also really active to develop the model contract and so on and there was in these times a lot of strong, political back-up.

The City of Berlin is now only slightly involved in the BESP, and its implementation is the responsibility of the Berlin Energy Agency (BEA), which confirms a building pool (the client) and organises tenders for the ESCOs. Buildings willing to take part in the programme have to fulfill a set of criteria. The minimum size of the project is also important and, similarly to the Morris Model, in order to allow smaller buildings to take part in the programme, BEA can create a 'building pool'. After the client is chosen, BEA organises a tendering process for the contractor, who then implements the energy efficiency measures. The successful implementation of the BESP largely depends on the careful planning and development of the project.

Kungsbrohuset office building is managed by Jernhusen, who built it as a replacement for the old unattractive office building. The idea of making the new building sustainable came after watching Al Gore's film 'An Inconvenient Truth' and the consequent realization that climate change presented a good business opportunity. Having purely financial profit as the main aim, Jernhusen also wanted to prove that it was possible to build a highly energy efficient building using only materials easily available on the current market as well as mature existing technologies:

> We had no research in this building. There's no special materials that you just can buy from the American government or something. This is all purely made with normal stuff that you can find everywhere. And put together in a very delicate way. Any technology, any method, anything that we have done here is found somewhere else in the world. We don't want to be first with anything because we don't want to take the risk, and thereby showing people that you can do it as well if you just put your effort in it.

Because of the technologically challenging design and, the main problem experienced by the company during the project implementation was the coordination of the large amount of contractors;

> The main challenge is organisational I'd say. People who are not really… To get everybody on the train, to get everybody to co-work with these goals of getting it as energy efficient as we wanted, to work with the environmental situation. Some people just said "Why are we going to do this? Can't we do it like we've always done it? Why do you want to make energy calculations every 4 months? You're not going to earn many per cent on that," etc. etc. That kind of to persuade people and finally it comes to "Either you do as I tell you to do or we get rid of you." That was one of the hardest parts—to keep the line, to keep the focus on the target.

Problems were also caused by the Stockholm Sky Line Group who petitioned against high-rise buildings, and the public planning consultations. Similarly to The Hague case, this delayed the projects construction; this, however, did not affect the project negatively.

The success and popularity of the Kungsbrohuset office building can be attributed not only to access to finance by the building owners: they have managed their risks with a good market understanding, active involvement and strong commitment into the construction and operation process, together with a precise matching of new technologies and products with customer needs.

Financial Aspect

The total cost of The Hague system was €7.5 mln, of which €7 mln came from Vestia Housing Corporation and €0.5 mln from the City of Hague. The price of the energy for the end users is similar to the previous conventional system; this however, does not reflect the actual unit cost price—it is currently being subsidised by Vestia and is guaranteed to stay at the same level for 10 years.

Initially, the estimated payback period accounted for 20 years, however at the current rate this does not seem to be achievable due to one of the stakeholders leaving the project at its implementation stage. This caused a 25 % gap in investment, which was later covered by Vestia as no other subsidy was found. The National Authority was asked to invest in the project, but they rejected this, as they did not believe that the project would be successfully implemented. However, 10 years later the same National Authority was awarded the Climate Star for the "Best Innovation". In order to make this project profitable, more houses than the original 750 have to be connected to the system. A Further 250 houses are planned to be connected in the nearest future. As this project is the first of its kind, and was experimental in nature, it was developed not for profit but to help raise the profile of the City of The Hague as a sustainable city and to support Vestia's belief in sustainability. Vestia stated that although financially this project is not yet mature, it also raised the image of Vestia:

For the energy saving it is a success, and also for CO_2 reduction it's a success, and to learn about it for a lot of people is a success.

In the Morris Model, the MCIA played a very important role in financing. In the first phase the saving were around 35 % for the developers, and this lowered the cost of energy from US $0.15 or US $0.16 down to US $0.106. In essence, the private developer does not invest any of its own money. The main benefit of the model is that the County (through the MCIA) is fronting the money for the local towns, and instead of the private developer using their own private money from a bank, they go to the Improvement Authority acting as the bank to give them cheaper finance. The schools and others participating in the programme buildings do not have to invest anything, as all the installation and maintenance costs are covered by the developer. In addition, some of the participants needed a new actual roof as well, the price of which was also embedded into the project.

Morris Model gave a financial opportunity to install PV for those participants who would not be able to afford it otherwise. A good example is a Boonton School District:

As a school district we had a big construction project that went out for referendum for our voters in 2007 and I believe it was almost a $25 m referendum. It included the installation of solar panels and it was defeated. So when the solar panels were removed from the project and the project was scaled down a little bit the voters approved it. So this kind of came right at the right time when the community was not willing to pay for it.

Now the School District has 728 PV panels installed and in 2011 they aimed at saving around US $18,000.

Unlike Morris Model, BESP did not have any initial investment and the Berlin government did not provide any financial support to the ESCO. All the financing was made by the contractor. When signing a contract with the client, the contractor guarantees a minimum level of energy savings—on average it was 26 %. The contractor then receives his agreed earnings if the stated savings have been reached. At the same time, the client is able to save money through reduced heating and electricity consumption, itself achieved through enhanced energy efficiency measures. The investment carried out by the contractor is also refinanced through these savings. Any remaining savings are shared by the partners according to a ratio system agreed in the contract. The contractor is responsible for the maintenance and servicing of the system for the duration of the project (5–15 years), and the client only fully benefits from the complete savings once the contract has expired. In some cases, part of the refurbishment costs also come from the client, if the client wishes to implement additional energy efficiency measures that are not offered within BESP due to their high costs, such as windows replacement or renewable energy technologies installation.

The financing of the project may become a problem in the near future however: while the energy performance of the buildings is improving, the potential energy savings are decreasing, therefore there is an ongoing need for further energy saving measures, such as window replacement or insulation:

> We have the contract for this and we want to do this with some pilot projects, but still it's we still have to find a pilot case and we still have to find the financing because you need then some financing from subsidies or from other. The ESCOs cannot finance this.

This causes uncertainty among ESCOs, as energy performance contracting (EPC) may soon become more attractive to construction companies rather than ESCOs.

The construction of the Kungsbrohuset office building was financially driven and the project was fully financed by Jernhusen, the owner of the building:

> We want to build this product on solely an economical base. […]we had the land and we had the former building, so we had you could call it a business opportunity, but it's not [about sustainability]. It's mainly…to earn money.

The concept of the building as being 'green' and 'user-friendly' as well as the central city location of the building allows the owner to charge higher rents:

> We earn money on the tenants because they pay us money to rent the letting. We don't earn the money on the energy efficiency. That's just a bonus kind of. We earn more money because its energy efficient, but we don't earn money only because it's energy efficient.

The construction of the energy efficient office building was not a core business for the company; however, it now is a part of the company's strategy. After the Kungsbrohuset attracted a lot of attention and brought higher than planned profit, Jernhusen is planning to construct similar building in other cities in Sweden.

Social Aspect

Social aspects are crucial when discussing energy consumption reduction, particularly in building use, and introducing new low-energy initiatives does not necessarily mean rapid carbon reductions, as most of them require some form of human adjustment and change in behaviour.

In order for the seawater heating to work efficiently, for example, an understanding of how the system works is required from the end-users (occupants). To encourage the acceptance of the new heating system, Vestia organised information evenings for the occupants, as well as distributed information brochures; yet it took a long time for those living in the houses to accept some of the changes. The main challenge was the idea of the constant heating: when using seawater heating system, it takes about two days to warm up a house to the desired temperature, whereas with conventional gas heating, it is possible to obtain the required temperature within a few hours. Another barrier that slowed down the social acceptance was the fact that the system consisted of under floor heating, not wall-mounted radiators like the occupants' previous systems. Many did not appreciate that a particular type of carpeting must be used: otherwise the heat gets trapped and the temperature in a house does not increase efficiently. Again, this problem was being addressed through educational campaigns.

Vestia admits that the installation of the seawater district heating did not dramatically change end-user behaviour, partly due to the lack of interest and awareness:

> Because people with low income and low education, they… don't understand exactly how to use all this kind of stuff and they don't care about it. They care about other stuff—what the neighbours do and how to get beer or something. It is a social housing… It's a group where everyone knows each other. It's something like Coronation Street….

Although the change in end-user behaviour towards the acceptance of the seawater heating is slow, it does not dramatically affect the overall success of the project from a financial or efficiency point of view, and Vestia continues to run educational programmes in order to improve the awareness.

This raises the additional point of ensuring that any new type of renewable energy or energy saving system is designed with the end-user in mind, in order to work with the vagarities of occupant behaviour, and not against. The Kungsbrohuset building did exactly that:

> People don't want to change and they just want to have it the way that they've always had it and if they're going to change it has to be something better or easier or something. They don't want to do something that takes more time and they don't want to pay more money. They just want it to work anyway. So no, we have built this building so it kind of like helps them to save their energy.

In order to help the tenants save the energy without extra effort, the building is provided with energy efficient appliances, motion lighting, and the 'Green Button' that allows switching off of the electricity in the entire building (except for the computers). In addition, the energy monitor at the entrance hall of the building provides the occupants an opportunity to see how much energy has been generated and consumed.

Although behaviour change was not a part of the original idea, in order to maintain the 'green' reputation of the building, all the tenants in the building are supported by an expert who helps to minimize their impact on the environment. The building is also provided with a secure bicycle storage area, while the car parking space in purposefully limited. These factors, as well as the location of the building being close to the central railway station and bus terminals, encourage commuting:

> So there's 1800 people [in the building] and 100 car places. So that's 100 bosses who drive their cars. 400 go by bicycle and then it's 1300 who go by commuting I'd say.

The Morris Model did not have behaviour change towards sustainability as its primary objective; however, the buildings particularly the schools participating in this programme, saw a good opportunity

> to show our community and our students that our school district was attempting to do something that would be positive for the environment and also positive for the taxpayers.

In order to encourage a better understanding of renewable energy, solar developers were required to include educational components, such as interactive kiosks and LCD monitors. Some schools have portable kiosks that can be moved from class to class: this allows students to generate graphs and charts to see how much energy is being produced at any given time. They provide informative campaigns for the community and the taxpayers, as many see the low costs of energy *as too good to be true*.

Social aspect is an important part of the BESP. Every ESCO that carries out implementation of energy efficiency measures in the building is required to provide a user motivation programme, in the form of information distribution, workshops or others. This is particularly important in the current projects of the BESP, as the profit of the ESCOs depends on reaching the established energy saving target. There is a limit on how much savings the technical disruption can provide however, and in some cases the way users consume energy plays a crucial role, therefore it is in the interest of the ESCO to educate the end-user and hence, as a result to achieve higher energy savings. It is important to mention that user motivation is aimed not only at particular building staff such as estate officers, but rather at actual building users/occupiers, including even as far as kindergarten children. One of the companies involved in BESP commented:

> they[users]'re often very interested and very open to that, but the knowledge about energy saving, and also the ideas of what you can get as energy savings, is really far from reality. So there's a lot of lack of knowledge.

Workshops and awareness campaigns however, can sometimes cause problems:

> The expectations are often that high that they say "okay, we can replace the windows" like you said, or "Why can't we do some other things?".

These measures go beyond the technical possibilities of ESCOs and hence can sometimes cause tension between the client and the contractor.

Conclusions

The four case studies presented here vary greatly not only in terms of their technology, scale and location, but also in terms of their governance and financial mechanisms. It was demonstrated that governance and social barriers rather than technical and financial ones constitute central problem areas in the adoption of decentralised energy approaches, indicating multi-dimensional complexity associated with organising and staging energy supply. Governance drivers play the most significant role, although not necessarily in the form of regulations, whereas financial drivers that are normally believed to be crucial were not viewed as such. Our discussion—although it does not exhaust the full list of potential drivers—offers useful hints regarding these, including regulations with legally-bound targets, and social drivers, such as word-of-mouth. Such a variety of drivers implies that there are different, and often inter-connected, pathways to decentralised energy development. All four projects have already been replicated or are planned to be replicated, in their own countries and abroad, including in two cases (BESP and The Hague), the UK (although on a much smaller scale). Indeed, they have potential for replicating and scaling up in the UK and hence contributing to carbon reductions. Although the implementation of decentralised energy systems is facing various obstacles, it is important to remember that energy-related decisions made today will have long-lasting consequences not only in terms of investment but also in terms of their impact on society as well as wider global climate change.

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Chapter 24
Strengthening of R&D Competences and Engineering Skills for Renewable Energy Systems: Examples from the Hamburg University of Applied Sciences

Timon Kampschulte

Abstract The need for climate-smart technology has generated rapidly growing markets for renewable energy (RE) systems, and, in turn, a high demand for engineers and further specialists worldwide. Driven by the German energy policy strategy of transforming the German energy sector to be far more sustainable, up to half a million new jobs are expected to be created in the RE industry in Germany by 2030. At the same time, demand for research and development is increasing, and stronger cooperation between industry and research institutions is required. Furthermore, a transfer of technology and expertise from industrialised to developing countries is needed. Higher education institutions are challenged to meet this demand. Looking at the strategy of the Hamburg University of Applied Sciences (HAW Hamburg), we discuss how universities can focus more on renewable energy engineering in research and development, industrial cooperation and educational programmes. The formation of a Competence Centre for Renewable Energy and Energy Efficiency (CC4E), the adjustment of study programmes to include more RE content, the founding of an international master's programme in RE systems and the involvement of students in international RE technology and expertise transfer projects are discussed as a best practice example of RE activities at higher education institutions.

Keywords Climate-smart technology · Green jobs · Renewable energy engineering · Educational program · Technology transfer centre · Developing countries · Solar home systems · Rural electrification

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_24,

Short introduction

Facing climate change, the development and dissemination of climate-smart technologies are an important objective for industrialised and developing countries. The better use of renewable energy (RE) sources is the key to reaching climate goals. While in some countries, like Germany, the renewable energy industry is already booming, in other regions the use of RE is in its infancy. However, they have in common a high demand for well educated engineers and technology transfer. Examples from the Hamburg University of Applied Sciences show how higher education institutions can play a key role in this.

Introduction

The booming market for renewable energy (RE) technology has caused a significant demand for engineers and further specialists in green jobs worldwide. In Germany, the number of employees in the renewable energy industry increased by about 130 % from 160,500 in 2004 to 367,400 jobs in 2010 (O'Sullivan et al. 2011). Although financial and economical crises also affected Germany, a further increasing number of jobs in this industry is expected. This is mostly driven by the German government's ambitious plans to take the energy sector from the age of fossil fuels and nuclear energy, into an era of renewable energy. According to this plan, nuclear power stations will be switched off by 2022 at the latest, and by then at least 35 % of Germany's electricity demand should be supplied using RE resources (German Federal Ministry of Economics and Technology 2010; German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety 2011). Therefore, half a million jobs in the RE sector in Germany are predicted for 2030, based on a study on behalf of the German government (van Mark and Nick-Leptin 2011).

In order to meet the significant need for highly qualified manpower, universities recently started to develop specialised undergraduate and postgraduate programmes, during which students become acquainted with the technology of wind, biomass and solar power. Besides the labour demand, the request for stronger cooperation between industry and universities in R&D becomes relevant at the same time. Furthermore, cooperation in technology projects and transfer of expertise between industrialised and developing countries is an important objective in order to develop global sustainable development.

The Hamburg University of Applied Sciences' (HAW Hamburg) strategy to focus on renewable energy engineering in research and development (R&D), industrial cooperation and educational programmes is shown as a best practice example.

Formation of a Competence Center for Renewable Energy and Energy Efficiency

As one of the biggest higher education institution for engineers in northern Germany, HAW Hamburg has already identified renewable energy and energy efficiency as a major task and as a core area of the university's scientific competences for many years. In order to bring together the competences of about 50 professors and experts from engineering to economics, the university's "Competence Centre for Renewable Energy and Energy Efficiency" (CC4E) was founded in 2008 (Fig. 24.1). The competence centre is an internal platform for interdisciplinary exchange between the university's experts, and serves externally as a point of contact for cooperation partners. Since then, new cooperation with industrial partners, R&D projects, scientific conferences and also students' projects in the field of RE have been generated with support of CC4E.

The following list illustrates some of the projects and cooperation:

- Greenovation Initiative Hamburg: an association of the Hamburg headquarters of the three companies Siemens, IBM and Philips with HAW Hamburg was founded in order to work on projects to increase the efficiency of the city's infrastructure. As an example, engineering students, supported by the industrial partners, analyse school buildings in Hamburg to indentify energy saving potential in heating and lighting.

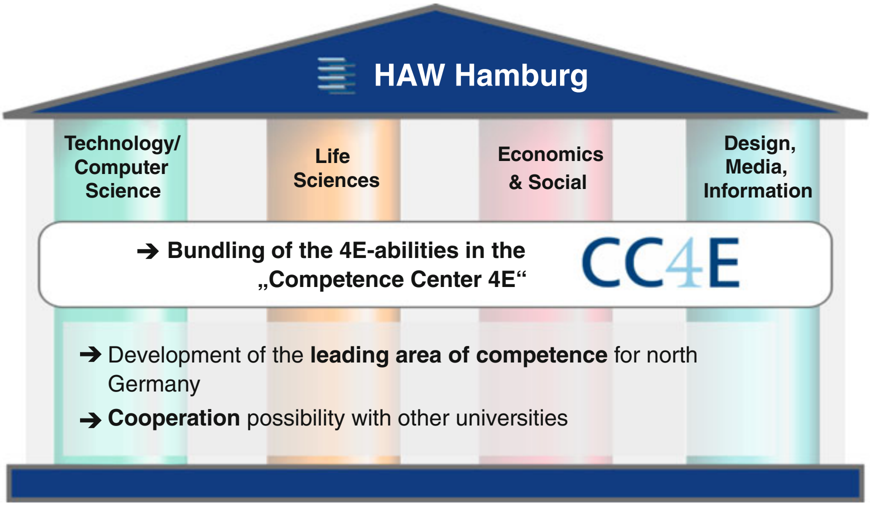

Fig. 24.1 The competence centre for renewable energy and energy efficiency, CC4E, at Hamburg brings together the university's competences for energy (4E) across the four faculties, and was founded in order to strengthen this area of education, R&D and cooperation with industry and other universities

- Smart Power Hamburg: a project funded by the German Federal Ministry of Education and Research HAW Hamburg, the Technical University of Aachen (RWTH Aachen) and the Hamburg-based utility company “Hamburg Energie” Research on so-called “smart grids”, which are much better at handling decentralised power plants, which are expected to increase in number due to the extension of wind farms, solar power plants and biogas systems. Furthermore, aspects of demand-side management and energy storage are covered by this R&D project.
- PVOpti: funded by the Hamburg municipality, photovoltaic (PV) systems were installed at the university’s roof. These systems are used in the R&D project “Photovoltaic-System Performance Optimisation” (PVOpti) aiming at an improvement of the system performance of grid-connected PV systems. With the help of extensive measurement equipment and good simulation tools, external effects like temperature, shading, soiling etc. can be analysed (Kampschulte 2009). In cooperation with a local engineering company, a new approach to energy yield simulation for PV power plants has been developed.
- More projects in the field of batteries, biofuels, biogas, fuel cells, RE management and marketing, solar energy, wind energy, etc. have been generated or supported and can be found on the CC4E website: www.cc4e.de.

Founding an International Master’s Programme in Engineering for Renewable Energy Systems

Until today, engineers employed in the RE industry mostly have backgrounds from traditional degree programmes in electrical, mechanical, environmental, process or industrial engineering; other experts with backgrounds in economics, law, media etc. are also hired. When talking to companies’ human resources departments, it was often bewailed that graduates and job applicants mostly have significant deficits when entering a job in the RE business. A survey of more than 120 RE companies in Hamburg by HAW Hamburg in 2007 revealed the companies’ high expectations and requirements of their applicants in the areas of suitable technical knowledge for renewable energy systems, interdisciplinary thinking and communication, social and management skills (Fig. 24.2).

Following the outcome of the survey and further internal and external discussion in the faculties, study programmes were adjusted to better meet the requirements of the RE industry. For example, in mechanical engineering and environmental engineering a greater focus has been placed on renewable and sustainable power generation.

In order to meet the demand from the international RE markets, a new master’s programme in “Renewable Energy Systems—Environmental and Process Engineering (RES)” (Master of Engineering) was launched successfully in 2009

Fig. 24.2 Percentage of RE companies requesting improved skills from their job applicants according to a survey of more than 120 RE companies in Hamburg by Hamburg in 2007

(Hamburg 2011). In this English-taught programme students gather both specific RE engineering and economics skills; in projects, they learn teamwork and solution-driven performance. As indicated by the module structure in Fig. 24.3, the programme covers mainly bio, solar and wind energy and sets a strong focus on systems engineering. Finally, in the master's thesis, which is usually completed in a company or external institution, students gain a deep insight into professional

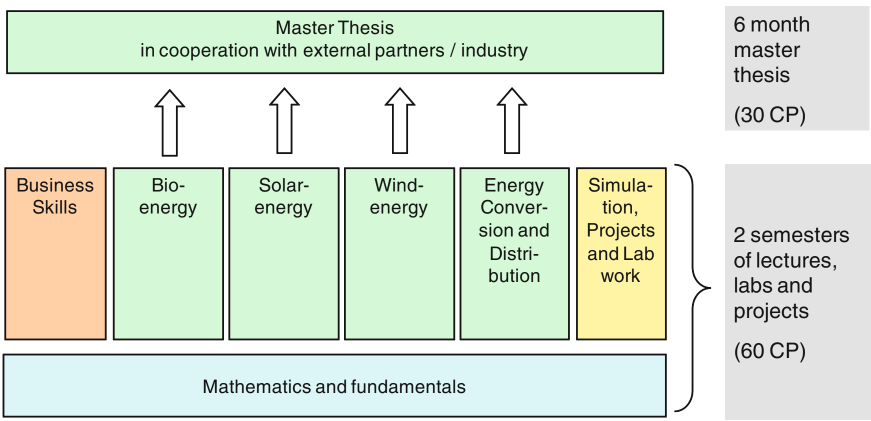

Fig. 24.3 Modular structure of the "Renewable energy systems—environmental and process engineering, (MEng)" master's programme at the Faculty of Life Sciences at Hamburg. Within three semesters, students gain 90 credit points (CP) in total, and are awarded the qualification of master of engineering (MEng)

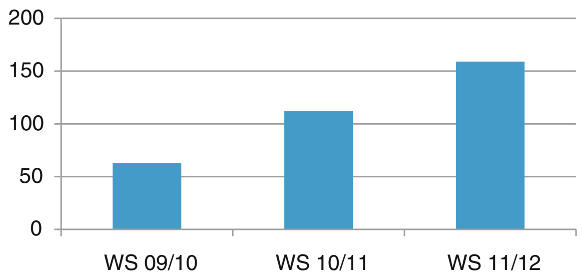

Fig. 24.4 Number of applicants for the "Renewable energy systems—environmental and process engineering, (MEng)" master's programme at the Faculty of Life Sciences at Hamburg for the winter semesters 2009/10, 2010/11 and 2011/12

problems which are relevant in practice. Alumni of this master's programme are in high demand in the export-oriented RE industry, as well as in technology transfer programmes.

Since 2009, more and more graduates from bachelor's programmes (bachelors in engineering) have been attracted to the RES master's programme due to its good reputation and the good connections between the university and RE companies, which allows alumni to find relevant work particularly quickly. As shown in Fig. 24.4, the number of applicants for this master's programme has increased significantly in the last few years. For example, for the winter semester 2011/12, about 160 applications were received for just 25 places on the master's programme. One benefit of this is that the standard of new students could be raised by the selection process.

To foster the international orientation of its students and academic staff, Hamburg also maintains several partnerships with universities around the world. In the field of RE, partnerships have been established with universities in Bolivia, Brazil, Kazakhstan, Sweden, Turkey and other countries. These partnerships between universities can help them to learn from each other and to establish or improve local educational programmes for the engineering of RE systems.

Involving Students in International Technology and Expertise Transfer Projects

In order to prepare students for the international environment of the RE industry, and in order to practise project management and communication skills, the involvement of students in international technology and expertise transfer projects is a promising approach. A successful example of a project introducing students to technology transfer between industrialised and developing countries is provided by the development and installation of a training stand for a photovoltaic solar home system for rural electrification, within the framework of a joint European and

Latin-America universities cooperation (JELARE 2011)—a project funded by the ALFA program of the European Union.

The goal of this student project was to develop a set-up of devices similar to the conventional solar home system used in developing countries. In addition, the set-up was to have more applications and loads, switches, sockets and meters to be prepared for use as a training stand for technicians and undergraduate students. A team of four master's students from different countries (France, Germany and Venezuela) was brought together and they arranged this project in six months alongside regular lectures and labs in 2011. The students' tasks ranged from researching local conditions in Bolivia (as a representative country in Latin-America) to calculating the electrical layout, selection and purchasing of components, mechanical and electrical installation, and final documentation and demonstration (Fig. 24.5). A local solar engineering company was also involved and provided practical knowledge. Finally, as an outcome of the project, the training stand now serves as demonstration equipment in solar energy lectures and can be used as a blueprint for similar course programmes. Although developed based on the environmental conditions of Bolivia, the engineering and the set-up can be easily transferred to the needs of small developing islands as they have similar requirements.

A second example of an international technology and expertise transfer project is a feasibility study for a solar power supply for a broadcasting transmitter of a public educational TV channel in Afghanistan. Since March 2012, three master's

Fig. 24.5 Master's students demonstrating the training stand for a solar home system which was developed and executed as a student project

students have been working on this project supported by the founder and operator of the TV channel.

Besides projects like those mentioned above, HAW students also make use of a practical semester as an intern or volunteer at a company, institute or NGO in a developing country to experience local needs and conditions first hand. For example, one student, who worked as an intern at a Bolivian solar company, continued with a bachelor's dissertation comprising his own field study on the reliability of solar home systems in several areas of Bolivia (Krink et al. 2012). Other HAW students undertake their practical semester in developing countries and small islands like Peru, Nicaragua, Chile, the Philippines, Mauritius, Barbados, etc. As in important outcome and learning point from those projects, internships and voluntary placements, students and university staff gain a lot of understanding of the cultural and structural characteristics of these countries and of the technical requirements for the use of RE systems. Furthermore, the RE concepts are disseminated with the projects.

Conclusion

A booming RE market creates high demand for skilled employees and for RE expertise, as well as a need for technology and expertise transfer from industrialised to developing countries, which is a big challenge for higher education institutions. In order to meet this demand, the Hamburg University of Applied Sciences has founded a competence center for renewable energy and energy efficiency (CC4E), which successfully brings together the university's RE competences and supports R&D projects and cooperation. In addition, study programmes have been adjusted to cover more RE content and an international master's degree in renewable energy systems has been introduced at HAW Hamburg. In these degree programmes, students are involved in international technology and expertise transfer projects in the field of RE, with partners in Latin America, Asia–Pacific and on small developing islands. This best practice example from HAW Hamburg demonstrates how R&D competences and engineering skills applicable to renewable energy systems can be strengthened by higher education institutions.

Acknowledgments The author would like to thank the municipality of Hamburg for the initial funding of the CC4E and for funding photovoltaic equipment for education and R&D. The author is grateful for the support of the JELARE project team and for funding from the European Union.

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Chapter 25
Software and Information Technology Support in a Virtual Renewable Energy Laboratory, Based on Areal Physical Environment—ECO UQAR—UOM Potential Collaboration

Drishty Singh Ramdenee, Adrian Ilinca, Dinesh Surroop and Romeela Mohee

Abstract The present project aims to propose a new training approach based on communication and information technologies, which can be easily exported to different universities interested in growing and diversifying, such as the University of Mauritius. Specialized software and information technology is used to develop a virtual platform of a real, physical renewable energy laboratory, shared with different users and clients via VPN services and global web-based services. From an engineering point of view, the concept is simple, but the computer and information technology requirements are challenging. ECO-UQAR is a new entity created at the Université du Québec à Rimouski, and aims to provide "learn by projects" training in the field of renewable energy. A physical laboratory has been set up for this purpose. The physical set-up consists of a wind blower, wind turbines, solar panels, irradiation systems and other standard equipment. The whole laboratory is completely instrumented. Specialized software is used for data acquisition, data transfer and data processing. In this paper, the emphasis is placed on the virtual environment that is set up using LabView, the data transfer from remote wind turbine installations to the laboratory, the data acquisition within the laboratory, and the security involved in using such a system. Specialized training is offered on

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_25,

high-level software, as a final step. This paper focuses on one particular project, whereby such software is used to illustrate the computational challenges involved in the use of specialized high-level software.

Keywords Virtual environment · Engineering · Training · Wind power · Renewable energy

Short Introduction

In order to make maximum use of renewable energies (RE), it is very important for engineers and technicians to be well-trained in different aspects of RE. The main problem in this field is the lack of infrastructure and the high cost of equipment to develop adequate set-ups for training.

This paper presents a new training approach based on communication and information technologies. A virtual platform of a real, physical RE laboratory has been developed with the help of specialized software and information technology. It provides "learn by projects" training and allows distant access and provides an idea-exchange platform for users from all around the world at a minimal cost.

Introduction

In the context of attempts to develop the concept of sustainable development and pave the way for advances in alternative renewable energy, it is becoming crucial for engineers and technicians to be trained in diverse aspects of renewable energies. The main problem in this field is the lack of infrastructure and the cost of equipment to develop adequate set-ups for training. For example, the size of wind turbines and the corresponding wind tunnels to operate them can be prohibitively large. Similar limitations exist for solar panels and biomass generators. In this paper, we focus on the ECO-UQAR physical renewable energy laboratory at the Wind Energy Research Laboratory (WERL), which aims to provide pedagogical training for engineers and technicians on different concepts of renewable energy via a "learn through projects" approach. In the second part of the paper, we illustrate the use of different softwares in this approach and the computational and security challenges that are encountered. In the third part, we describe the multiple location data acquisition and training technique used in this laboratory through a virtual platform. This laboratory allows users around the world to have access to real-time visualization of the whole system via motorized VPN cameras, and the ability to access the quantitative data of the set-up via the virtual instrumentation platform. Furthermore, the indoor laboratory is connected via Wi-Fi and a high-speed data acquisition system to a real 50 kW wind turbine and solar panel platform to enable real wind turbine and solar data analysis in outdoor conditions. Such installations and equipment are very expensive; however, specialized software and information and communication technology (ICT) have allowed access at a distance for users dispersed all around the world, and an idea-exchange platform at minimal cost.

Motivation and Literature Review

In engineering education, it is becoming necessary to develop interaction with equipment in the field of green energy using real systems or simulation environments. Such activities are generally indispensable to consolidate the theoretical concepts learned in the classroom (Calvo et al. 2010; Jara et al. 2009; Jara et al. In press; Tanyildizi and Orhan 2009). The major difficulty in this domain is the lack of industrial systems that can be used easily in academic contexts, and the non-existence of scaled laboratories that can be installed at an institutional level. Although difficulties still exist, recent progress in communication tools has helped managerial staff, engineers and technicians to enhance productivity and optimize industrial systems without the need for any physical platform. Moreover, automation technology allows remote control, and often involves more complex situations, implicating the real-time data exchange, video streaming of different plant sections, and, finally, the reception of process input commands and controller program modification. These methods have been introduced for the first time by service and equipment providers to allow distance troubleshooting with clients. Moreover, in a market becoming more and more global, methods of remote control and monitoring are the ultimate trend for manufacturers to stay ahead in their respective industries. Consequently, business intelligence is becoming a significant advantage for industries in an ever-changing business environment (Chan 2007; Zavbi and Tavcar 2005; Wang et al. 2006). It is also important to adapt engineers and eventually technicians to rapid technological changes in automation systems. The solution can be based on the training of graduate engineers, and it is also necessary to teach the required skills to future graduates during academic training (for both engineers and technicians). In fact, academic content also needs to be constantly updated according to current technologies and future trends.

The literature review demonstrates that some related works exist on distance learning or remote experiments (Calvo et al. 2010; Liang In press; Scanlon et al. 2004; Zavbi and Tavcar 2005). However, only virtual set-up is discussed and they do not imply real-time monitoring with effective operators monitoring the equipment (Jara et al. In press; Liang In press; Tanyildizi and Orhan 2009). The present work is original because it implies real-time collaboration between distant teams of students on a common problem. Furthermore, it integrates the interaction between future technicians and engineering students.

Physical Set-Up

ECO-UQAR proposes a real physical bench test for multiple renewable energy sources with the aim of allowing students to learn the different aspects of renewable energy-related technologies through applied projects and the setting up of bench tests. The laboratory contains a wind blower, of which the speed can be varied. The wind speed controller is connected via a data acquisition card to a computer. In the short term, we wish to simulate real wind in the blower through data collected by anemometry, and analyze the behavior of wind turbines according to different wind regimes. In this section of the laboratory, the parameters of the different sections are measured. For instance, the speed of the wind coming from the wind blower is measured, and the data recorded, in real time. The same applies to the instantaneously evolving turbine speed, voltage and current at the exit to the generator and batteries, etc. Similarly, the laboratory contains a number of solar panels and a variable insolation lamp. Like the wind section, the solar section is completely instrumented. The light intensity and the output voltage and current are all measured. The laboratory is, furthermore, equipped with a biomass generator. The three energy sources are of very different types but are coupled using a control panel. Figure 25.1 shows a schematic representation of the laboratory, while Fig. 25.2 shows the actual indoor set-up. Figure 25.3 shows

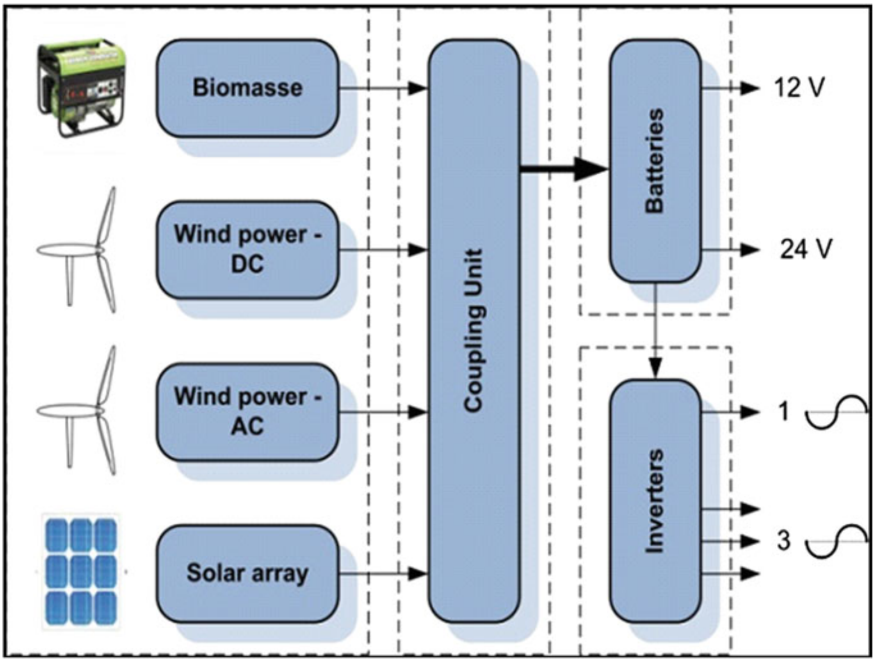

Fig. 25.1 Schematic representation of the green-power installation

Fig. 25.2 Indoor physical set-up of ECO-UQAR

the whole physical set-up, whereby data from outdoor installations are made available to the indoor laboratory for analysis. The outdoor installation is WERL equipment. Data from the real, large-scale outdoor installation is injected into the instrumentation system of ECO-UQAR to address issues it would not be possible to tackle in the indoor laboratory, such as wind variability, insolation cycles, aeroelastic phenomena, icing, etc. A National Instruments® DAQ acquisition system is used in the WERL outdoor installation as well as in the ECO-UQAR indoor installation for optimized compatibility.

Software Challenges and Consideration

In the first instance, choice and optimization of the laboratory components were supported by HOMER software. HOMER is a specialized software program developed at the National Renewable Laboratory, which integrates different characteristics of commercial wind turbines, solar panels, diesel units, etc. By choosing a particular site, the software can calculate the best-choice scenario based upon a financial optimization technique (energy coupling or not, number of solar panels, wind turbines, etc.). The laboratory set-up was based on HOMER analysis only for training purposes. However, as with many other software programs, the problem resides in the lack of flexibility, since the software is not open source.

Fig. 25.3 Data exchange between outdoor installation and ECO-UQAR

As already mentioned, the HOMER optimization technique is based on a financial consideration, itself dependent on resource availability and cost. For instance, if the site has low insolation but high wind penetration, the software will prioritize use of wind turbines. However, sometimes special considerations are required; for instance, in our case, diesel units are supercharged with compressed air from wind turbines during low energy demand in order to increase diesel efficiency by about 30 %. This will completely alter the financial consideration. However, this cannot be specified in the software. Thus, efforts are being made within ECO-UQAR, in collaboration with the Techno Centre Eolien, to propose more flexible, open-source software (Fig. 25.4).

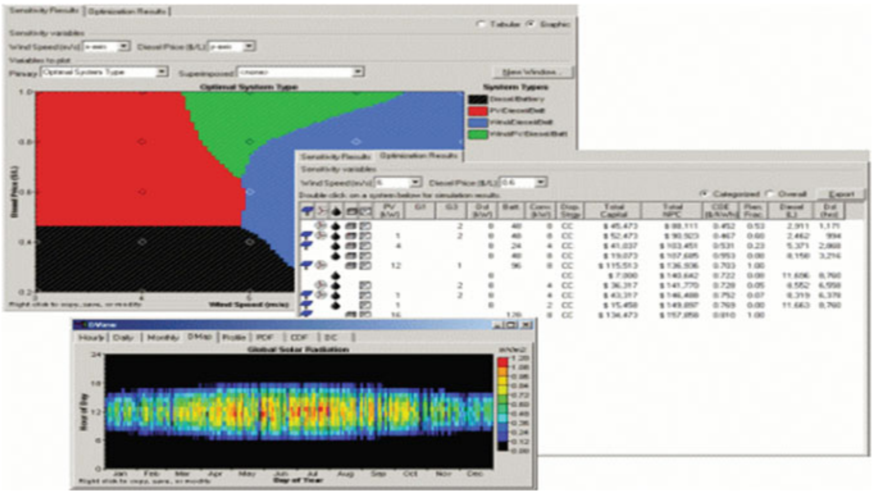

Fig. 25.4 HOMER interface

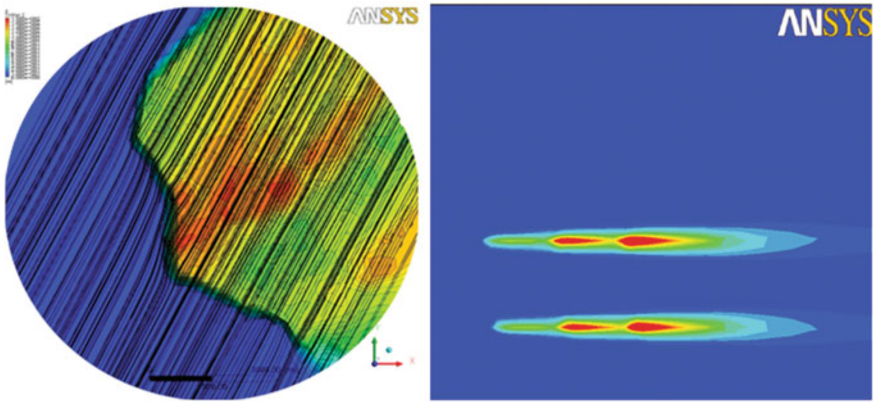

Fig. 25.5 Energy and wake assessment via CFD terrain aerodynamics to evaluate wind turbine requirements

A similar problem is faced with wind-potential analysis software. Computational fluid dynamics (CFD) terrain aerodynamics is run to evaluate the wind potential of different regions, and the energy assessment is calibrated via characterization of the machines within the ECO-UQAR laboratory. In order to avoid wake interaction between the turbines, wake modeling can also be performed using our software. Figure 25.5 below shows the streamlines of the wind speed over the region, and the wake modeling using high-level CFD modeling conducted over a region in Safi, Morocco.

Energy assessment via coupled aerodynamics and terrain-relief consideration requires running and solving very complex Navier–Stokes equations on morphed meshes on terrains, whilst applying turbulence models and considering atmospheric and temperature stratification. Though available software is very advanced, some problems still persist, the main one being the computational requirements. Such simulations take a very long time to resolve. We do not have any access to the software core to define particular parameter solving. Instead, the software always gives solutions for all regions and all parameters. The computational limitation may become the main asset for open-source software.

In relation to solar energy assessment, another problem should be highlighted that is encountered with closed source software. Solar energy assessment is achieved using a Milankovitch function. This relates solar power availability to the position of the earth, with reference to the sun as well as the earth's tilt. Available software does not allow users to see the data taken into consideration to perform the calculation. Instead, the model only provides results. In different projects, we used different software for convergence analysis, and each software program gave very different results for the same simulation. For these reasons ECO-UQAR built its own open source software for such analysis.

ECO-UQAR aims to promote the coupling of various renewable energy sources. Since the output signals are very different from different sources, it is imperative to

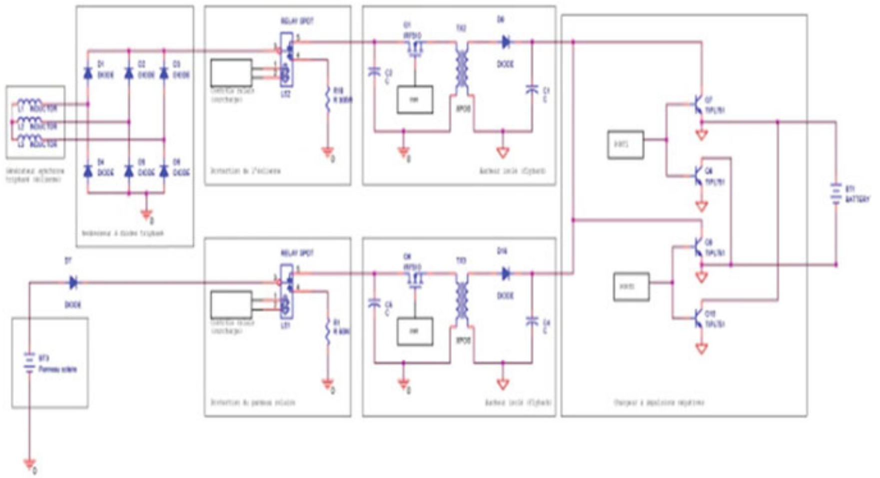

Fig. 25.6 ORCAD-based design of coupling unit optimized using Simulink

use special coupling units that can rectify the signals, and upscale or downscale them for constructive superimposition. Commercial units have been used for a long time, but, surprisingly, many of them do not actually couple the energies, but merely prioritize the higher intensity one. Within ECO-UQAR, using electronics and control software like ORCAD and Simulink, a new unit that couples the energy sources is now being developed. Here, we can clearly see that specialized software programs have an appreciable use in design and optimization procedures in a domain like renewable energy. Furthermore, ORCAD perfectly illustrates the concept of flexibility and lean design of software to improve upon computational cost and time (Fig. 25.6).

Virtual Platform

During the activities, the interaction process can be divided into two categories, namely "people-to-people", and "people-to-equipment". People-to-people interactions are to happen in real-time (synchronous) and off-line (asynchronous) mode. When present in the laboratory, UQAR students have access to a computer, a large video-conference screen, webcam, microphone, speakers and an Internet connection. Distant-sites students, for their part, are physically present in close proximity to the mini-plant, and they can communicate to the UQAR students using the same accessories. To allow people-to-equipment interactions, a Virtual Private Network bridge (VPN) was instated between both sites' LANs (Local Area Networks) via the Internet. The programming of the controllers (Allen-Bradley CompactLogix series) was possible remotely using RSLogix5000 software.

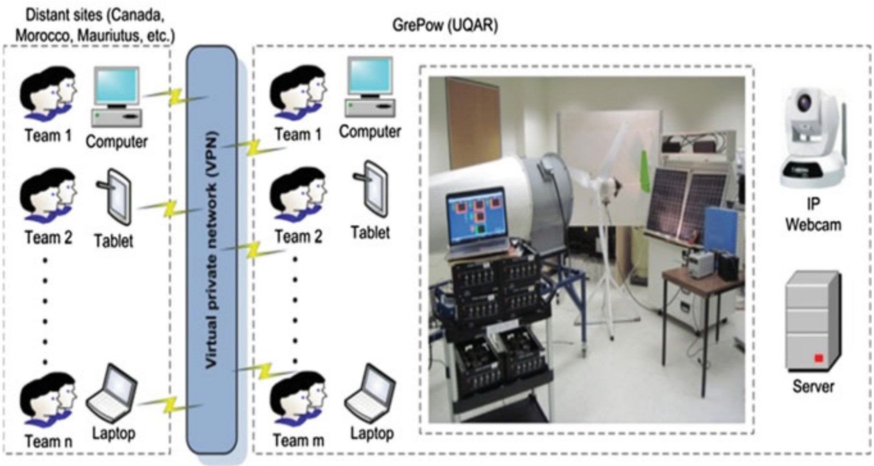

Fig. 25.7 Virtual platform schematic

Real-time visualization of the physical systems was possible through additional dedicated IP cameras positioned to adequately cover all mini-plant units. The applications were developed using LabView software to monitor the global system and to measure the different signals. Their video streams are accessible using any web browser software. A schematic representation of this environment between the sites is illustrated in Fig. 25.7. Since process control and automation applications require quick response times and high data-throughput automation equipment, STRATIX 8,000 switches were chosen at the core of the Ethernet-IP network.

ICT aspects within the virtual platform will be examined considering three different aspects: the instrumentation and server within ECO-UQAR, the web-based interface, and the instrumentation and server within outdoor WERL facilities.

ECO-UQAR can be seen as the central core of the concept. It is equipped with a wind blower, wind turbines, solar panels, insolation systems, a biomass generator, coupling units and the usual laboratory equipment. The whole physical unit is instrumented and uses real-time acquisition systems: the speed of the fan, the wind speed at the end of the blower, the temperature of the air, the rotation speed of the turbine, the insolation, the power outputs of all units, and the signals at the ends of each electrical unit, as well as the temperature of the batteries, is all monitored. All the data are acquired using a DAQ LabView unit. The LabView software has been used to set up a user-friendly interface for Web use. It is very interesting to note that LabView as a software program, and its data acquisition cards, allow simple, lean design systems to be built. Previously, in order to monitor pressure, there were special cards and software for particular sensors. Using a single card with multiple channels like the NI DAQ, the process is highly simplified. Figure 25.8 below shows the LabView software based Web interface.

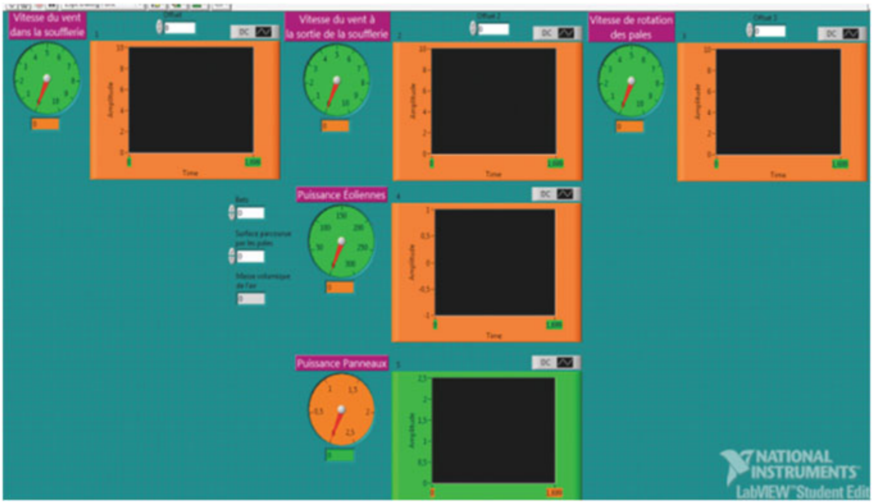

Fig. 25.8 Virtual LabView interface

As we can note, the interface allows the monitoring of all parameters that can be pertinent for the understanding of the renewable-energy laboratory operation. Furthermore, different aspects of renewable-energy courses have been integrated within the application to enable students to familiarize themselves with certain theoretical concepts: the limit of Betz can be altered, the density of air can be changed, an albedo correction factor can be applied, and generators can be supercharged with compressed air. It is evident that software development can play a major role in training and learning.

ECO-UQAR is also equipped with IP motorized cameras to enable users over the Web to access online video streams of the physical laboratory with the corresponding instrumented LabView interface. This simulates a real laboratory, but from a distance, and this has only been made possible through breakthroughs in software and ICT.

The instrumentation of the LabView interface and the online video streams from IP cameras are made available on a secure website. The website has also been set up by UQAR students in line with the “learn by project” strategy. The website is hosted by the ECO-UQAR domain on an internal server.

The same server is used to enable connection via Wi-Fi to a computer at WERL outdoor installations. At the WERL facilities situated at Pointe au Père, Rimouski, data can be recorded online via a NI DAQ on a computer acting as a server. Data are collected from 300 watt wind turbines, 50 kilowatt wind turbines, solar panels and the instrumentation of a number of control panels. To correlate the apparatus outputs with available resources, the wind speed and direction, as well as the insolation, are measured and continuously recorded. A buffer system is used with a very short lag; data is transferred via high speed Wi-Fi to the ECO-UQAR installations.

Finally, ECO-UQAR offers a physical pedagogical laboratory and a real wind turbine–solar panel outdoor installation that can be viewed in real time, the instrumentation being made available simultaneously.

Software for E-Learning

E-learning is the use of the new multimedia technologies of the Internet to improve the quality of learning by facilitating access to resources and services on the one hand, and exchanges and remote collaboration on the other. The experiment is based on the interactions between client and equipment suppliers, and is useful in order to develop expertise in intervention and remote debugging. This concept is being applied by the ECO-UQAR laboratory. As of winter 2012, the ECO-UQAR laboratory will be used in a number of courses at UQAR and proposed to other educational institutions in other parts of the world. To illustrate this, we will take the example of the wind-energy course. In this course, students are familiarized with a number of diverse concepts related to the wind-energy sector, which can range from aerodynamics to the legal aspects of wind-farm installation. It is utopian to believe that someone can be an expert in all the different aspects of wind energy. The aim of this course is to provide a broad understanding of the wind-energy sector for all students and to encourage them to develop expertise in one particular aspect through an applied project. The difficulty in this is that different projects will require different software, and every software program is very costly. For example, there could be a student who wishes to develop expertise in blade aerodynamics using ANSYS-CFX software. The cost of the license for this software amounts to tens of thousands of dollars. Although the WERL is well equipped with different softwares, it is difficult to provide this course to students in universities abroad, where such facilities are not available.

The e-learning process allows us to offer the course with the "learn by project" approach through our tailor-made website, and at the same time offer a real physical laboratory that can be accessed from a distance. This is an advantage of the ECO-UQAR laboratory, where breakthroughs in software and ICT technologies allow for full distance training without the need for cost handicaps. One such project has been the implementation of a coupled wind–solar project in Morocco for water-pumping purposes. This project aims at pumping water from an 85 m deep borehole in the region of Safi, Morroco, for a small village of around 500 people. The pump will be completely fuelled by a coupled wind–solar system. This project integrates several aspects of renewable-energy technology and can be defined as follows: to design the system, we need to evaluate equipment requirements. To do so, we need to predict pump energy needs from water demand, and consequently design the system according to the wind and solar potential of the region. A high-level computational fluid dynamics (CFD) simulation has been run over the region and the wind potential evaluated. Similarly the insolation of the region was simulated. From these data and ECO-UQAR designed

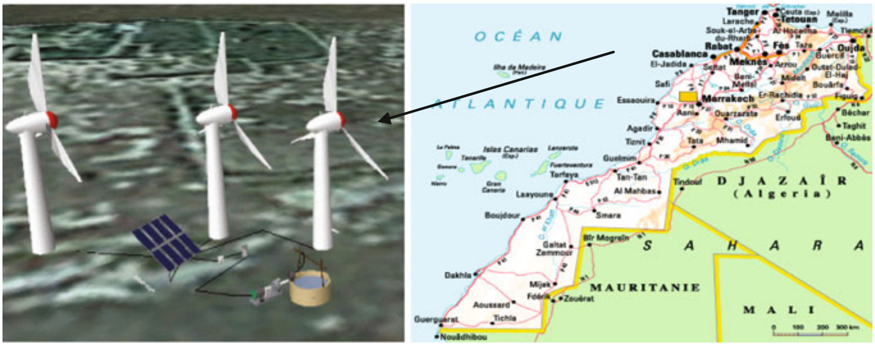

Fig. 25.9 Project set-up and location of site

wind-turbine characteristics and bought solar panels, the number of pieces of the latter equipment was evaluated and the accessorial units (batteries, filters, etc.) bought. The control system that allows the coupling of the two energy sources is also being designed within ECO-UQAR. Similarly, the aerodynamics of the turbines, the aeroelastic and static effects on the blades, as well the control of the overall system, have also been worked out by different teams at ECO-UQAR. Each team was leaded by an expert in the given field. Finally, in the light of all the equipment, a financial analysis was run to evaluate the cost and potential profitability of the project, were the energy to be sold. Weekly meetings regrouping the different specialized groups allowed an exchange of pertinent information via an MS-project-generated project management scheme, and enabled all the different actors to get an idea of the different projects and clarify points related to the technologies studied. Figure 25.9 illustrates the project as a whole via a superimposition of the equipment onto the Safi region in Google Earth, and a map of the region.

Conclusion

This paper has emphasized the support provided by software and ICT in allowing distance training in renewable energies. Furthermore, it has illustrated the possibilities offered by Wi-Fi and VPN technologies to couple a real, large-scale wind turbine–solar panel installation with an indoor pedagogical laboratory. The paper has also described the work performed to set up a virtual interface and online streaming of the laboratory operation made accessible to worldwide users via a secure website.

The paper has highlighted the support provided by ICT and software to allow optimal e-leaning possibilities and present a project where numerous software programs are required, as well as international cooperation.

Certain weaknesses in some software programs have also been identified. This has been mainly attributed to the closed source of the tools. In many cases, the sources cannot be modified to reduce calculation time and the computational handicap becomes a real problem. In other cases, the model used in the software cannot be identified, and it becomes very difficult to identify error sources.

However, students have shown a real appreciation for ECO-UQAR and we believe that this concept could become a trend in the future. We firmly believe that, with improvements in Internet services, computational capacity and software architecture, distance learning and collaboration on projects worldwide will become common aspects of training.

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Chapter 26
The New Green Revolution: Sustainable Agriculture for the Caribbean Through the Use of Renewable Energy

Indra Haraksingh

Abstract The Green Revolution, which occurred from the 1940s to the late 1970s, saw a major boom in the Agriculture sector in many parts of the world. It was based on the introduction of chemical fertilisers and superior varieties, irrigation improvement and agricultural extension programmes. This led to a dramatic increase in wheat yields and world coarse grain production. Following this, for numerous reasons, many of which were social and economic, there was a major decline in agricultural production. The main objective of this paper is to explore and propose new ways of stimulating growth in agriculture by the introduction of the "New Green Revolution", through the use of green technologies. Different forms of renewable energy, such as solar, wind and biomass, are proposed to have greater penetration in the agriculture sector, thereby stimulating growth, creating a new revolution in agriculture.

Keywords New green revolution · Renewable energy · Sustainable agriculture · Caribbean

Short Introduction

The Caribbean region has a long history in agriculture, with this being the backbone of the economy for many of the islands, but the economic and social benefits have not propelled the region to the level of sustainability. The University of the West Indies in Trinidad has recognised the urgent need to revitalise agriculture by reintroducing separate faculties for science and agriculture, to foster self-sufficiency and food security for the Caribbean region. The effects of climate

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_26,

change are also making it imperative to search for more sustainable paths. This paper focuses on the application of renewable energy technologies in the agriculture sector, and its projected impacts on the region.

The Green Revolution

The Green Revolution, led by former (USAID) director William Gaud, involved a series of initiatives which occurred between the 1940s and the late 1970s, with a focus on research, development and technology transfer. The effect of this was increased agricultural production in many parts of the world, especially in the late 1960s. This, significantly, led to saving more than a billion people from starvation because of the high-yielding varieties of cereal grains from the distribution of hybridised seeds, the introduction of synthetic fertilisers and pesticides to farmers, the expansion of irrigation infrastructures and the modernisation of management techniques (Borlaug 1968). The impact of the Green Revolution was particularly significant in India, as shown by the graph in Fig. 26.1 (Killoran et al. 1998).

The Green Revolution was based on three pillars:

- the introduction of chemical fertilisers and superior varieties
- irrigation improvement, and
- agricultural extension programs.

Fig. 26.1 Impact of the green revolution in India

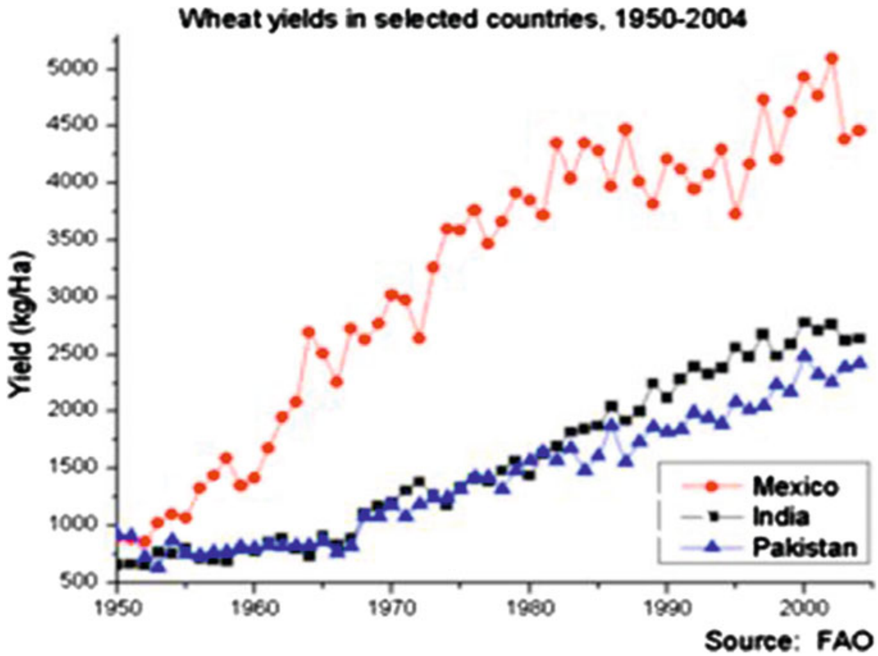


Fig. 26.2 Wheat yield in selected countries

The dramatic increase in wheat yield in selected countries from 1950 to 2004 is shown in Fig. 26.2 (Brian 2008), while the total world production of coarse grain for the same period is shown in Fig. 26.3 (Brian 2012).

Decline in Agricultural Production

The continuous increase was not sustained for many reasons. Global decline in agricultural production in recent years has its roots in many sources, of significance are social and economic factors. There are numerous challenges associated with agriculture. Insurance companies are covering less and less risky areas, and agriculture is considered high risk due to disasters such as hurricane, floods and droughts. Financial institutions do not give priority to agriculture as opposed to other businesses. Lack of resources for developmental purposes has hampered growth in this sector. Even at the University of the West Indies in recent years, the number of agriculture programmes was dwindling as low student intake was making them unviable. It is clear that the crisis in Caribbean agriculture must be dealt with as a matter of urgency. Food security is paramount for the development of the region.

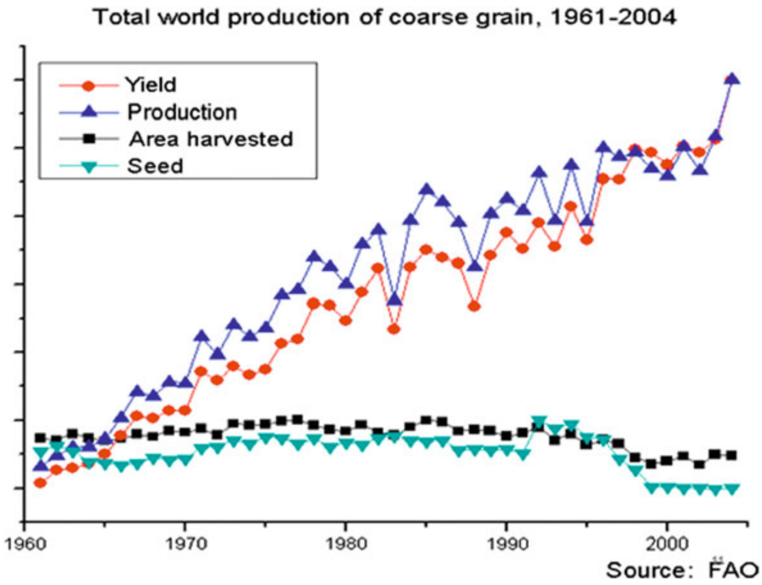


Fig. 26.3 Total world production of coarse grain

Climate Change

Climate change issues are especially applicable to Small Island Developing States (SIDS), such as the Caribbean, for instance. The effects of climate change on crop yield are a major problem. While the Caribbean ranks low in Green House Gas (GHG) emissions at a global level, SIDS are the most vulnerable to sea level rise due to climate change. Temperature records have shown an increase in the last century, with the 1990s being the warmest decade since the beginning of the 20th century. The year 1998 also appears as the warmest year on record. Warmer sea temperatures support the development of stronger hurricanes at lower latitudes, a more rapid transition to category four and five, and an increase the likelihood of coral bleaching.

Climate change has negative effects on agriculture, tourism, health, water security, economic and social vulnerability. Forests, livestock and fisheries are impacted upon negatively. There is the threat of low food security, economic sustainability, and an increase in vector-borne and other heat-related diseases. Even a one degree rise in temperature has dire consequences on fish, such as yellow tuna and dolphin fish. The environmental conditions become less favourable, causing fish to migrate to cooler temperatures, leading to severe consequences for the region. Adaptation policies for all sectors must be instituted for agriculture, land use, water resources, the tourism sector and sea level rise.

The New Green Revolution

At a global level, transformation in the agriculture sector is critical. With the growth in clean technologies, agriculture could get a much needed boost by greater application of renewable energy technologies. This is being coined as the "New Green Revolution" which could mean significant increases in production, leading to greater food security. Renewable energy technologies could enhance the growth in agriculture in numerous respects, one of which is post-harvest technology.

The "New Green Revolution" will be based on:

- climate-smart agriculture
- energy security
- food security through renewable energy.

"Climate-smart agriculture" (CSA) is agriculture that

> sustainably increases productivity, resilience (adaptation), reduces/removes greenhouse gases (mitigation) while enhancing the achievement of national food security and development goals FAO (2011).

CSA addresses the challenges of food security and climate adaptation and mitigation in an integrated way, rather than in isolation. Trying to feed nine billion people in 2050, in a way that is not detrimental to planet Earth, is one of the biggest challenges of the 21st century. There is growing competition for land and natural resources and this could seriously compromise the world's ability to grow food sustainably. In order to achieve food security, agricultural production must increase by 70 % by 2050, whilst conserving natural ecosystems (Kelman 2009).

Agriculture is the only sector that offers a triple win of enhanced productivity and food security, increased climate resilience and reduced GHG emissions (Van den Berg 2011). The entire agricultural system must be redesigned to achieve this at a lower GHG emission rate. Striking the right balance between productivity and emissions per unit of agricultural product is key to this transformation. This can only be achieved by more efficient production with less of an environmental impact. Taking an integrated scientific approach and seeking innovative mitigation methods are important steps towards the transformation. National decision policies must be developed to overcome the barriers and promote change. Education programmes should be developed to adequately communicate the Science of CSA.

Renewable Energy and Agriculture

Application of renewable energy technologies can serve as an effective mitigation tool for climate change and lead to energy security for the Caribbean region. There are many drawbacks to the use of conventional fuels in agriculture. Fuel has to be transported through long and remote distances where the noise and fumes can disturb livestock. The possibility of spills is significant and this can contaminate the land. Generators require a significant amount of maintenance and, in case of failure, may need replacement parts that are not always available.

Renewable energy and agriculture are a natural fit; there is a direct relationship between energy and agriculture. Solar, wind and biomass can be harvested continuously, providing farmers with a long-term source of energy, thereby increasing their income. Renewable energy can be used on farms to replace conventional fuels, or it can be sold. The amount of solar energy that reaches the Earth every day is enormous. All the energy stored in the Earth's reserves of coal, oil and natural gas is equal to the energy from only 20 days of sunshine. Therefore, harnessing and utilising solar energy in a region such as the Caribbean, where the level of insolation is high year-round is important for energy security. There are innovative ways of using solar in agriculture, thereby saving money, increasing self-sufficiency and reducing environmental contamination.

Solar energy offers a suitable alternative for many agricultural needs. Modern, well-designed, simple-to-maintain solar systems can provide the energy that is needed to run agricultural farms. These systems have been tried and tested around the world and have proven to be cost-effective and reliable. They have already been proven to raise the levels of agricultural productivity worldwide, and can therefore have a significant impact on Caribbean agriculture. Both solar thermal and solar photovoltaic (PV) systems have numerous applications in agricultural operations, with an end result of increasing productivity and reducing energy usage from fossil fuels. Electricity derived from PV can be used to power a load, such as a water pump, or it can be stored in a battery. A PV-powered watergate can be used to divert excess runoff and prevent flooding. These can yield beneficial results for agriculture (Figs. 26.4, 26.5 and 26.6).

PV modules produce electricity when the sun is shining, so some form of energy storage is necessary to operate systems at night. Photovoltaics is a well-established, proven technology with a substantial international industry network. It is increasingly more cost-effective compared with either extending the electrical grid or using generators in remote locations. The cost per peak watt of PV power is decreasing continuously, making it an attractive option for the farming industry (Figs. 26.7 and 26.8) (Varga 2006; ISuppliCorp 2010). PV systems are economic at remote locations and can be much cheaper than installing power lines and step-down transformers in applications such as electric fencing, area or building lighting, and water pumping for watering livestock or for crop irrigation (Fig. 26.9).

Powering electric fans for air circulation is another solid use of PV. It has been proven that modern pig and poultry farms can double and even triple production by raising the animals in enclosed buildings. Proper lighting in agricultural buildings and enclosures can significantly reduce deaths caused among young chicks or animals due to trampling each other. Adequate lighting in these buildings can also significantly extend working hours, thereby increasing productivity. This will also facilitate the repair and maintenance of equipment during evening hours. Figure 26.10 shows a PV-powered chicken farm in Trinidad.

Fig. 26.4 PV-powered water pump

PV systems can be more economical choices than conventional battery-powered lamps, providing higher quality light without emitting smoke or fumes. PV systems can also be used on farms, ranches and orchards for electric-powered egg collection and handling equipment, product refrigeration, livestock feeders and sprayer motors and controls, compressors and pumps for fish farming, electric fencing to contain livestock and battery charging.

Solar thermal systems are equally effective in agricultural farms. Crop drying is an essential post-harvest technology in agriculture. Modern solar crop dryers are very simple, effective and hygienic. Crop dryers can be effectively used for Agriculture and Horticulture to increase yield and reduce the amount of perishables. In many instances, curing of products is essential for enhancing their shelf life, and this can be adequately achieved through the use of solar dryers. This will ultimately achieve not only an increase in income, but would also allow the possibility of food preservation for much longer periods, leading to a greater measure of food security (Fig. 26.11).

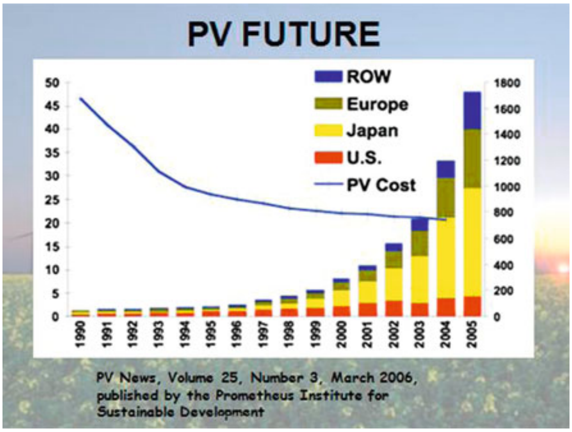
Fig. 26.5 PV-powered floodgate controller

Other solar thermal systems, such as solar water heaters, can also be effectively incorporated into agricultural operations, yielding higher agricultural productivity, particularly in livestock operations. Simple solar water heaters providing low to medium temperature hot water (140 °F or 60 °C) can be used for the cleaning of pens and equipment for raising poultry. These systems require a solar collector, a storage tank, plumbing and pumps. There are many commercially available systems on the market and they offer simple installation procedures. Barbados, in the Caribbean, is a world leader in solar hot water systems, providing systems of a high standard throughout the Caribbean and beyond (Figs. 26.12 and 26.13).

Wind energy offers superb options in the agricultural sector. Small wind systems can provide power that can be used directly or stored in batteries. These systems are very reliable in areas that get enough consistent wind. The systems can be very cost-effective and reliable for many power needs on farms and ranches. The space at the base of the wind turbines can be effectively utilised for farmers to plant crops and generate wind power simultaneously. Since these systems can be stand-alone in remote settings, farmers can have a sense of security not having to depend on the central grid for power (Fig. 26.14).

Fig. 26.6 PV-powered street lamp (*Photos* courtesy of I. Haraksingh)

Fig. 26.7 Cost of PV—1990 to 2006



Cooling is one of the most important steps in post-harvest handling chain. By reducing the temperature of produce, the respiration rate can be greatly reduced, thus extending shelf life and preserving the quality of the produce. The initial cooling, processing, and cold storage of fresh fruit and vegetables is among the most energy intensive segments of the food industry. Solar assisted cooling can be extremely beneficial to the industry. Renewable energy powered technologies, such as back-up generators, PV-powered evaporative cooling and solar chillers can be effectively utilised in food preservation aspects of agriculture.

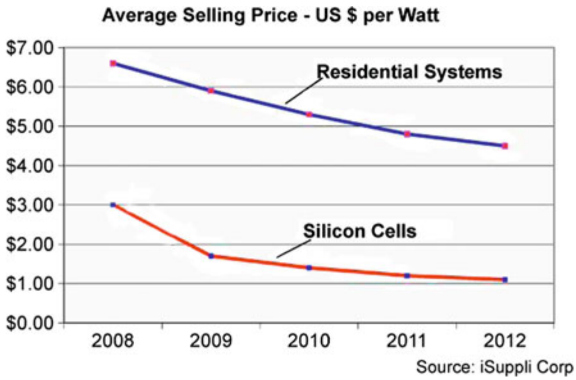


Fig. 26.8 Cost of PV—2008 to 2012

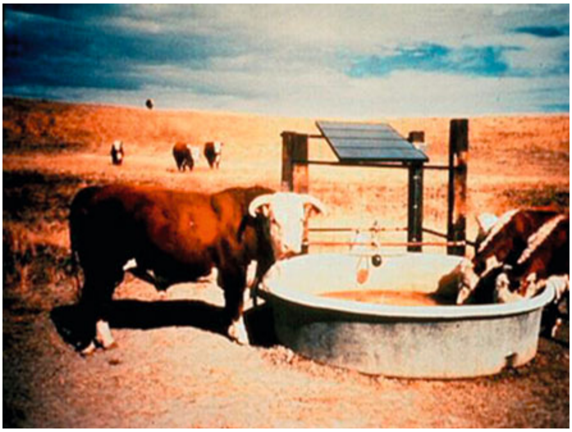


Fig. 26.9 Watering livestock

There are additional options for alternative energy use in agriculture. These include the production of liquid fuels from indigenous plants and agricultural crops, and the use of biomass residues to power biomass gasification units that produce both heat and electricity (combined heat and power). These renewable liquid fuels include biomass-derived ethyl alcohol (ethanol) and biodiesel (derived from various types of vegetable oils). The liquid fuels option sometimes requires large-scale cultivation and processing of a crop to produce the renewable fuel economically. This can pose a dilemma with respect to land use for food or fuel. Production of ethanol can be derived from sugar cane, corn, cassava or sugar from beet, and the production of biodiesels from plant oils, such as palm oil, coconut oil, jatropha oil and other seed crops.

Alternatively, the renewable fuel may be produced on a small scale; often in conjunction with the farmer's other agricultural crops. The end result for the farmer is to reduce the cost of motive power, electricity and heat, and to increase the reliability of adequate, affordable energy supplies. Small modular gasification technology has important potential for farmers' cooperatives. Such systems use a

Fig. 26.10 PV-powered chicken farm (*Photo* courtesy of DC Power Systems Limited)

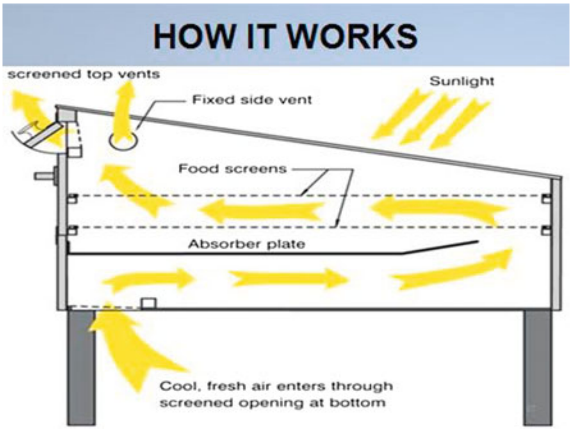


Fig. 26.11 Working principle of a solar dryer

wide variety of biomass residues, such as coconut shells, coffee husks, wood wastes and other woody biomass, to produce a high-quality gas that can provide heat, shaft horsepower and electricity.

Fig. 26.12 Solar water heater (*Photo* courtesy of Solar Dynamics Limited)

Fig. 26.13 Solar water heater (*Photo* courtesy of Apex Caribbean Limited)

Biomass is broken down thermochemically in gasification systems by heat and oxygen, to produce a synthesis gas that can be used to power internal combustion engines, boilers, furnaces, dryers and chillers.

Combined heat and power systems allow a high degree of cogeneration. In the sugar cane industry the raw material, sugar cane, uses its own fuel for processing, with other side benefits. It has high thermal (steam) demand for processing, while its demand for mechanical energy is low. The Caribbean sugar cane breeding research centre is located in Barbados. Strategic research is conducted to develop new varieties of fuel cane to enhance the bio-energy content to meet future challenges. Barbados is undergoing a reform of its sugar cane industry in this regard (West Indies Sugar Cane Breeding Station 2011). Research includes high quality breeding, genetic base broadening, high biomass and multipurpose cane varieties, maturity, breeding strategies and the genetic basis for important agronomic traits (Fig. 26.15).

Fig. 26.14 Wind energy (*Photo* courtesy of Warren Gretz, NREL)

Fig. 26.15 Sugar cane breeding *Source* West Indies Sugar Cane Breeding Station

However, there are many criticisms of biofuels: food insecurity, ecosystem destruction and inaccurate climate science. Some of these include land use being diverted away from food production to crops for biofuels, leading to scarcity of food. This can lead to an increase in world food operating costs by 40 % in less than 1 year. It has been touted that

> filling the tank of an SUV with ethanol once requires enough corn to feed a person for a year (E-Parliament).

Clearing of rainforests, grasslands and other ecosystems for biofuel production, removal of vital carbon sinks leading to massive release of the CO_2 stored in these systems can all result in ecosystem destruction. Studies show that as a result of this land clearance and other emissions related to biofuel production, there are more GHG emissions than when using conventional fuels (*Science*). This leads to a dichotomy, for which a solution is yet to be found.

Possible solutions include fuels based on non-edible sources; sustainable biofuels can be synthesised from waste cooking oils and waste organic materials produced from sugar cane processing, and can be used for generating electricity. This leads to third generation biofuels, fuels from algae gases. It has been claimed that the region's technical exportable bioenergy potential over the long term (2050) is projected to be amongst the highest per capita. If Guyana, Jamaica and Barbados adopt the latest technology, these countries could cogenerate a total of 100 MW of electricity by burning sugarcane bagasse (Moreno 2007).

At the global level, International Energy Agency (IEA) Ministers recognise that current energy trends are not sustainable and that a better balance must be found between the three E's:

- energy security
- economic development
- protection of the environment.

Energy is part of many environmental problems, including climate change, and must be part of the solution. Focus must be placed on energy efficiency and energy conservation, and there must be a deepened focus on renewable energy applications in agriculture. There must be a concerted shift towards sustainable agriculture. The manner in which energy for agriculture is produced and consumed is crucial to the sustainable development of the Caribbean region. Renewable energy technologies must be employed in agriculture as a matter of urgency. An IEA study suggests that renewable energy alone has the potential to contribute 21 % of the reductions in energy-related CO_2 emissions necessary to maintain its levels in the atmosphere at no higher than 450 parts per million (ppm) (International Energy Agency Solar Heating and Cooling Programme 2011), as targeted by the Intergovernmental Panel on Climate Change (IPCC).

The New Green Revolution must also incorporate the Green Economy Initiative (GEI) which seeks to foster awareness of innovative responses to investment in energy efficiency and low-carbon technology. Greening of the economy, with reference to agriculture, means reconfiguring the infrastructure necessary to deliver better returns on capital investments, while also reducing greenhouse gas emissions in its operations.

GEI is designed to assist governments in greening their economies by reshaping and refocusing policies, investments and spending onto a range of sectors, including sustainable agriculture and forests. This can generate demand for workers at all skill levels, thereby reducing unemployment, causing a reduction in poverty, enhancing tourism activities, stimulating growth in the economy and protecting the environment from the devastating effects of climate change. The end result is the stimulation of growth in sustainable agriculture.

Conclusion

Caribbean agriculture has been on the decline for decades. Increasing importation has been a direct result of the inability to produce in a sustainable manner. With exports on the decline, economic growth in agriculture is stunted. However, together with adequate government policies and fiscal incentives, innovative technological advances can have a significant impact and can further stimulate growth to the extent that agriculture can become economically viable and impact positively on export earnings. These measures form the "New Green Revolution", in which renewable energy is the base for energy generation and use within the agricultural sector. The Caribbean region is therefore poised to undergo a "New Green Revolution" in the next two decades, through the use of renewable energy technologies.

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Chapter 27
Assessment of the Most Sustainable Renewable Energy Configuration in Mauritius and Rodriques

M. Tsang Pun Yin, J. Jayasuriya, T. Fransson, Surroop Dinesh and Mohee Romeela

Abstract The Maurice Ile Durable (MID) initiative was launched by the Government of Mauritius in year 2009 to transform the country into a sustainable island. The wind sector is experiencing a sustained growth and many wind farm projects have been announced by the private sector under the Clean Development Mechanism (CDM) and sales of carbon credits namely the 18 MW wind farm project at Plaine des Roches and the 22 MW Wind Farm at Britannia. As land resource in Mauritius and Rodrigues is not unlimited and only a few sites have the necessary characteristics for exploiting wind potential. Therefore, it is essential for policy decision makers to consider the possibility of using other local renewable energy resource as part of the energy mix (including wind energy) for electricity production in Mauritius and not to concentrate solely on wind energy. In that context, this study was initiated to assess the renewable energy configuration system in Mauritius and Rodrigues including wind energy using a simulation optimization model. An economic assessment was carried out for different configuration of renewable energy system including wind energy for Mauritius and the island of Rodrigues using a simulation tool namely HOMER software. Two case studies were proposed for Mauritius and Rodrigues to include renewable energy sources such as the use of bio-fuel, renewable biomass, mini hydro plant and solar energy using PV Grid tied systems.

Keywords Renewable energy · Homer software · Mauritius · Rodrigues

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_27,

Short Introduction

Recently, in Mauritius and Rodrigues, wind sector is experiencing a sustained growth, but considering the fact that land resource is rather limited, it is essential for policy decision makers to consider the possibility of using other local renewable energy resource for electricity production in Mauritius. In this paper, the economic assessment for different configuration of renewable energy system (including wind energy) was carried out for Mauritius and the island of Rodrigues by using HOMER software. Two case studies to include renewable energy sources such as the use of bio-fuel, renewable biomass, mini hydro plant and solar energy using PV Grid tied systems were proposed.

Introduction

Exploiting renewable sources of energy for power generation is today the priority of the Government of Mauritius to reduce the high dependency on fossil fuels. The emissions of Carbon Dioxide (main GHG emitter) was about 3,256 thousand tons in year 2007 and has slightly decreased by 3.5 % to 3,075 thousand tons in year 2009 (Mauritius Central Statistic Office Report 2009).

Mauritius presently obtains around 17.5 % of its energy needs from renewable sources (mainly from bagasse which is a by-product of sugar cane, wind and Hydro representing only 4.8 %) (Mauritius Central Statistic Office Report 2009). Some 2,577 GWh (222 ktoe) of electricity was generated in 2009 in Mauritius and the peak demand for electricity in Mauritius continued to increase every year and have reached 388.6 MW in 2009 (Mauritius Central Statistic Office Report 2009).

In 1980s, a United Nations Department of Technical Co-Operation for Development (UNDTCD) funded project entitled 'Wind Energy Resource Assessment for Mauritius' was conducted to identify the most potential sites for wind power generation in Mauritius. Only a few sites were recommended by the study and since Mauritius is a small country where land is an important resource, it would be wiser for the Government or the private sector to explore and invest on other economically sustainable renewable energy sources other than wind energy. Therefore, there is a need to assess the cost and environment benefits of having other renewable energy source together with Wind energy such as bio-fuel or synthetic gas-fuel, PV solar energy or other types of renewable sources.

In recent years, a feasibility study of wind farming in Mauritius has been conducted in 2002 by Palanichamy and the wind potential has been estimated to be 60–65 MW taking into consideration wind speed data obtained, the CEB grid capacity and the available land resources (Palanichamy 2002) (Table 27.1).

The proposal of an assessment of the most economical and sustainable mixed Renewable Wind energy Configuration System in Mauritius and Rodrigues using a simulation optimization model will enable future investors or policy decision

Table 27.1 Total installed capacity for electricity production 2008 and 2009 [*source* Mauritius Central Statistic Office Report (2009)]

Years	Effective capacity (MW)	Peak power demand (MW)		Electricity generated from wind	Electricity generated from thermal	Total electricity
		Mauritius	Rodrigues			
2008	612.2	378.1	6.0	0.4	2,448.8	2,557.2
2009	656.3	388.6	5.6	1.5	2,453.5	2,577.4

makers to understand the important parameters to achieve a mixed sustainable renewable power generating system in Mauritius while decreasing at the same time our dependency on fossil fuel.

Objectives

The main objective of this report is to use HOMER Simulation and optimization tool to economically assess the different combinations of Wind energy with other renewable energy resources at namely;

1. The existing wind farm at Grenade and Trefles region in Rodrigues;
2. The two proposed wind farm in Mauritius namely the 22 MW Wind Park at Britannia and the 18 MW Wind farm at Plaine des Roches.

Different combinations of Wind energy with other renewable energy resources will be proposed and analyzed for the above projects to see which mixed renewable system configuration would have been the most cost effective and at the same time which will be the most environmentally sustainable system. An optimization model will be formulated for this project using the HOMER free software. The HOMER simulation tool a computer model developed by the U.S. National Renewable Energy Laboratory (NREL) and is used to simulate and compare different design system based on its technical and economical aspects.

Proposed Configuration System for Mauritius and Rodrigues

The proposed system configuration system for Mauritius will include the proposed Wind Farm at Plaine des Roches and Britannia, proposed two mini hydro plants at Midlands Dam (350 kW each) and Bagatelle Dam, PV grid tied power generating unit (430 kW) and the Gas to energy project (3 MW) at Mare Chicose land fill site.

The proposed wind farm at Plaine des Roches will consist of 18 wind turbines of model Vergnet GEV HP 1 MW aero generator each rated 1 MW. The promoter Aerowatts (Mauritius) ltd through the Clean Development Mechanism (CDM) involving reduction of greenhouses gases has actually finance the 18 MW wind farm project at Plaine des Roches over 7 years using 210,000 carbon credits contract sold to the Swedish Government represented by the Swedish Energy Agency (Press release 2010).

Similarly, the proposed renewable system configuration for Rodrigues will include the existing wind farm at Grenade and the possibility of considering biomass resource (1 MW) and a PV grid tied system (1 MW), mini hydro plant (350 kW) and generators running on coconut oil instead of diesel.

Modeling Using Homer Simulation Tool

Methodology

The simulation results for each proposed hybrid wind configuration can be easily evaluated by HOMER simulation tool and can be discussed in terms of economic sensitivity of hybridization and the economic and environmental benefits. HOMER performs three principal tasks: simulation, optimization, and sensitivity analysis.

In the simulation process, the performance of a selected design configuration is determined each hour of the year including its technical feasibility and life-cycle cost. In the optimization process, simulation of different system configurations is carried out to find the most appropriate system configuration that satisfies the technical constraints at the lowest life-cycle cost. In the sensitivity analysis process, HOMER software performs multiple optimizations under a range of input assumptions to gauge the effects of uncertainty or changes in the model inputs (Lambert et al. 2006).

When proposing a hybrid configuration and simulating its technical and economical behavior using HOMER, many important criterions that can impact on the proposed system need to be input into the simulation tool. Examples of such input that need to be identified are namely;

1. Daily power load requirement

A baseline load profile data for Mauritius is created using one typical daily load profile 24 h average (Month is March 2008) obtained from the sole distributor of electricity in Mauritius i.e. the Central Electricity Board (CEB) Central Electricity Board Report (2008).

Information on daily baseline load profile for Rodrigues is could only be obtained from CEB for year 2003. The maximum peak for 2003 was 3.8 MW whereas the maximum peak demand for Rodrigues Island in year 2008 was obtained to be 5.97 MW. (5) Similarly, a baseline load profile data for Rodrigues Island can be created using the above information and a typical daily load profile 24 h average for Rodrigues (data November 2003 scaled to November year 2008) and HOMER Software will scaled the data for the rest of the year.

2. Wind data input

The user needs to input wind data for the proposed system since wind power is an integral part of the proposed hybrid system. HOMER application will use this wind data to calculate the output of the wind turbine in each time step specified. For Mauritius the wind dataset will be computed using data received from the Mauritius Meteorological Services Institute services (Cahoolessur 2010).

3. Wind Turbine data

Since different wind turbine will be used in Rodrigues and Mauritius, the wind turbine data for each sites namely at Grenade in Rodrigues, Plaine des Roches and Britannia need to be input in HOMER individually. For the island of Rodrigues, the wind turbine type assessed will be the four new 275 kW Wind turbine Vergnet GEV MP 275 which was commissioned in 2009 and 2010. Similarly, for the island of Mauritius, the wind turbine type to be used at the proposed project Plaine des Roches and Britannia is the model Vergnet aero generator each rated 1 MW.

4. Temperature

The effect of temperature on the efficiency of PV system is also taken into consideration. The output of the PV system is dependent on temperature. The PV cell temperature is the temperature of the surface of the PV array and during the day the cell temperature can exceed the ambient temperature.

5. Grid data

The user has to input grid information data such as the cost of buying power from the grid, emission data of the grid and other advanced economic information such as interconnectivity charges and standby charge of the grid.

6. Solar data resource

The user needs to input the solar data resource information for both Mauritius and Rodrigues to calculate the output of the PV array if included in the hybrid system configuration. The solar radiation data for Mauritius is calculated using the Photovoltaic Geographical Information System (PVGIS) website designed by the European Commission whereby solar data for the region of Mauritius can be found.

The solar PVGIS radiation estimates for long-term monthly average for Mauritius is obtained by entering the longitude and latitude data (20°20′40″, 57°31′27″). Similarly the data for Rodrigues is obtained by entering the longitude and latitude data (19°42′, 62.25).

7. PV data

The user needs to input data for PV power system that will be used. Other parameters such as the lifetime (years) of the PV system, the de-rating factor and ground reflectance etc. need to be input together with its associated costs. A proposed system of 430 kW PV grid tied system is proposed for Mauritius and a 1 MW grid tied system is proposed for Rodrigues.

8. Biomass data

For Rodrigues Island, the user has to input biomass resource data for a proposed 1 MW BIONERR gasification unit. About 8,450 t of wood is required annually i.e. 23.08 t/day. HOMER will use this information to calculate the amount of biogas produced from the 1 MW proposed unit for each hour of the year.

The average cost of fuel is estimated by ARER (2007) to be 60 USD/t. The gasification ratio is 3.5 kg of wood is necessary to produce 1 kg of biogas according to ARER report (2007). The LHV of biogas produced comes mainly from hydrogen gas, CO and CH_4 is 10.4 MJ/m^3.

The LHV of bagasse in Mauritius is estimated to be 17.9 MJ/kg.

9. Current Power plant Capacity data

The user needs to input data on the type of generator to be used. The size of the generator and the capital cost need to be input together with the type of fuel. Diesel fuel and coconut oil fuel will be investigated here.

10. Economics data and any constraints

Other important parameters such as investment costs on different technologies, technical features, maintenance requirements and lifespan of equipment and the cost of energy produced by different energy configuration will also be computed. Economics parameters that will be considered in this project are namely;

- Annual Real interest rate (%)
- Project life time (years)
- System Fixed capital cost.

The project lifetime is also set to 25 years and the system fixed capital cost and system fixed operation and maintenance cost is set to zero. Calculated annual interest rate is calculated to be 1.85 % taking into consideration present inflation rate of Mauritius which is 6.8 %.

A total of 500 MW is allowed to be purchased from the Grid for Mauritius at a purchase price of 0.11 USD/kWh. This figure of 500 MW represents the contribution of electricity production from the CEB and two IPPs Belle VUE Ltd and FUEL Ltd to meet the daily load requirement. This is due to the complexity of estimating the capital cost price and operating cost of fuel running of both bagasse and coal due to lack of cost data.

Results and Discussion

For the above mentioned case studies, simulation have been carried out by HOMER simulation tool, the latter simulating the operation of the different proposed system by making energy balance calculations for each of the 8,760 h in a year. HOMER then performed energy balance calculations for each system configuration that is proposed and have considered whether a configuration is feasible. After simulating all of the possible system configurations, HOMER have displayed a list of configurations, sorted by net present cost (NPC).

Rodrigues Results and Discussion

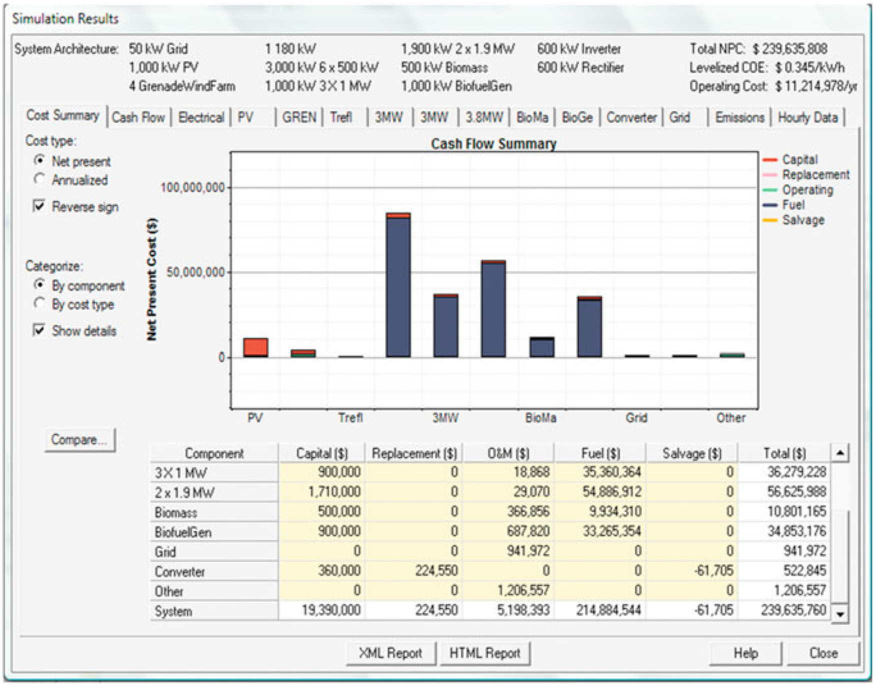
The renewable energy system configuration that has the lowest Net Present Cost (LCOE of 0.345 USD/kWh, cost of electricity generation) of 239.6 Million USD for Rodrigues Island has the following renewable energy resource component namely;

- Renewable Biomass resource running a 500 kW gasification unit
- 1 MW PV array is considered economically feasible by HOMER
- Mini Hydro power station at Grenade is not considered feasible (Least NPC cost)
- Bio-fuel renewable resource (coconut oil) running a 1 MW generator unit
- A 1,000 kW PV grid tied system array
- Trefles and Grenade Wind Farm are considered economically feasible
- The total installed power capacity for the existing 6 × 500 kW MAN diesel generator to be reduced to 1 MW installed capacity
- The total installed power capacity for the existing 2 × 1.9 MW diesel generator to be reduced to 1.9 MW installed capacity.

The annualized cost amounts to 12.2 Million USD and it is interesting to note that the fuel component account for most of this annualized cost, 10.94 Million USD (Fig. 27.1).

For the island of Rodrigues, the PV array component that has the least cost benefit is the 1 MW PV array system and for the Biomass generator, a 500 kW unit is the most appropriate one (category winner) and a 1 MW unit coconut oil generator is the best option in term of cost. The existing 6 × 500 kW MAN diesel installed capacity remain 3 MW whereas the 3 × 1 MW MAN diesel generators can operate as only 1 MW power capacity. Moreover, the 2 × 1.9 MW diesel generators can also reduce to a 1.9 MW capacity i.e. using one generator set instead of two.

This is economically possible by adding 1 MW generating running of renewable fuel oil such as coconut oil. Reduction of the import of diesel in Rodrigues by coconut oil (CNO) is economically feasible and sustainable and can serve as a



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
3X1 MW	900,000	0	18,868	35,360,364	0	36,279,228
2 x 1.9 MW	1,710,000	0	29,070	54,886,912	0	56,625,988
Biomass	500,000	0	366,856	9,934,310	0	10,801,165
BiofuelGen	900,000	0	687,820	33,265,354	0	34,853,176
Grid	0	0	941,972	0	0	941,972
Converter	360,000	224,550	0	0	-61,705	522,845
Other	0	0	1,206,557	0	0	1,206,557
System	19,390,000	224,550	5,198,393	214,884,544	-61,705	239,635,760

Fig. 27.1 Cost summary for the least NPC system configuration for Rodrigues

successful case study for Mauritius. About 2,870 t of CNO fuel will be required for the 1 MW generators running of bio-fuel. The question is whether the 2,870 t of CNO fuel can be 100 % available is Rodrigues is further investigated here. The coastal strip of Rodrigues could easily be planted with coconut trees. If all the coastal area is planted with coconut trees, 180 hectare of plantation can be achieved and using an estimate of 1 hectare of land containing about 200 coconut trees, around 36,000 coconut trees can be harvested.

Bradley et al. (2006) mentioned in a study entitled "Cocos Nucifera: An Abundant Renewable Source of Energy" that Palm oil and coconut oil have extremely high yield. About 0.1 L of coconut oil can be extracted from a coconut or about 2.7 Kilo-liter of coconut oil per hectare can be obtained using standard extraction techniques (Bradley et al. 2006). Around 500 t of coconut oil can be obtained locally and the rest of the 2,370 t of CNO have to be imported from Agalega or purchased internationally. Thus **although a 1 MW bio-fuel generator is the most economically feasible system configuration, the constraint of availability of CNO oil should be carefully addressed.**

In a latest study conducted in the year 2007 by the Reunion Island Regional Energy Agency (ARER) for Rodrigues with regards to the potential of exploiting renewable energy resources in the island, a 1 MW biomass unit has been recommended. **However, HOMER simulation tool have shown that only a**

500 kW biomass system is sufficient for the input electricity demand curve for Rodrigues.

With regards to the electricity production for the least NPC cost configuration system, Trefles 180 kW wind farm and 1.1 MW wind farm at Grenade, the biomass unit 500 kW, the 1 MW PV array and the bio-fuel generator 1 MW will contribute to 47 % of the total electricity production. The 1 MW PV array proposed system and the 500 kW biomass gasifier will account to 5 and 7 % respectively of the power generating capacity whereas the Bio-fuel generator of 1 MW using coconut oil will have the greatest share of electricity production from renewable energy resource if implemented (24 %).

Although the potential of hydro power exist at Grenade, it is still not considered as economically feasible by HOMER simulation tool to install a 350 kW mini hydro power station.

Mauritius Results and Discussion

The renewable energy system configuration that has the lowest Net Present Cost of 6.45 Billion USD (COE of 0.124 USD/kWh, cost of electricity generation) has the following component namely;

- Mini Hydro station at Bagatelle and Midland Dam with total installed capacity of around 700 kW
- 3 MW Gas To Energy system at Mare Chicose Land Fill site
- No PV grid tied system array is considered economically feasible by HOMER
- The 18 MW Wind Farm at Plaine Des Roches and the 22 MW Wind farm at Britannia is economically feasible.

With regards to the economics of the most feasible hybrid system configuration, the annualized cost amounts to 335 Million USD (Fig. 27.2).

With regards to the electricity production for the least NPC cost configuration, the 18 and 22 MW wind farm at Plaine des Roches and Britannia, the Gas to Electricity 3 MW, the two mini hydro power stations (total installed capacity of 700 kW) and the bio-fuel generator 1 MW will contribute to 5.1 % of the total electricity production. The potential of two mini hydro power stations (total installed capacity of 701 kW) at the existing Midlands Dam and at the future Bagatelle Dam has been considered economically feasible by HOMER simulation.

Moreover, based on the actual solar resource available energy and the price of PV technology, neither a 430 kW nor a 1 MW PV array is considered feasible by HOMER simulation tool. The price of PV technology is still on the high side requiring an investment of around 4.3 Million USD for a 430 kW PV system.

The 3 MW Gas to Energy proposed unit at Mare Chicose landfill station has been considered feasible by HOMER simulation tool requiring a total initial investment capital of 6.5 Million USD. When implemented the Gas To energy unit will provide electricity to around 20,000 households.

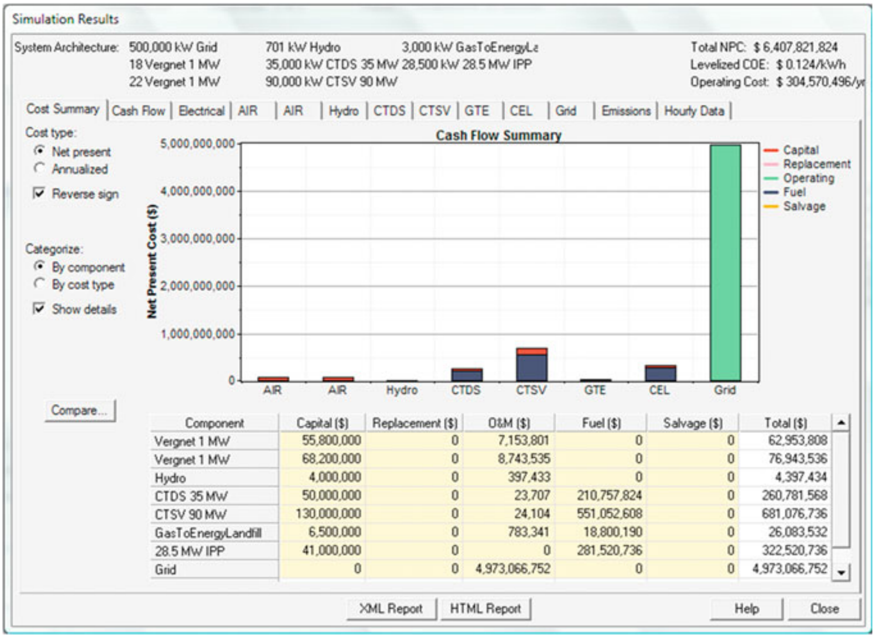


Fig. 27.2 Cost summary for the least NPC system configuration for Mauritius

If we compare the LCOE cost to produce 1 kWh of electricity for Rodrigues and Mauritius, the LCOE cost for Rodrigues is 0.345/kWh and is higher than the LCOE cost for Mauritius which is 0.124/kWh. The LCOE value for Mauritius calculated by HOMER is closer to was is actually paid by the consumer in Mauritius (around 0.103/kWh for the first 25 kWh for residential purpose and gradually increasing).

A sensitivity analysis is also performed by HOMER simulation tool for the least NPC hybrid configuration system for Mauritius. The main reason to perform a sensitivity analysis for Mauritius the cost price of PV technology is expected to decrease in the coming years. A multiplier factor of 0.4, 0.3 and 0.2 will be applied to see at what falling price the PV technology will be integrated in the least NPC cost configuration system. Sensitivity analysis results have shown that if the present price of PV technology should fall by 80 % to become economically feasible. Moreover, if the local authorities of Mauritius can decrease the present inflation rate of 6.8 %, the least NPC cost would decrease from 6.4 to 4.25 Billion USD.

Conclusion

From the above simulation results by HOMER simulation tool and sensitivity analysis for Rodrigues Island, it can be concluded that the most economically feasible hybrid configuration will include a 500 kW biomass BIONEER gasification unit, a PV array system, no mini hydro power plant and a decrease in the use of diesel generator by replacing the latter with bio-fuel generator such as coconut oil (CNO).

A proposal for a mini Hydro power station at site Grenade is not considered feasible by HOMER simulation tool and this may arise from a very high initial investment of around 1.8 Million USD for a 350 kW unit.

The LCOE cost for Rodrigues system configuration is found to be high compare to that of Mauritius and this is due to high fuel cost coupled with high initial investment cost required and Operational and Maintenance costs involved especially that most of the electricity is generated from Diesel fuel.

From the above simulation results and analysis for Mauritius Island, it can also concluded that the most economically feasible hybrid configuration will include the 18 MW wind farm at Plaine Des Roches, the 22 MW Wind farm at Britannia, a 3 MW Gas to Energy power station at Mare Chicose landfill site, two mini hydro power station at the existing Midlands Dam and at the future Bagatelle Dam.

Therefore, exploiting renewable energy resources such as hydro and wind should be further encouraged by the Government of Mauritius in order to achieve the objectives set under the Maurice Ile Durable initiative for a sustainable island by 2020. However, no PV power generating plant is considered feasible by the HOMER optimization tool.

But although a renewable energy resource is not considered economically feasible, this does not mean that it should never be implemented.

Under the Maurice Ile Durable initiative, a 430 PV power generating unit has been built by a private firm to power its new eco-building headquarter.

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Part III
Climate-Smart Energy Technologies

Chapter 28
Adoption of Climate-Smart Technologies: The Case of Rural Solar Electricity in the Pacific Islands

Tony Weir and Shivneel Prasad

Abstract The small island developing states of the Pacific suffer from both the high cost of fossil fuel imports and from numerous climate-related disasters. Apart from traditional wood-fuelled cooking, the only substantial uses of RE in the Pacific currently are hydropower in some of the hillier island countries and household photovoltaic systems in rural areas and outer islands. In several Pacific Island countries hundreds of such PV systems have already been installed on individual houses, and more are on the way. Almost all are rated at 100 W or less and are used mainly for lighting but with some battery charging for telecommunications, portable lamps, radios, etc. The main issues for the sustainability of these systems are not so much technical but financial and institutional. The paper reviews these issues as they apply in the Pacific Islands and some of the ways that have been used to address them.

Keywords Pacific islands · Solar home systems · Off-grid · Solar · Photovoltaic · Rural electricity

Short Introduction

Thousands of small solar electric systems have been installed in individual households of the Pacific Islands. The main issues for the sustainability of these systems are not so much technical but establishing, financial and institutional

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_28,

mechanisms that allow the cost to the cash-poor users to be spread over time and to ensure the occasional maintenance needed to keep the systems operational. This paper reviews the issues for the sustainability of those systems (normally rated at 100 W or less) in Pacific Islands.

Introduction

Thousands of small solar electric systems have already been installed on individual houses in the Pacific Islands, and more are on the way. Almost all are rated at 100 W or less and are used mainly for lighting but with some battery charging for telecommunications, portable lamps, radios, etc. The adoption of such systems is driven largely by cost: averaged over a few years, their cost is less than that of the climate-unfriendly kerosene lamps they replace. The main issues for the sustainability of these systems are not so much technical but establishing financial and institutional mechanisms that allow the cost to the cash-poor users to be spread over time and to ensure the occasional maintenance needed to keep the systems operational. The paper reviews these issues as they apply in the Pacific Islands and some of the ways that have been used to address them.

Geography

The 15 independent Small Island Developing States of the Pacific, often referred to as PICs (Pacific Island Countries), comprise many islands scattered across a very large area of ocean. (See map at Fig. 28.1.) For example, Kiribati comprises some 50 islands, with about 3,000 km between the most western of its islands and the most eastern. Fiji has over 300 islands, though two are much larger and more heavily populated the rest. All the Pacific SIDS are small in land area and population (except for Papua New Guinea); in most cases the label on a map is far bigger than the island(s) to which it refers! Papua New Guinea (PNG) is the only PIC with a population exceeding 1 million; Tuvalu, Nauru, Cook Islands, Palau, and Marshall Islands all have populations of less than 50,000 (SPC 2012b). The geographical fragmentation of the Pacific island countries, their remoteness and their small size are fundamental constraints on their economic development. Most Pacific island countries are heavily dependent on their marine resources, although some have relatively fertile agricultural land and tourist potential. Overseas aid and remittances for islanders working abroad make major contributions to the GDP of several PICs (Rao et al. 2008).

The per capita consumption of commercial energy in the Pacific island economies is closely linked to the per capita GDP, so that countries with low levels of commercial energy consumption also have low levels of GDP per capita. For example, Solomon Islands has a per capita energy consumption of about 0.27 toe/

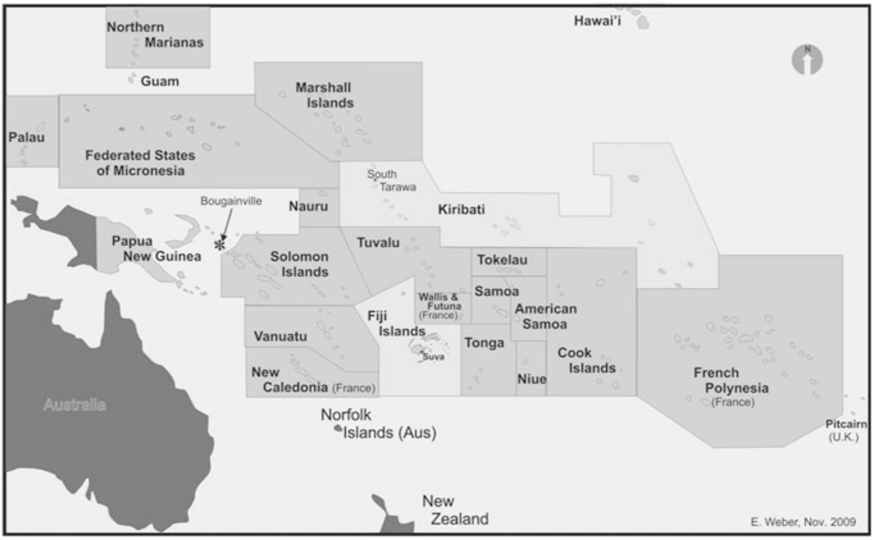

Fig. 28.1 Map of the Pacific showing the Pacific SIDS and some neighbouring countries. Note that New Caledonia, French Polynesia and Wallis and Futuna are French overseas territories and do not count as SIDS; similarly for Tokelau (a territory of New Zealand) and Guam and the Northern Marianas (territories of USA) [map by courtesy of E Weber]

year and a corresponding per capita income of approximately US$1,200. More than 80 % of the population of Fiji, Samoa and Tonga have access to an electricity supply, but less than 30 % in the populous PICs of the south western Pacific (PNG, Solomon Islands, and Vanuatu) (SPC 2012b). Except in PNG, Fiji and Samoa (which are hilly and derive about half their electricity from hydroelectricity) virtually all this 'commercial energy' comes from expensive imported petroleum fuels.

In all Pacific countries the economic activity is concentrated on the few biggest islands. Hence the majority of the places in any country can be considered to be isolated. In particular, grid electricity exists only on the main island(s) of each country and/or in the main towns. Villages in other places (where much of the population lives) are costly or impossible to connect to grid electricity.

Life in most of these rural villages centres around subsistence farming. The people grow their own vegetables (especially staple root vegetables), and also harvest coconuts and fish (from sea or river). In all but the most extreme years, there is sufficient rainfall all year round for crops and domestic use, accessed traditionally from the nearest stream (on hilly islands) or from the groundwater lens (on atolls). Many recent development projects have made access to this water more convenient—a significant issue for village women—by small storage tanks, pumps, small dams, etc.

The Role of Solar Energy in the Pacific Islands

The warm tropical islands of the Pacific all enjoy good sunshine all year round. Even in winter in the cloudier locations the average insolation is around 9 MJ m^{-2} day^{-1}, with most locations receiving considerably more solar energy than this on most days. Thus solar energy can be regarded as the most readily available renewable energy resource in the region, although some countries also have resources of hydro-energy, biomass energy, wind-energy, or geothermal energy (Wade et al. 2005; Bijay et al. 2012).

In the PICs, all fossil fuel is imported. In the smaller island states, fuel imports account for around 30 % of GDP, and in the larger PICS around 7–15 % of GDP (SPC 2011) Consequently Pacific Island countries have been striving since the 1980s to decrease their use of fossil fuels, including by greater use of renewable energy (Newcombe et al. 1982a). Doing so will also reduce their emissions of CO_2. Although small island developing states are among the most vulnerable places to climate change (IPCC 2007), the PICs collectively account for less than 0.3 % of global CO_2 emissions (WRI 2010), so direct action by the PICs will have negligible effect on the mitigation of climate change. Therefore actions by the SIDS are intended to set an example to the large industrialised countries. In the international treaty negotiations and other forums, the SIDS can then ask: "if we can reduce our emissions, why can't you do so too?" (Weir and Orcherton 2012).

Energy Use in Rural Villages

The largest use of energy in the villages is firewood for cooking, which is gathered locally at no financial cost. Commercial energy is mainly fuel for outboard motors (or for pick-up trucks, where there is a road of sorts), and kerosene for kerosene lamps.

It is for lighting—a use which is small in Mega Joule terms but large in social terms—that solar energy can make a significant contribution to sustainable development in the rural parts of the Pacific Islands. Kerosene is expensive ($\sim$US$2 per litre by the time it gets to the outer islands) and a basic kerosene 'hurricane' lamp doesn't give very much light (0.1 lm/W). Though a high pressure 'benzine' lamp (Coleman® lamp) gives much more intense light (roughly the same as a 60 W incandescent lamp) it is much more expensive to buy ($\sim$US$120) and takes careful tending to maintain its performance. Either way, villagers are prepared to pay cash each month to buy the fuel (which is actually petrol/gasoline for the pressure lamp) in order to socialise with family and fellow-villagers.

In rural areas, and especially on outer islands (where delivery of goods from the main port is very erratic in much of the Pacific) the retail price of kerosene and similar fuels is usually at least US$2 per litre and not uncommonly becomes infinite when the inter-island boat fails to turn up. This strongly suggests an opportunity to use solar electricity systems to provide the light, since the solar resource is always available in the tropics, as there are no long winter nights. However, ways need to made available for the cash-strapped villagers to make small periodic payments, since very few can afford to buy a PV system outright (see below).

Using electric lighting—especially energy efficient lighting like [compact or tube] fluorescent lights, or even LEDs—has additional advantages. The light from a kerosene lamp is barely enough to read by, even close to the lamp, as the authors can testify from personal experience. A brighter light makes it much easier for children to do their school homework in the evening and for their mother to do sewing, whether for the family or for sale. Thus better lighting can contribute to achieving at least two of the Millennium Development Goals: wider education and poverty alleviation (Mala et al. 2009).

These advantages are so obvious that some of the pioneering work in the world on solar electric systems for rural household took place in the Pacific in the 1970s and 1980s, notably in French Polynesia (Weir 1985) and Cook Islands (Newcombe et al. 1982b). Diffusion has now reached the stage that several thousand such PV systems have already been installed on individual houses in the Pacific Islands, and more are on the way. Almost all are rated at 100 W or less and are used mainly for lighting but with some battery charging for telecommunications, portable lamps, radios, etc. A typical installation is shown in Fig. 28.2, and a typical circuit is shown in Fig. 28.3.

Similar considerations apply in the rural areas of many other developing countries around the world, including in Africa, Latin America and Asia. An excellent recent review finds that in all these places, the key challenges in making

Fig. 28.2 A solar house system in Solomon islands (*Photo* Solar electric light fund: http://www.self.org/solomonislands1.shtml)

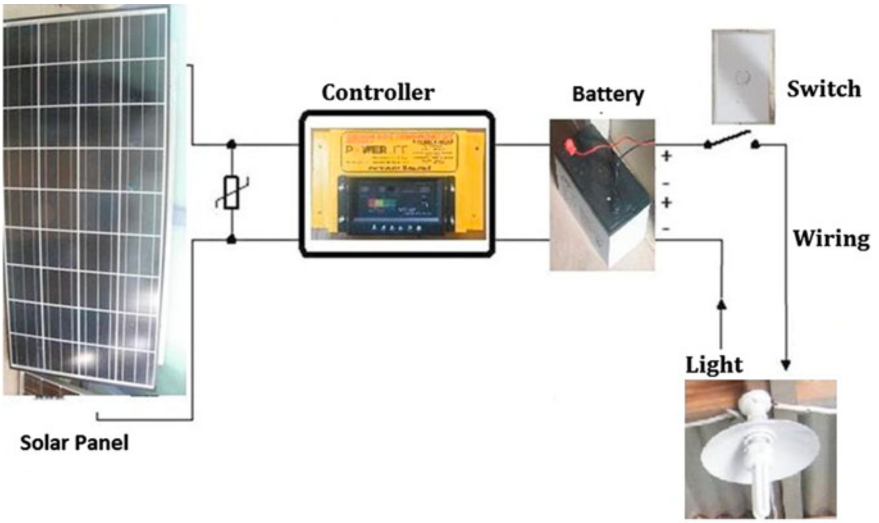

Fig. 28.3 Block diagram of a typical solar home system (image by courtesy of Fiji Department of Energy)

such systems sustainable are no longer technical (as was the case in the 1970s) but institutional and financial (Chaurey and Kandpal 2010). However, appropriate solutions to these non-technical challenges depend on local culture. Experience in the Pacific Islands has led to solutions that are quite different from those reported for other regions, some of which have been tried in this region but failed because they did not fit well with local cultures and attitudes (Wade et al. 2005). There is not much widely accessible or academic literature on this subject from the Pacific Islands; the short bibliography at the end of this paper lists most of it!

In the following sections of this paper, we first describe the technical set-ups which have found favour in the Pacific Islands, then the institutional challenges (which are similar in all PICs) and then some of the of national institutional arrangements which have been used to address those challenges. The issues around grid-linked PV are very different, and, so we do not discuss them in this paper, especially as there have been only a very few and very recent such projects in the Pacific Islands.

Technical Issues

The system used in the main SHS program in Fiji since 2001 is typical of those used in the Pacific. As indicated in Fig. 28.3, for each household it comprises:

- One PV panel rated at 100 W (peak) [100 Wp] or two panels each rated at 55 Wp.

- One open-cell lead-acid battery, rated at 12 V, 100 Ah.
- 4 CFL lamps (3 rated at 11 W).
- One 'night light' (a single LED, or sometimes a smaller CFL).
- One controller unit (which regulates the current flowing into and out of the battery so it does not overcharge or discharge too deeply, both of which damage batteries).
- A small charger suitable for charging mobile phones, C-cell batteries for torches and radios, and the like.

Most of the Fiji systems also incorporate a 'prepay meter', discussed below.

In 2011, with bulk buying, these systems cost F$2,300 each (about US$1,400) including installation.

Some technical points of note are:

- The panel is sized for the solar regime in the wetter (less sunny) parts of Fiji. (Measurements at Suva suggest average insolation of about 13 MJm^{-2} day^{-1} (=3.8 kWh m^{-2} day^{-1}), but as low as 9 MJm^{-2} day^{-1} in some 'winter' months.
- Modern solar panels are remarkably robust and reliable. Users can expect at least 10 years of output if not more, even if the output energy declines by a few percent over that time. The newest panels are also impact-proof and can withstand a coconut falling on them!
- The battery is sized so that the system can cope with about 3 successive days of only dim sunshine, assuming about 4 h use per night. Such batteries nowadays are usually specially designed for this use; they are not the same as batteries for motor cars, which fail quickly in this application. Even so, the battery is one of the weakest points of most such systems—which is certainly true of the locally built Fiji batteries Even with care, it will probably need replacement after about 2 years. If abused (e.g., discharged too deeply) it may fail within 2 weeks.
- The wiring, the connections, and all components (including the controller) must be specified as "suitable for marine use", as all Pacific locations are exposed continuously to warm salt-laden moist air (like boats!). Lesser grade components are cheaper but will fail in the PICs within days.
- The lamps are of course designed to run at 12 V DC.

Earlier systems (e.g., in the 1980s) offered fewer lamps, because the solar panels were much more expensive then, so the systems had to be sized 'smaller' to keep the cost down. The recent advent of LED lamps (which offer higher efficiencies, around 100 lm/W) similarly allows smaller (cheaper) panels to be used but with undiminished output of light. Such systems are currently being trialled in some Fiji villages under the auspices of the University of the South Pacific. However, manufacturers' strong claims about the long-term reliability of LED lights are not yet demonstrated in this application.

In principle, the I–V characteristics of lead-acid batteries and PV panels complement each other in such a way that the battery is self-regulating. Systems without a separate controller were tried in the past, especially in the Cook Islands in the 1970s where they did indeed work satisfactorily, helped by close supervision of the local electronic wizard, the late Stuart Kingan. However, experience suggests that, without such personal wizardry at hand, having a separate controller makes for a more robust system, and is worth slight the extra cost.

Institutional and Financial Issues

The Pacific Regional Energy Assessment of 2004 reported on experience to that point with solar rural electrification, which already included several thousand systems. They found that that although the technical issues with such systems were now largely under control, the main barriers to further use —and to the sustainability of the systems already installed—institutional and financial (Wade et al. 2005).

Most obviously, few villagers can afford the full up-front cost of such a system ($\sim$US$1,000). But even if a donor pays the whole initial cost—perhaps even including installation—inadequate maintenance and the lack of appropriate technical skills in the rural villages will render the systems unusable within a year or two (or even less). If individual householders do not have a financial stake in the system, they will simply abandon it and go back to the older 'alternatives', even if they are technically inferior. This is a generic problem for many aid projects: funding is short-term and does not allow for follow-up support.

Villagers can find enough intermittent cash flow (e.g., from the sale of copra or kava) to pay for top-ups of kerosene for lamps. In principle this cash flow can be diverted to periodic payments to the 'solar energy scheme', to cover both the capital and maintenance costs. But the problem is not purely financial. Microfinance schemes, which could convert this cash flow to an upfront payment to purchase a PV system, have been almost unknown in Pacific before the last year or two, but that would still leave untouched the necessary technical support.

For technical support, the ideal is to have someone in each village (or least in the local district) who has the basic technical skills to reconnect broken wiring, to advise on battery care (including top-up where required) and the parts supply to replace the components most likely to fail, i.e., the CFLs and the battery. Many of the solar programs in the Pacific have not had the resources to enable this—with the honourable exception of the Kiribati Solar Electric Company (see below). This means technical support and parts have had to come from the main island, which often leads to the system being inoperable for a month or so, which is not very satisfactory.

Actually collecting the money is a non-trivial issue in a close-knit small community, where the society works on the basis of favours that are (eventually) reciprocated, rather than of cash payment, e.g., I help build your house in the expectation that sometime later you will help me clear land for garden. For this reason, village shops are often run by outsiders who can be a little firmer with their lines of credit. This sociological reason is also why communal PV schemes (in which a central set of PV panels supplies each house in a mini-grid) have usually failed in the Pacific, though successful in some other regions of the world (Chaurey and Kandpal 2010). Thus, fund collection for the solar systems is most effectively done by an outside organisation, e.g., a specialist Renewable Energy Service Company (RESCO).

Another general issue is the extent to which island governments can or should subsidise solar electric schemes. As (Urmee and Harries 2012) put it:

> It is completely understandable, for example, for a government to regard the provision of access to electricity as a service and to be willing to subsidise programs aimed at achieving this. The governments of many developed countries in the early twentieth century implemented rural electrification programs and uniform tariff policies that inflate electricity prices paid by urban electricity customers in order to cross-subsidise rural electricity customers are still common in countries such as Australia. The subsidisation of SHS is, however, a double edged sword as the funding provided to the government agency vested with the responsibility for implementing the program is limited and this severely limits the number of rural households that can be provided with a SHS under [government's] rural electrification policy.

In the interests of perceived fairness, and in part for technical simplicity, most schemes, provide a standard one-size-fits-all system to each participating household. However, slightly richer users may want some extra power to operate extra appliances (e.g., a small refrigerator, or a video player—there is no television transmission to the remoter parts of the Pacific) while poorer households may settle for less than standard (e.g., fewer lights), especially if prices are adjusted to match. Such systems (all at the larger end!) were common in French Polynesia.

These issues are not new. They were also reported in earlier reviews by (World Bank 1992); (Jafar 2000).

National 'Solutions' and Experience

This section briefly outlines the institutional a and financial aspects of some of the schemes (programs) that have been used in the Pacific Islands to spread the use of PV household systems.

Kiribati

The Kiribati Solar Energy Company (KSEC) is perhaps the best established program in the region. It is self contained government-owned corporation, established in 1984. It provides, installs and maintains the systems, through a network of TRAINED technicians—at least one on each of the islands they service (which is not yet the whole group), who are also responsible for collecting "monthly" payments, and for disconnecting households who do not pay. In short, KSEC operates as a RESCO. It has headquarters on the main island of Tarawa, but no household systems, as the Government has given a monopoly of electricity supply on Tarawa to the Public Utilities Board, who operate a diesel-fuelled grid. KSEC has good internal technical capacity, to the point where it designs and manufactures its own controllers. KSEC is supposed to run as a GBE without subsidy, but the Kiribati Government has been reluctant to allow it set prices (fees) high enough to cover full costs.

Tuvalu

The Tuvalu Solar Energy Corporation was a RESCO even before KSEC. It operated in a similar mode to that described here for KSEC, and was widely acclaimed as the most successful scheme in the region (World Bank 1992); (Jafar 2000). It collected enough funds from users to cover its full costs, including new and replacement systems, but these collected funds proved too much of temptation, and TSEC collapsed about 10 years ago when the then General Manager absconded with most of the collected monies! It has not been revived since then.

Fiji

The Fiji Department of Energy has been responsible for installing over 1,400 solar household systems, mainly in the rural areas of the second largest island (Vanua Levu). Detailed descriptions and critiques of its operation have been published by (Dornan 2011); (Urmee and Harries 2012). In brief, installation and maintenance are delegated to local electronics companies. However, the Department has retained responsibility for bulk purchase and warehousing of parts and for the financial aspects. A major practical weakness has been slow response to maintenance problems, even though the subcontractor (RESCO) is supposed to visit each site at least once every 2 months. This would be even more of a challenge on the smaller outer islands of Fiji, which is why DOE are only recently starting to extend the program to other islands. However, there is already a long waiting list for these PV systems.

Each household was charged F$50 initial fee + $14/month “rent” (paid to DOE though the nearest post office). The post office issued a voucher with a number which the user then entered into a keyboard built into the controller. Thus the system operated like the prepay mobile phones which are now very common in Fiji—no electricity (or phone calls) unless the device is financially ‘charged’. Unfortunately the New Caledonia maker of these prepay meters has ceased production, so alternative arrangements will have to be found. The fee was based on the notional cost of kerosene not used. Over 20 years, the user at this rate, the user would pay a total of about F$ 3,500, which is about 75 % of the estimated full cost over that time. The Fiji Government regards this subsidy as comparable to that which it pays for village electrification by a small diesel generator (~4 kW), where the government pays 95 % of the installation but the village has to buy all the fuel and pay for any subsequent maintenance.

In an interesting attempt to address the lack of trained technical help in the villages, in 2012 a group of a 10 mothers from rural villages have been trained as 'solar engineers' in India by the Barefoot College in the state of Rajasthan (Marau 2012).

French Polynesia

In an effort to compensate the islanders for the traumas of the bomb tests carried out in the 1980s, the French Polynesian government heavily subsidised the development and installation of solar household electricity systems on the outer islands. At the time, this program was a pioneer in this application, and one of the largest customers for photovoltaic panels in the world. Typically no less than 200 Wp of panel was installed and over 1 kip with an inverter was relatively common (Weir 1985). This allowed the use of major appliances such as a refrigerator or colour TV and brings electrification to a level comparable with urban use. The program was supported by a special new technical institute (SPIRE), which among other things developed highly efficient and reliable DC-powered refrigerators and other appliances, of which hundreds were produced locally, with some exported to other Pacific Island countries. More recently, the territory government has set up diesel-based grids on most islands, so the solar systems have been wound down (Wade et al. 2005).

Papua New Guinea

PNG has a surprisingly large number of relatively rich individuals in rural areas, with coffee farmers being particularly noticeable examples. Consequently there are reported to be several thousand SHS in PNG, mostly provided through private suppliers. Some of these are also associated with church boarding schools and the like (Wade et al. 2005).

Solomon Islands

Private suppliers of PV systems have been similarly active in the Solomon Islands. One supplier interviewed in 2012 claimed to be installing over 600 SHS systems per year, most of them paid for up-front through the 'constituency allowance' granted to members of parliament for development projects in their electorates.

However, the system pictured in Fig. 28.1 is one of a hundred or so installed on Guadalcanal (the island where the capital of Honiara is located) by a local NGO, with backing from the Solar Electric Light Fund (SELF), which operates in numerous developing countries around the world (see www.self.org). The original capital came from US Agencies; householders pay a monthly fee of US$15 into a revolving fund which is supposed to pay for maintenance (from Honiara, a few hours drive away) and for replacement parts and new systems.

Micronesia

A regional technical body, the Energy Division of the Secretariat of the Pacific Communities, SPC) is the implementing agency for the North-REP program funded by the EU. This program has a budget of several million Euros over 5 years and serves the Federated States of Micronesia, Marshall Islands and Palau. One of its major activities is the installation of PV household systems. SPC runs this program on a similar model to Fiji Department of Energy, but with even les delegated to subcontractors. System design and procurement of separate components rests with SPC, with actual installation by qualified electricians within each country; it is planned to have maintenance done by technicians from local utilities, trained on PV by SPC (SPC 2012a).

Economic Comparison with Alternatives

All the above programs have undergone some sort of cost-benefit (economic) analysis at some stage in their operation—perhaps most often in an initial feasibility study. Usually in such studies solar home systems are compared to one or both of the 'conventional' alternatives for remote areas: (1) kerosene lamps (or similar), and (2) a small diesel–generating set serving a whole village. Woodruff's study is an accessible example; she also examines the economics of other renewable energy—based systems (Woodruff 2007). In 2007, she found PV solar home systems to be the least cost system unless a diesel system could serve at least 500 households. The price of PV modules (solar cells) has continued to decline since then (Edenhofer et al. 2011), so a similar comparison today would be even more favourable to solar systems.

Conclusions

Solar household PV systems are technically well suited to supply the low wattage, decentralised demand for energy in the rural and remote areas where a large proportion of Pacific Islanders live. But to do so sustainably requires close attention to the institutional and financial issues posed by Pacific societies and cultures. A successful scheme certainly requires provision for small periodical payments that can cover the maintenance and replacement costs and technical assistance and parts available as close as possible to the users. Several schemes that approach this ideal are flourishing, but none are yet perfect.

The cost of PV modules fell rapidly through to about 2005 and then stalled as demand exceeded supply, but the manufacturers have now re-geared and prices are falling again. Together with the widening use of LED lights (which require less electricity per unit of light than earlier lamps) this will decrease the capital cost of each solar home system. This will ease, but not remove, the financial constraints on wider use of such systems in the Pacific Islands. However, the institutional and skill constraints can be removed only by appropriate policies and actions within the Pacific Island countries. Innovative training schemes such as that by the Barefoot College of India may help provide a cadre of on-site 'technicians', but they will need back-up from an increased number of local suppliers and of skilled professionals in-country (who will need training in local technical colleges).

Acknowledgments This paper is an amplification of one section of TW's keynote address to the International Conference on Technology Transfer and Renewable Energy, held at University of Mauritius, 21–22 June 2012. Both authors acknowledge financial assistance and encouragement from Project DIREKT, without which neither of us would have been able to participate in that conference. We also thank an anonymous referee for helpful comments.

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Chapter 29
A Geographic Information Systems Approach to Mitigating Sea Level Rise: Examples from Bermuda

Richard Snow, Mary Snow and Sebastian Brisson

Abstract Most island inhabitants, along with their infrastructure and socioeconomic activities, are situated just a few hundred meters from the shore and, as a result, are likely to experience negative impacts from rising sea levels. The destructive effects could include coastal flooding, loss of wetlands, saltwater intrusion, increased erosion, and higher storm surges. Projected sea level rise could seriously damage the socioeconomic growth of smaller island states, with practically every social and economic sector being disrupted. Smaller, low elevation islands might not have the physical size to deal with rising sea levels, and residents might be forced to relocate to other countries, which could have dire socioeconomic costs. The objective of this study is to demonstrate that a Geographic Information System (GIS) is an efficient instrument for conducting surveys and inventories to assess those small islands at higher risk and to develop mitigation strategies. Efficient monitoring requires the assessment of various coastal data baselines and the evaluation of subsequent alterations in spatial patterns. While monitoring involves real-time components, among the most powerful tools of a GIS are its modeling capabilities, which allow simulation of various climate change scenarios. The results of this research reveal that GIS techniques and applications play an integral role in defending small islands from climate change and other threats.

Keywords Climate change · Sea level · Tropical storms · GIS · Bermuda · Storm surge · Aviation

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_29,

Short Introduction

A geographic Information System (GIS) is an effective way to organize large amounts of information, while allowing the user to complete a spatial analysis that readily identifies patterns. Depicting the impacts associated with climate change, such as sea level rise and the ability to determine the best way forward, make GIS an appropriate tool for decision makers. For this research, data were collected and analyzed for the Bermuda International Airport with the purpose of finding a practical solution to ensuring a sustainable aviation infrastructure into the future, while taking into account projections of sea level rise and storm surge.

Assessing Vulnerability

Since 1961, measurements demonstrate that the oceans absorb more than 80 % of the heat added to Earth's climate system, with this warming occurring to depths of at least 3,000 m (IPCC 2007). From 1955 to 1995, the global ocean warmed 0.7 °C with more than half of the heat stored in the uppermost 300 m (Levitus et al. 2000). This warming results in the thermal expansion of ocean waters and contributes to a rise in sea level. The observed rate of sea level rise due to thermal expansion was 0.42 mm per year from 1961 to 2003, and that rate was highest during the latter decade of that period (1993–2003) averaging 1.6 mm per year (IPCC 2007). When modeling thermal expansion to make predictions, there is a projected sea level rise of 0.1–0.4 m by 2100 (Mann and Kump 2009).

Presently, 20 % of the people in the world live within 30 km of a coastline (Cohen et al. 1997). Most island inhabitants, along with their infrastructure and socioeconomic activities, are situated just a few hundred meters from the shore, and, as a result, they are likely to experience the most resounding repercussions from rising sea levels (Burns 2000). The destructive effects will likely include inundation of properties, loss of wetlands, sea water encroachment into fresh water supplies, increased erosion, higher storm surges, and dislocation. Simultaneously, these impacts will affect many smaller islands worldwide due to certain shared traits such as dependence on tourism as their primary means of income, limited access to natural resources, small geographic size and little local topographic relief, and infrastructure that is often concentrated along coastlines (Leatherman 1997). The projected rise in sea level would seriously damage the socioeconomic growth of smaller island nations (Granger 1997). On the smaller, low elevation islands, residents are, and will continue to be, displaced from their homes and forced to relocate to other locations (Nicholls and Mimura 1998).

Bermuda resides in the North Atlantic Basin of tropical cyclone (hurricane) activity. This area is at its highest exposure to tropical cyclones between the months of June and November. The naturally developing weather occurrence is particularly dangerous in low lying coastal regions; however, it affects inland areas

Fig. 29.1 Bermuda international airport on St. David's island

as well. Wave energy of high intensity, produced by hurricanes, has been found to affect the coastline of Bermuda. The highest wave energy was found to be along the south shore, specifically in two regions. The two regions include the central south shore and the entrance to Castle Harbour. Erosion susceptibility around Bermuda is divided into four categories: low, moderate, high, and very high. Areas around Bermuda International Airport are susceptible to erosion in the high, moderate, and low categories. The eastern portion of the airfield is considered to have the highest vulnerability to erosion, although the direction of an approaching storm will determine the rate of erosion. The runway dimensions are 2,961 m long and 46 m wide (Fig. 29.1). The coastline, which comes into contact with the southern portion of the airfield, is Castle Harbour, and is considered an area of low erosion probability. However, wave energy has been known to pass through and around Castle Islands at the southern entrance of Castle Harbour. This wave energy can then continue to cause erosion issues for the current terminal and the southern coastline of the airfield, which is rated in the moderate erosion susceptibility category.

Hurricane Fabian

In September 2003, Bermuda was hit by a Category 3 hurricane named Fabian. The hurricane was a typical Cape Verde storm and was the first major hurricane to directly impact Bermuda since Hurricane Edna of 1953 (Miller et al. 2009). Some locations on the island reported atmospheric pressure during the event as low as 953 millibars. However, the official pressure at its closest point of approach to Bermuda was 961 millibars. Storm surges impacted the island for several days and reached estimated heights of 6–9 m along the most exposed south shore of the island with 1.8–2.4 m storm surges affecting the airport area (BWS 2003).

It should be noted that elevation of the terminal floor in the departure area of the airport is approximately 3 m above mean seal level and the runway elevation is a mere 1.8 m higher. Storm surge wave run-up created by Hurricane Fabian and impacting the airport reached approximately the same level as the runway elevation, as evidenced by debris lines left by the sea water on the runway. The terminal building was flooded by 0.91 m of seawater.

Figure 29.2 is a GIS rendering of sea level and storm surge of 1.8 m, such as was experienced as a result of Hurricane Fabian. The resulting repair work at the Bermuda International Airport was reported to have been $15 million (USD) from damages, which included damage to the passenger terminal, Instrument Landing System (ILS), radar, and debris on the runway from ocean water, completely inundating the runway during the event. No proactive damage limitation measures have been installed since that time. As sea level increases, storm surge may impact the Airport at a higher cost to the Government of Bermuda (Miller et al. 2009).

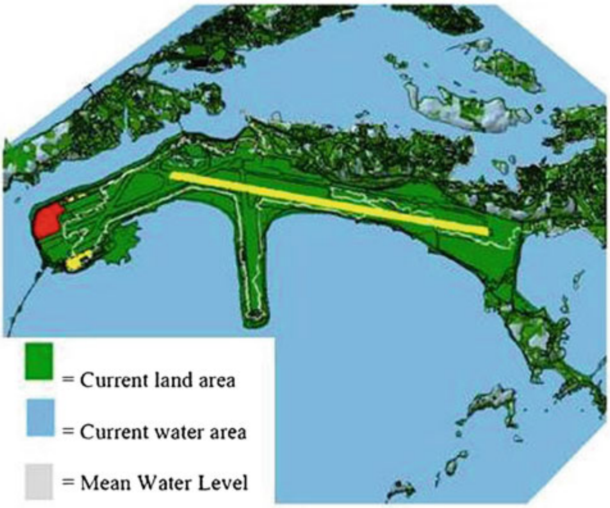

Fig. 29.2 Hurricane fabian mean water level 1.8 m

GIS Simulation of Mean Water Level

Various sea level rise scenarios and the associated threats to coastal locations can be modeled using GIS. The simulation begins with the establishment of mean sea level for a specific coastal area based on topographic quadrangle contour lines, which are the most important data source for assessing areas that might be flooded. Local mean sea level can be increased according to the elevation estimations derived by the models allowing the user to project future high water marks to reveal the areas under the greatest risk of inundation.

After demarcations of high water marks are made, the GIS can be further developed to incorporate a wide range of applications, such as surveys, inventories, monitoring, and modeling.

Surveys that are useful for assessing vulnerability near airports include navigational aids, service facilities, cargo, maintenance, aprons, taxiways, runways, civil terminal areas, and service roads. Also, the infrastructure that supports the airport's land use, such as fresh water supply, power transmission, and production were added to the GIS to approximate demands and keep disruption to a minimum. In a study conducted for the Government of Bermuda, synthetic storms were created in models that computed storm surge sea levels and did not factor in a specific directional approach of a hurricane. These models assumed a predicted global sea level rise (GSL) in the next 50 years to be 0.25 m (0.82 feet).

This prediction is on the conservative side of forecast sea level rise and could be as much as approximately 0.6 m (1.97 feet) more or less depending on the impact of climate change in the near future. A GSL of this magnitude or higher will have a significant impact on the aviation infrastructure in Bermuda due to the storm surge water levels reaching unprecedented heights in a 1-in-150 year event. To assess the vulnerability of Bermuda's airport, multiple factors such as the inverse barometric pressure rise (IBR), GSL, tide heights, intensity of the storm, effects of inland regions of water, and the nearshore environment need to be taken into account. Previous studies have compiled values that will be used to predict a worst-case scenario storm surge in the Castle Harbour north region in a 1-in-50 year hurricane event. The values also include a predicted worst-case scenario storm surge in the Castle Harbour north region with a 1-in-150 year or major hurricane event. IBR is dependent on the pressure inside the storm. The deeper the low pressure inside of the hurricane, the less weight is exerted on the ocean causing it to increase the water level in that specific region. The closer to the center of the low pressure, the higher is the effect of IBR, which may create a dome of water. Tide heights were calculated by using mean higher high water (MHHW) measurement above mean sea level (MSL) around Bermuda based on recorded data (NOAA 2010).

The GIS simulation included expected normal high tide level and expected tropical cyclone storm surge plus a wave setup factor from extreme wind. The Bermuda Coastal Erosion Vulnerability Assessment (2004) calculated static storm surge data by using a model to simulate waves, named Simulating Waves

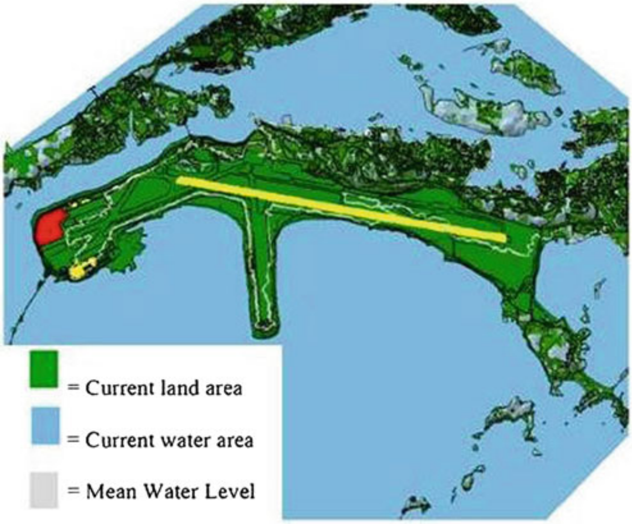

Fig. 29.3 Mean water level 2.25 m

Nearshore (SWAN). Using SWAN, interpolation, and data attained from previous hurricanes, static storm surge was given a value for each category of hurricane under a proposed sea level rise of 1.5 m by 2100 (Grinsted et al. 2009). Finally, the combination of factors was used to graphically represent the mean water level (MWL) at specific regions of coastline around the airport. Figure 29.3 depicts an MWL of 2.25 m, which is equivalent to a Category 4 hurricane striking Bermuda today, or a Category 2 making landfall in 2075, based on the suggested sea level rise of 1.5 m by 2100. Under this scenario, the new terminal, old terminal, and much of the operational runway would be underwater and most likely damaged beyond repair.

Taking the simulation to the worst case scenario, Fig. 29.4 depicts MWL of 3 m which could be associated with a Category 5 hurricane striking in 2100 under the suggested sea level rise. The only areas of the airport not completely inundated in this extreme case are the land reclaiming facility, roofs of the civil air terminal, and the mail center. The area for the future air terminal would also be underwater.

Implications for the Bermuda International Airport

With rising sea levels and possible increased storm surge and erosion, the distance to the Atlantic Ocean and the runways and taxiways will decrease. The International Civil Aviation Organization (1999) requires, where practical, to have a runway strip area of 150 m either side of the centerline and 60 m beyond the end

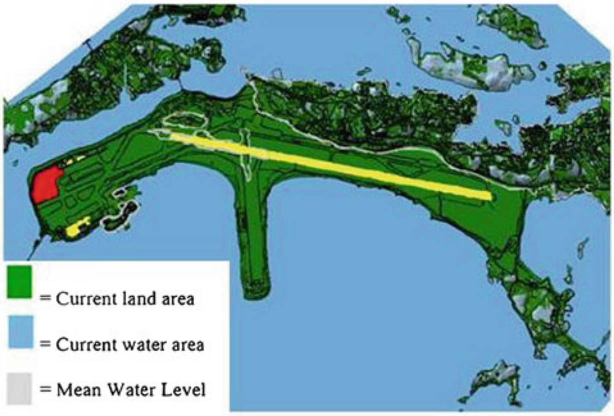

Fig. 29.4 Mean water level 3 m

of the runway. Also, the runway end safety area (RESA) should be at least 90 m from the end of any runway strip totaling 150 m. For the length of Bermuda's runway, the RESA is a code number 4 and is suggested to be 240 m or as far as practicable. The purpose of the RESA is for aircraft overshooting or undershooting a runway, and they have been proven to greatly increase the safety at a particular airport. Due to the Bermuda airport's position in relation to Castle Harbour, the Atlantic Ocean, and being on St. David's Island, it may prove difficult to create a sufficient RESA due to the site of the runway and taxiways.

With more tropical cyclones impacting Bermuda with increased intensity, storm surge levels will become higher than ever before due to increased sea level. This could lead to MWL higher than witnessed during hurricane Fabian at Bermuda's airport. Increased MWL would lead to more damage to facilities from floating debris, wave forces, water weight, and erosion of surface features. Areas reached by Fabian's storm surge made portions of the airport and the island's infrastructure unusable after the hurricane had passed. Examples of the storm surge destroying or damaging Bermuda's infrastructure during hurricane Fabian include much of the causeway bridge, the civil air terminal, and area service roads on the Castle Harbour side of the airfield. This type of damage could reach the only currently active runway and cause increased damage to the civil terminal at the Bermuda International Airport. Damage felt by increased storm surge would lead to a crippled aviation infrastructure in Bermuda.

Although navigational aids are shifting to more space based technologies for instrument approaches such as GPS/RNAV approaches, Very-high frequency Omni-directional radio Range (VOR) approaches are still used. Airport lighting in the ground would also be damaged during storm surge inundation. Damage to Bermuda's ground-based facilities and equipment due to the increase in major hurricanes would reduce the airport's redundancy and safety measures for aircraft landing in Bermuda. Instrument approaches, lighting for night operations, and visual aids for approaches such as the PAPI are aids used by airports to conduct safe and effective operations for the users.

Other ground based facilities and equipment at the airport are already vulnerable to damage from major hurricanes and may be more significantly and frequently damaged as sea level rises. Bermuda's airport will be more likely to experience damage into the future as more major hurricanes affect the island, combined with sea level rise due to elevation and location of the ground facilities and equipment. The VOR is located in an area less than 2 m above sea level and is continually vulnerable to inundation by passing hurricanes. Significant damage to Bermuda's only operational runway due to a higher storm surge during tropical cyclone events in the future, would lead to a slower and more difficult recovery effort for the island.

GIS depictions of storm surge inundating much of the airport show that it could become a more common occurrence with increased sea level and a more active yearly hurricane season. Medical aid, food supplies, and outside assistance would have to find different sources of transportation to reach people in a relief effort. The delay in assistance could lead to slower economic and social recovery from the tropical cyclone event. Hurricane Katrina's effect is still being felt over five years after it plowed into the gulf coast. Fabian's cost to repair Bermuda's airport and the Government of Bermuda would be dwarfed if a category 3, 4, or 5 hurricane struck in the future due to higher MWL. Bermuda's fastest link to the rest of the world would be crippled with the next closest means of transporting goods then being marine transportation. The longer the airport is not operational in bringing goods, services, people, and business to and from Bermuda, the greater will be the impact on the island's economic well-being. The cost of a lengthy airport shutdown to Bermuda's public and private sectors must not be underestimated. Ripple effects would further impact the island's economy due to Bermuda's heavy reliance on aviation for international business, tourism and perishable goods being transported. Runway repair would be costly and difficult to accomplish in a short amount of time without outside assistance and services, due to limited access to supplies and specialized workers in Bermuda.

Some engineering measures have been taken to protect the civil air terminal since Fabian, but it has not been tested by a hurricane of similar intensity and proximity to Bermuda. Increased damage to the civil air terminal due to increased exposures to tropical cyclones or increased intensity could lead to extreme costs for repair or replacement. Factors of erosion and corrosion, from increased exposure to the ocean due to climate change, could increase operational costs for the Government of Bermuda.

Recommendations for Mitigating Sea Level Rise

GIS depictions show that the airport is already at risk of being inundated from storm surge. As time progresses, the GIS depictions show less powerful hurricanes having increased impact on the airport. Although most scenarios do not expect sea level to increase a significant amount in the next half century, Bermuda's long-term airport plan should consider solutions to sea level rise due to climate change in advance to prevent a heavy burden on tax payers in the future.

With Bermuda's new civil air terminal still in its planning stage, adjustments may have to be made to current plans. Adjustment may include increased elevation of the planned height above sea level for the future terminal. The new terminal will not be built for some time, as the priority of Bermuda's citizens is currently with the construction of the new hospital. Due to the current economic climate, the project may not happen for quite some time. Considering possible future outcomes of climate change, such as sea level rise, an assessment into the elevation and vulnerability of the new civil air terminal should be accomplished to ensure a strong aviation infrastructure into the future.

Possible solutions should start with a more in depth hazard assessment of the potential damage and costs versus the cost to prevent damage. It may take an extreme event for action to be taken for prevention solutions to justify the costs of seawater protection. Further research should examine the cost of a major hurricane impacting Bermuda's airport in the future. The total toll on the economy should be assessed for factors such as the transportation of goods, services, and people being completely cutoff from the outside world. The cost of unplanned repair of the runway, taxiways, civil terminal, navigational equipment, and other essential services should be included.

Engineering solutions should be further researched to ensure that the people and government of Bermuda are prepared, protected, and secure from the threats to the airport from storm surge and sea level rise. Engineering seawater protection should consider short and long-term solutions including breakwaters, revetment, and raising airport elevation. A long-term airport plan of land reclamation efforts at Bermuda's airport should be instigated to optimize efficient use and protection of the airport. Environmental impacts of land reclamation to Bermuda's marine life and Castle Harbour should be examined to prevent negatively influencing the area through pollution.

The Government of Bermuda should consider using a seaplane access for emergency relief efforts in future extreme events. Areas that are limited to exposure should be investigated as possible areas for seaplane docking. Since the former flying-boat stations are available, an assessment of the use of these facilities for relief efforts and emergencies in the future should be considered for additional options to Bermudians. Finding the exact height of wave-up action during storm surge inundation of the Bermuda International Airport should be further studied. This would give indications of possible impacts to other areas of Bermuda besides the airport, which includes residences, businesses and infrastructure. Other infrastructure besides aviation that may be affected by the increased sea level and storm surge due to climate change could be electricity, water, and marine and ground transportation.

Lastly, additional research should be done on the cost of building up the elevation of the airport for long-term implications of climate change. An example of other airports being elevated is the artificial island airport in Japan, named Kansai

International Airport. Although the scale of Kansai International Airport construction is much larger than Bermuda's elevation rise and land reclamation project will need, lessons could be learned from the project (KALD 2008). For efficient planning to occur, an effective policy is needed that assesses the numerous coastal databases and projections of both global temperature and sea level rise. GIS can be an important planning tool for this task due to its ability to speed the decision-making process by allowing easier management of data, modeling various climate change scenarios, and graphically depicting the impacts.

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Chapter 30
Estimation of Carbon Stock in Church Forests: Implications for Managing Church Forest to Help with Carbon Emission Reduction

Tulu Tolla Tura, Mekuria Argaw and Zewdu Eshetu

Abstract Forests play a significant role in climate change mitigation by sequestering and storing more carbon from the atmosphere than any other terrestrial ecosystem. Church forests, including other sacred places, are relatively more protected than forests in any other places. The overall objective of this study was to estimate the contribution of church forests to the reduction of atmospheric carbon concentration by conducting case studies on selected churches in Addis Ababa:—Seven churches was selected to estimate carbon in above and below ground biomass; dead litter and soil; each tree in the study site which had Diameter at breast height (DBH) greater than 10 cm was measured for DBH, height, basal height, and crown height while sampling of dead litter and soil carbon was conducted by sampling quadrates. Above ground biomass was estimated by using allometric models while below ground biomass was determined based on the ratio of below ground biomass to above ground biomass. The results show that there are 1,519 trees in the study sites which had DBH $>$ 10 cm. The mean above ground and below ground biomass carbon stock ranged from 129.85 $\pm$ 154.11 and 25.97 $\pm$ 30.82 t ha^{-1}, respectively. The mean above ground biomass carbon per tree was 0.6 $\pm$ 0.69 t. The mean carbon in dead litter and soil carbon was 17.83 $\pm$ 19.13 and 135.94 $\pm$ 21.25 t ha^{-1} respectively. From the point of view managing forests for climate change mitigation, the result suggested well managed sacred forests could have a significantly contribution to carbon emission reduction and enhancing in situ conservation of biodiversity.

Keywords Carbon sequestration · Church forests · Climate change and sacred site

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_30,

Short Introduction

The impact of green house gases play a significant role on the global climate system and forests play an important role in the global carbon cycle, sequestering and storing more carbon than any other terrestrial ecosystems. Ethiopian Orthodox Tewahido churches have a long experience in conserving trees around churches and monasteries. Church forests, including other sacred places, are relatively more protected than forests in any other places. The overall objective of this study was to estimate the contribution of church forests to the reduction of atmospheric carbon concentration by conducting case studies on selected churches in Addis Ababa, where seven churches were selected.

Introduction

The impact of green house gases play a significant role on the global climate system. When the concentration of green house gasses in the atmosphere increases; the temperature of the earth's surface is also expected to increase (IPCC 2001; Petit et al. 1999; Wigley 1993). Forests play an important role in the global carbon cycle (IPCC 2001). It sequesters and store more carbon than any other terrestrial ecosystems and is an important natural damper on climate change (IPCC 2007; Malhi and Grace 2000). Ethiopian Orthodox Tewahido churches have a long experience in conserving trees around churches and monasteries. Conducting study on forests managed under Ethiopian Orthodox Tewahido churches and monasteries to appreciate their role in climate change mitigation and adaptations is very important. It will have a cumulative knowledge of thousands of years, experiences of many people, wisdom of the spirit mediums, the wise council of elders and the leadership of religious leaders, institutions in managing and conserving resources and strong sanctions and 'gizet' for Outliers (Alemayehu Wassie 2002; Sibanda 1997).

Materials and Methods

The study was conducted in Addis Ababa city, the capital of Ethiopia and the seat of African Union. The study sites were largely incorporated in the Northern-West of Addis Ababa since older churches are located in this part of the city (Fig. 30.1). The study sites range between 2,984 to 2,381 m a.s.l. with location of $9^{\circ}05'$N–$9^{\circ}00'$N and $38^{\circ}45'$E–$38^{\circ}42'$E with mean annual rainfall about 1,128 mm (Table 30.1). Data collections were conducted from August 27 to October 10, 2010.

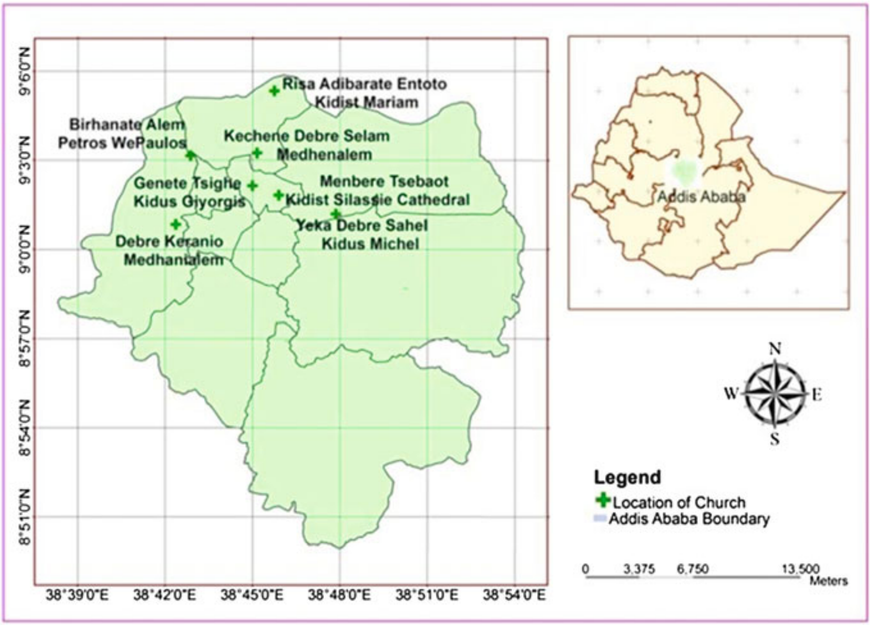

Fig. 30.1 Location map of Addis Ababa and location of churches selected for the study

Diameter and Height Measurement

The DBH and height of all trees having a diameter >10 cm in the study site were measured. Diameter at 1.3 m above the ground unless there is abnormality of all living trees (woody plants) was measured using a diameter tape. Trees with multiple stems at 1.3 m height were treated as a single individual and the DBH of the largest stem was taken. A canker, gall or branched trees at 1.3 m was measured at the smallest point below where the stem assumes near cylindrical shape. Trees with multiple stems or fork below 1.3 m height were treated as a single individual, with an identification code placed on it. Trees on a slope area were measured on the uphill side while the Heights, crown height and basal height of all trees were measured using a Haga hypsome the position possible to observe the tip of the trees. Areas of forest in each study sites were determined from the coordinates collected.

Litter Sampling

A quadrate with the size of 10 m × 10 m was used for sampling litter. In each study site four sampling quadrate were laid. The litter sample was collected from sub-quadrate of 1 m × 1 m laid by Z sampling method. From each quadrate four

Table 30.1 Mean monthly and mean annual rainfall of Addis Ababa

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann. mean
A. A. Bole (1964–2004)	13.7	37.4	68.6	93	76.4	119	235.4	242.5	143.3	32.7	7.2	5	1,074
Akaki Beseka (1951–2004)	14	36.8	67.5	91	67.1	123	264.1	283.9	131.1	24.5	3.8	3.1	1,109
AA Observatory (1900–2004)	16.4	42.9	65.9	93.4	85.5	131	259	278.4	175.1	38.1	7.5	9	1,201
Mean monthly	14.7	39	67.3	92.5	76.3	124	252.8	268.3	149.8	31.8	6.2	5.7	1,128

Source (National Meteorological Services Agency) samples were taken. Wet weight of each sample was measured while 100 gm sub-sample was taken from each sample for laboratory analysis.

Laboratory analysis: The 100 gm sub-sample wet weight was oven dried at 65 °C while oven dry weight was taken for each sub-sample. The oven dried sub-sample per sampling quadrate was homogenously mixed and carbon fraction was measured in the laboratory using the Walkley–Black Method.

Soil Sampling

Soil samples for soil carbon analysis were collected at the same sampling and sub-quadrates used for litter sampling (section "Soil Sampling"). In each sub-quadrate soil sample was taken using core sampler auger at depth of 30 cm.

Laboratory analysis: The collected sample was air dried while the dry weight of each sample was taken. All samples collected in each sampling quadrate were mixed homogenously while carbon fraction of each homogenous sample was measured in the laboratory using the Walkley- Black Method.

Estimation of Carbon in Above and Below Ground Biomass

Above ground biomass (AGB) estimated by:

$$Y = 34.4703 - 8.0671(DBH) + 0.6589(DBH^2) \tag{30.1}$$

where, Y is above ground biomass, DBH is diameter at breast height,

Below ground biomass (BGB) estimated by:

$$BGB = AGB \times 0.2 \tag{30.2}$$

Finally, carbon content in the biomass was estimated multiplying by 0.47, while multiplication factor 3.67 was used to estimate CO_2 equivalent.

Estimation of Carbon in Dead Litter Biomass

$$LB = \frac{W_{field}}{A} * \frac{W_{sub\_sample(dry)}}{W_{sub\_sample(fresh)}} * \frac{1}{1,000}. \tag{30.3}$$

where LB = Litter (biomass of litter t ha1^{-1}), W_{field} = weight of wet field sample of litter sampled within an area of size 1 m^2 (g); A = size of the area in which litter were collected (ha); $W_{\text{sub-sample,dry}}$ = weight of the oven-dry sub-sample of litter (g), and $W_{\text{sub-sample,fresh}}$ = weight of the fresh sub-sample (g) (Pearson et al. 2005).

$$CL = LB \times \%C \quad (30.4)$$

where CL is total carbon stocks in the dead litter in t ha^{-1}, %C is carbon fraction determined in the laboratory (Pearson et al 2005).

Soil Carbon Estimation

$$V = h \times r^2 \quad (30.5)$$

where V is volume of soil in the core sampler augur in cm^3, h is the height of core sampler augur in cm, and r is the radius of core sampler augur in cm (Pearson et al 2005).

$$BD = \frac{Wav, dry}{\mathrm{V}}. \quad (30.6)$$

where BD is bulk density, Wav, dry is average air dry weight of soil sample per 10 m × 10 m quadrate, V is volume of the soil sample in the core sampler auger in cm^3 (Pearson et al. 2005).

$$SOC = BD * d * \%C \quad (30.7)$$

where SOC = soil organic carbon stock per unit area (t ha^{-1}), BD = soil bulk density (g cm3), D = the total depth at which the sample was taken (30 cm), and %C = Carbon concentration (%).

$$C_{density} = C_{AGB} + C_{BGB} + C_{Lit} + SOC \quad (30.8)$$

where C density = Carbon stock density in all pools for each site [t ha^{-1}], C AGTB = Carbon in above—ground tree biomass [t C ha^{-1}], CBGB = Carbon in below-ground biomass [t C ha^{-1}], C Lit = Carbon in litter [t C ha^{-1}], SOC = Soil organic carbon [t C ha^{-1}], while CO_2 equivalent was estimated by multiplying 44/12 or 3.67 of carbon density.

Results and Discussion

The number of tree species in the study sites range from 3 at site IV to 18 at site VI. Tree density site VI ranked first with 442 trees ha^{-1} and site IV ranked the least with 75 trees ha^{-1} but the maximum exotic species had been recorded in study site VI (Table 30.2). In terms of plant species distribution, *Juniperus procera* has the highest density with 884 individuals while *Pinus radiata, Spathodea nilotica* and *Araucaria jussieu* accounts for the lowest density with 2 individuals (Table 30.3). Density of trees per hectar for site II and site VI were virtually greater than that of Munessa-Shashemene state forest, which supports 306

Table 30.2 Summary of exotic and indigenous species recorded in the study site

Study sites	Year of establishment (E.C)	Species				Total density in the study site
		Indigenous		Exotic		
		Species (no)	Density	Species (no)	Density	
I	1901	4	136	–	–	136
II	1903	6	305	5	35	340
III	1826	5	130	3	6	136
IV	1370	2	67	1	8	75
V	1903	6	208	4	27	237
VI	1924	9	355	7	58	442
VII	1919	7	115	3	38	153

individual ha^{-1} (Getachew Tesfaye 2007). In the seven studied sites, a total of 22 different tree species with density of 1,519 were recorded. Their DBH ranges from 10 to 162 cm.

Juniperus procera and *Olea europaea* were commonly recorded in all study sites (Table 30.3). The numbers of species in the study sites differ with the time of establishment of the church. The earliest churches had less number of exotic species and higher number of indigenous species. This might be due to the fact that introduction and planting of exotic species were not common in earlier times

Table 30.3 Types of species, mean, density, DBH and height

Species name	Density (No/ha)	Height (m)	DBH (cm)
Juniperus procera	884	23.58	47.70
Olea europaea	291	15.50	38.50
Millettia ferruginea	3	17.67	36.87
Cordia africana	8	18.75	46.38
Cupressus lusitanica	25	11.28	16.70
Dracaena steudneri	42	11.57	29.13
Eucalyptus saligna	88	33.67	58.59
Pinus radiate	2	16.00	23.50
Acacia melanoxylon	18	16.44	25.71
Casuarina cunninghamiana	26	18.35	38.05
Allophyllus abyssinica	11	10.73	24.71
Phoenix reclinata	12	10.00	19.50
Dalbergia melanoxylon	8	18.13	60.29
Croton mcarostachyus	27	18.30	48.59
Spathodea nilotica	2	13.00	30.75
Euphorbia abyssinic	6	10.00	29.58
Araucaria jussieu	2	11.00	25.50
Callistemon citrinus	9	14.67	15.00
Ficus sur	22	16.59	44.48
Erythrina brucei	3	13.33	24.93
Acacia abyssinica	4	12.50	70.93
Gravillea robusta	26	21.23	51.62

(Table 30.2). In general, 86.77 % (1,318) of trees in the study sites are indigenous and also some of them are endemic. Even if the study sites were more susceptive to introduction of exotic species, the church conserved significant indigenous tree species. In addition the density of trees per hectare in most of the study sites was comparable with other studies conducted in the country and the international standard recommended for afro-montane forests.

The forest coverage area in each studied sites extended from 1.815 to 0.082 ha. Churches established in earlier times (as old as 1,370 years E.C) had a smaller area covered by trees than the most recently established churches (as old as 1,924 years E.C). On average the area of study site covered by forest was 0.531 ha. According to this study church forests in the study sites are potential for carbon finance as they fulfill the requirements to be forest. Tree species with a minimum mean height of 10 m were *Phoenix reclinata* and *Euphorbia abyssinica* while tree species with a maximum mean height of 33.76 m has *Eucalyptus saligna*. Both species with a minimum mean height were indigenous. The maximum and minimum DBH recorded in the study sites were 162 and 10 cm respectively. *Callistemon citrinus* and *Acacia abyssinica* had minimum and maximum DBH; their values were 15 and 70.25 cm respectively. According to the results in the study, some study sites had high regeneration rate while the others were poor regeneration rate. This may be due to human interaction and lack of land for planting new seedlings in the church compound.

Carbon Stock in the Above Ground Biomass

The minimum value for carbon stock recorded per tree species was 0.01 t, while 7.53 t is a maximum value. These refer to *Juniperus procera* and *Grevillea robusta* respectively. According to this study, planting a single tree in a church compound could sink 0.60 ± 0.69 SD t mean carbon stock that is a significant contribution to climate change mitigation. The maximum carbon density was 444.15 t ha^{-1} in study site VI while the minimum carbon was 20.03 t ha^{-1} in study site IV. The overall summations of carbon and carbon dioxide in above ground biomass in the study sites are 908.99 and 3,335.99 t respectively. The churches in the study sites potentially mitigate climate change by sinking mean 129.86 ± 154.11 SD t ha^{-1} carbon stock in above ground biomass (Table 30.4).

Carbon Stock in Below Ground Biomass

Trees in the study sites captured a mean 0.12 ± 0.14 SD t of carbon stock in below ground biomass while 25.97 ± 30.82SD t ha^{-1} a mean carbon stock in below ground biomass. The results in the study sites indicated standing trees in addition to above ground biomass captured a significant amount of carbon stock

Table 30.4 Carbon and carbon dioxide stock in soil and dead litter (DL)

Study sites	Name of churches	C and CO_2 in AGB $t\ ha^{-1}$ respectively		C and CO_2 in BGB $t\ ha^{-1}$ respectively		C and CO_2 in DL $t\ ha^{-1}$ respectively		C and CO_2 in soil $t\ ha^{-1}$ respectively	
I	Birhanata Alem Petros Wa Pawulos	30.94	113.55	6.19	22.72	3.54	12.99	99.77	366.16
II	Geneta Tsige Kidus Giorgis	187.04	686.44	37.41	137.29	7.36	27.01	131.58	482.89
III	Debre Keraniyo Medihanalem	51.25	188.09	10.25	37.62	4.59	16.84	158.06	580.08
IV	Risa Adibarate Entoto Kidist Mariam	20.03	73.51	4.01	14.72	6.59	24.18	162.27	595.53
V	Kachane Debre Selam Medihanalem	154.46	566.87	30.89	113.37	5.52	20.26	127.28	467.12
VI	Menbera Tsebaot Kidist Silase Cathedral	444.15	1630.3	88.83	326.01	3.52	12.92	144.23	529.32
VII	Yeka Debre Sehil Kidus Micheal	21.13	77.55	4.23	15.54	3.5	12.85	128.37	471.1179
	Mean	129.86	476.59	25.97	95.31	4.95	18.17	135.94	498.89
	Total	909	3336.3	181.81	667.24	34.66	127.20	951.56	3492.22

in their roots. Over all trees in the study sites played a significant role by capturing 181.79 and 667.17 t ha^{-1} carbon and carbon dioxide in their roots which is major cause of global warming (Table 30.4).

Carbon Stock in Dead Litter

The mean carbon stock in dead litter in the study site was 4.95 t ha^{-1} (Table 30.4). This value is higher than the value cited in IPCC (2006), about 2.1 t ha^{-1} for tropical dry forests and 49 t ha^{-1} for moist boreal broad leaf forests. According to Brown and Lugo (1982) litter biomass in dry tropical forests ranged between 5.6 to 8.2 t ha^{-1} $year^{-1}$ while dead litter biomass in the present study ranged between 7.49 to 15.66 t ha^{-1} almost two fold the values reported for dry tropical forests. This might be due to older trees in the study site that cause more litter drop and makes some deviation the current study result from similar study conducted on other tropical forests.

Soil Organic Carbon

In 0.30 cm depth mineral soil in the study site, in addition to AGB, BGB and DL capture 135.94 ± 21.26SD t ha^{-1} mean carbon stock in soil (Table 30.4). Mean

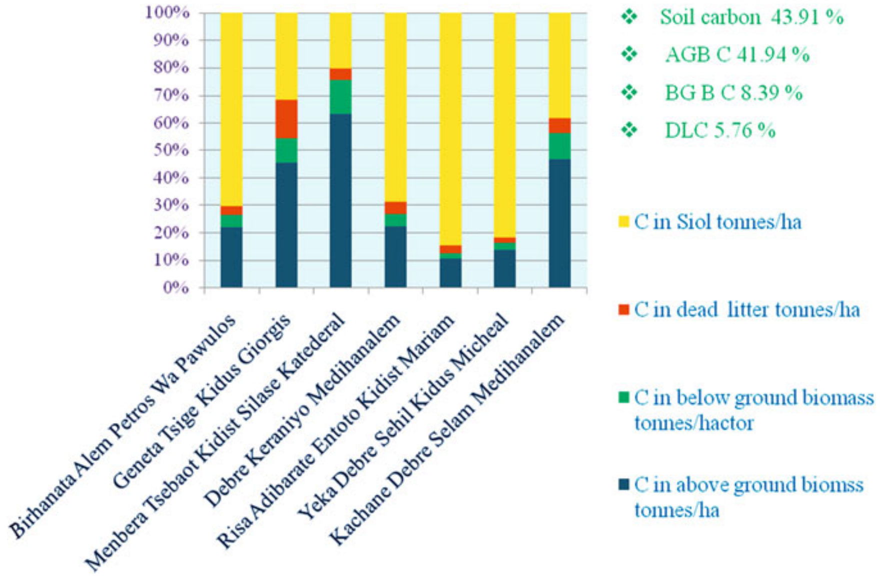

Fig. 30.2 Carbon stock in different pools each study sites

carbon stock captured in soil pool was relatively greater than other pools in the study sites which concur with the literature value.

In the seven studied church forests 2,077.88 and 7,625.82 t carbon and carbon dioxide was sequestered respectively (Table 30.4). The lowest carbon stocks were in the dead litter pool while the highest carbon stock was in the soil pool. The overall proportion of carbon in different pools was soil pool 43.91 %, above ground biomass pool 41.94 %, below ground biomass pool 8.39 % and dead litter pool 5.76 % (Fig. 30.2). Thus the highest carbon stocks were captured in the soil pool, in close agreement with established knowledge.

Conclusions

Most of the tree species in the studied churches are indigenous, which implies the contribution of churches in particular and sacred sites in general. Moreover, the carbon sequestered in these forests is analogous with the value stated in the literature for forests found in different life zones, consistent with what is seen in other forests in the country. This indicates that the role of church forest in carbon sequestration and urban climate regulation is highly significant, further suggesting their potential value for carbon marketing. Considering this forest for climate change mitigation and fund attraction is, thus, highly important. Therefore, recognizing this religious role for biodiversity conservation, climate change mitigation and urban greening is an important aspect which is often overseen.

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Chapter 31
Fast Pyrolysis and Kinetics of Sugarcane Bagasse in Energy Recovery

Mahir Said, Geoffrey John, Cuthbert Mhilu and Samwel Manyele

Abstract The trend for material and energy recovery from biomass-waste along with the need to reduce green house gases has led to an increased interest in the thermal processes applied to biomass. The thermal process applied to biomass produces either liquid fuel (bio-oil) or gaseous fuel. Liquid fuel is more preferred because it is easier to transport from one point to another and also it can be used for production of chemicals. One of the biomass obtained in Tanzania is sugarcane bagasse. The sugarcane bagasse is the fibrous materials that remain after sugarcane is crushed to extract juice. Currently, it is burnt directly in the boilers for production of steam, but it can be used for production of bio-oil. The bio-oil can be optimally obtained by fast pyrolysis, which is a fast thermal decomposition of biomass material at temperature range 523–800 K in the absence of an oxidizing agent. In order to undertake a parametric study on the fast pyrolysis of sugarcane bagasse, it is imperative to establish its thermal characteristics. The paper reports the proximate and ultimate analysis, and thermal degradation of sugarcane bagasse in nitrogen as heating agent. The thermal degradation was conducted in a thermogravimetric analyzer from room temperature to 1,000 K at different heating rates of 5, 10, 20 and 40 K min^{-1}. The thermo-gravimetric analyzer was used to study the effect of heating rate on the thermal degradation characteristics and to determine mass loss kinetics. The sugarcane bagasse was observed to be suitable for use in pyrolysis since it contains high volatile level of 80.5 % and fixed carbon of

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_31,

8.2 %. The peak temperature was observed at 573 K at 10 K min^{-1} and corresponding activation energy was 387.457 kJ/mol.

Keywords Sugarcane bagasse · bio-oil · Fast pyrolysis · Activation energy · Thermo-gravimetric analyzer

Symbols

Symbol	Description
A	Pre-exponential factor
AAS	Atomic Absorption Spectrometer
C	Carbon
Cl	Chlorine
E_a	Activation energy
H	Hydrogen
k	Reaction constant
k1	Rate constant for gas
k2	Rate constant for tar
k3	Rate constant for char
N	Nitrogen
O	Oxygen
R	Gas constant
S	Sulphur
T	Absolute temperature
TG	Thermo-gravimetric
TGA	Thermo-gravimetric analysis
T_{max}	Maximum temperature
w	Weight of a sample at time t
w_o	Initial weight
w_∞	Final weight
x	Reacted fraction
β	Heating rate

Short Introduction

In order to reduce the emissions of green house gases, an increased interest in the thermal processes applied to biomass-waste became a common trend in the world. Sugarcane bagasse (the fibrous materials that remain after sugarcane is crushed to extract juice) is a one of the important biomass-wastes of Tanzania. This paper reports the proximate and ultimate analysis, and thermal degradation of sugarcane bagasse in nitrogen as heating agent. The sugarcane bagasse was observed to be suitable for use in pyrolysis since it contains high volatile level of 80.5 % and fixed carbon of 8.2 %.

Introduction

Biomass is in fourth position in the ranks of energy resources on a global basis, providing 14 % of the world energy need (Garcia-Perez et al. 2001). In developing countries like Tanzania 90 % of the energy consumed is from biomass, in the form of wood and charcoal, while petroleum and electricity account for 8 and 1.2 % respectively, the remaining source of energy is 0.8 %, such as coal (Mshandete 2011).

Sugarcane is one of the largest products that are obtained in Tanzania; there are about 17,000 hectares of sugarcane. All the sugarcane farms are owned by sugarcane companies; these are Kilombero Sugar Company, Mtibwa Sugar Estate, Tanganyika Planting Company (TPC) and Kagera Sugar. Each company produces about 450,000 tones of bagasse per year (Gwang'ombe and Mwihava 2005).

The produced sugarcane bagasse from Sugar Company has a moisture content of about 50 %, with a calorific value of 10 MJ/kg. The mill bagasse has a low bulk density of 130 kg/m^3, which cause a storage problem, because it requires a large space and also equipment for handling (Deepchand 2001). In most of the sugar company the bagasse produced is directly burnt in the boiler for production of steam which can be used for production of electricity. This process generates residues that could lead to high disposal costs or pose environmental problem when disposed by means of open air burning (Szogs and Wilson 2008).

An advanced thermal technology is required to harness energy with the intimacy of minimizing disposal cost and environmental pollution. The thermal technology requires knowledge of thermal behavior of sugarcane bagasse before application. Thermo-gravimetric analysis (TGA) is one of the techniques that are used to study the thermal behavior of solid fuels. The TGA assists to calculate mass loss rate per unit time, reaction constant (k) and the value of activation energy (E_a) of bagasse. The results are useful during application in process such as pyrolysis.

Pyrolysis is one of the thermal process which favoring the upgrading of energy content of biomass. Pyrolysis can produce both charcoal and bio-oil. The bio-oil produced from sugarcane bagasse has the gross calorific value of about 22.4 MJ/kg, which is twice the original bagasse. Also charcoal has heating value of 36 MJ/kg (Garcia-Perez et al. 2002). The transportation and storing is easier for bio-oil than charcoal, also synthesis gas and valuable chemicals can be produced from bio-oil.

The theme of this paper is to characterize the sugarcane bagasse in relation to the frequency factor and activation energy and also to determine the quality of bio-oil that can be obtained from sugarcane bagasse.

The Sugarcane Bagasse Reaction Kinetics

Sugarcane bagasse mainly consists of cellulose, hemicellulose and lignin, the cellulose is in the range of 32–44 wt %, hemicellulose is between 27 and 32 wt %, and lignin is around 19–24 wt % (Sanchez 2009). Also bagasse has small amount of cane wax, organic acids and other materials, the composition of bagasse depends on the sugar beat content, age, nature of soil which the sugarcane plant was grown. The properties of each component are different, the cellulose fibers provide material strength and its degradation occurs at 240–350 °C to produce an hydrocellulose and levoglucosan. The hemicelluloses decomposition occurs at a temperature of 200–260 °C giving rise to more volatiles, but less tar and less char than cellulose. The third major component is lignin, which is more thermally stable and accounts for the production of residual char (Mohan et al. 2006).

The variation of the components in biomass materials result to complexity of thermal decomposition, due to that reason several researches have been done to determine the behavior of each component. Broido-Shafizadeh studied the pyrolysis kinetics of cellulose, observed that the cellulose reacts at elevated temperature to form active cellulose and then decomposes into volatiles and, gas and solid materials as shown in Eq. 31.1 (Bradbury et al. 1979).

$$Cellulose \rightarrow Active\ cellulose \begin{cases} \rightarrow volatiles \\ \rightarrow Char + Gases \end{cases} \tag{31.1}$$

In the Broido-Shafizadeh mechanism there is no change of mass in the transformation of cellulose to active cellulose, the transformation of the active cellulose to product is accompanied by a mass loss. In addition to that most of the pyrolysis mechanisms are based on cellulose since it is considered as a primary component of a lignocellulosic biomass. Finally, a mechanism which suggests the degradation of the biomass is the sum of the contribution of the individual degradation of the three components was applied, this is known as three-step mechanism, Eq. 31.2, in this paper the degradation of the sugarcane bagasse is assumed to follow three step mechanism.

$$Biomass \rightarrow \begin{cases} \longrightarrow k_1\ gas \\ \longrightarrow k_2\ tar \\ \longrightarrow k_3\ char \end{cases} \tag{31.2}$$

There are different methods for determination of pyrolysis kinetics from Thermo-gravimetric analysis. These are Coats and Redfern (Cai and Bi 2008), Agrawal sivasubramanian (Safi et al. 2004), Freeman and Carroll (Criado et al. 1982), Kissinger's method (Criado and Ortega 1986) among others. This study will consider Kissinger's method, since the process that used during thermo-gravimetric analysis of bagasse was non-isothermal.

The Kissinger's method does not depend on reaction mechanism for determination of activation energy, although the determination of the frequency factor assumes first order reaction mechanism (Tsamba 2008). The peak temperature (T_{max}) is used to determine the activation energy (E_a). Thermal decomposition rate are measured at different heating rate, through sequence of experiments. The pyrolysis rate is expressed by using Arrhenius Eqs. (31.3) and (31.4), k is the rate constant, which depends on temperature.

$$K = Aexp(-E/RT) \tag{31.3}$$

$$dx/dt = Af(x)exp(-\frac{E_a}{RT}) \tag{31.4}$$

$$x = (w_o - w)/(w_o - w_\infty) \tag{31.5}$$

where x is the reacted fraction as shown in Eq. (31.5), T is the absolute temperature, E_a is the activation energy, A is the pre exponential factor, R is the gas constant and f(x) is the algebraic function depending on the reaction mechanism.

If temperature rises at a constant heating rate (β), which is expressed as Eq. 31.6, the differentiation of Eq. 31.4 will result Eq. 31.7.

$$\beta = \frac{dT}{dt} \tag{31.6}$$

$$\frac{d^2x}{dt^2} = \left\{\frac{E\alpha\beta}{RT^2} + Af'(x)exp(-E_a/RT)\right\}\frac{dx}{dt} \tag{31.7}$$

The maximum rate occurs at a temperature T_{max}, defined by equating Eq. 31.7 to zero. Approximations from the calculations give the Eq. 31.8.

$$ln\left(\frac{\beta}{T_{max}^2}\right) = ln\left(\frac{AR}{E_a}\right) - \left(\frac{E_a}{RT_{max}}\right) \tag{31.8}$$

A straight line graph is obtained by plotting of $ln\left(\frac{\beta}{T_{max}^2}\right)$ v/s $1/T_{max}$, the slope is E_a/R and the intercept on the vertical axis is an $ln\left(\frac{AR}{E_a}\right)$.

Methodology

Materials

The bagasse used in this study was collected from Tanganyika Planting Company, which is located in Moshi region, Tanzania. Pure nitrogen gas was used as heating agent. The Thermo-gravimetric analyser was used to study the thermo-degradation of the bagasse, fixed bed pyrolyzer was used for production of bio-oil, bomb calorimeter was used to determine heating value, furnace was used for determination of proximate analysis of the bagasse and atomic absorption spectrometer (AAS) was used for ultimate analysis.

Method

The experiments were divided into three parts; the first part was to study the characteristics of rice husk through proximate, ultimate analysis and high heating value (HHV). Secondly, the determination of pyrolysis kinetics of the bagasse and finally, the production and analysis of bio-oil obtained from bagasse.

The proximate analysis of the bagasse was carried out according to ASTMD 3172 method, ultimate analysis was done according to ASTMD 3176 and the HHV was obtained by ASTM D2015.

The experiments under non isothermal conditions were carried out in the TGA. The sample of a ground bagasse was at an average particle size of 100 µm and 30 mg of the sample was used for each experiment. The TGA experiments were conducted at heating rates 5, 10, 20 and 40, in nitrogen atmosphere. The weight change of sample was recoded by thermo-balance.

The fast pyrolysis process was applied to the 100 gm of sugarcane bagasse by using fixed bed pyrolyzer. The operation of the fixed bed pyrolyzer is divided into, heating and experimental phase. The heating phase is done by heating the ceramic honeycomb to 600 °C by using methane burner. The flue gases that remain in the system are thereafter purged by nitrogen gas with the assistance of exhaust fan until the system is free of flue gases. The flue gases are monitored by using gas chromatography, at this stage the system temperature reduced to 500 °C.

The sample is stored in the chamber just above the reactor and it is continually blown with nitrogen gas so as to remove air in the sample. After the temperature of the system stabilizes, the nitrogen gas which is blown to sample is stopped and the sample is introduced to the reactor. The temperature of the reactor and the sample temperature will be measured by using thermocouples.

The sampling line has bottles which are immersed in the ice bath, which act like a condenser, volatile matters that passes through the bottle will condense, gases will go to Gas chromatography for analysis, while char will remain in the basket.

The pyrolyzer is shown in Fig. 31.1 and it consist of A is primary chamber, B is secondary chamber, C is ceramic honeycomb, D and E are Oxygen and methane

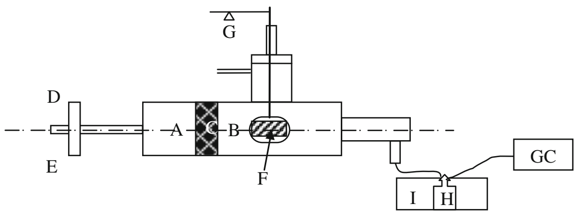

Fig. 31.1 Pyrolyzer for bio-oil production process

line for the burner, F is sample, G is weighing machine, H is ice bath, I is sampling bottle and GC is Gas chromatography.

Result and Discussion

The sample characteristics are shown in Table 31.1.

The carbon and hydrogen contents are the indicative of hydrocarbons that can be released during pyrolysis process. On the other hand the high oxygen content reduces the energy density of the fuel. The presence of chlorine and sulphur are not preferred since they contribute to the formation of corrosive compounds.

Thermo-gravimetric analysis of the sugar cane bagasse is shown in Fig. 31.2; it is the thermo-gravimetric (TG) against temperature. It is divided into three sections, the moisture content section which shows the mass change of the bagasse due to moisture released, secondly, the abrupt mass change due volatile matter and the last section is the constant section where there is no mass change or the mass change is significantly small.

There are differences between proximate analysis and thermo-gravimetric analysis, in thermo-gravimetric analysis the moisture content was 9.52 %, volatile matters were 83.5 %, while in proximate analysis the moisture and volatile matter are 9.00 and 80.5 % respectively.

The constant section in the thermo-gravimetric analysis is know as char, which consists of ash and fixed carbon, in Fig. 31.2 the char was 7.40 %, while in proximate analysis the fixed carbon and ash sum up to 10.5 %.

The thermo-gravimetric analysis shows that the heating rate affects the thermo-degradation of sugarcane bagasse. Figure 31.3 describes that when 5 °C/min was applied to sugarcane bagasse the char collected was higher than when 10, 20 and 40 °C/min were applied. It also shows that the suitable heating rate that provides minimum char at low temperature (i.e., 405 °C), this was 10 °C/min, while in 20 and 40 °C/min, the small amount of char obtained were at 420 and 500 °C respectively.

Figure 31.4 is the derivative of the Fig. 31.3. It shows clearly that after 500 °C there was no any weight change of the sample for all used heating rate, this

Table 31.1 The proximate, ultimate and higher heating value of the bagasse

Proximate analysis	wt %		Ultimate analysis	wt %
Moisture	9.00		C	48.10
Volatile	80.50		H	5.90
Fixed carbon	8.20		N	0.15
Ash	2.30		O	42.40
			Cl	0.07
			S	0.02
Higher heating value		17.33 MJ/kg		

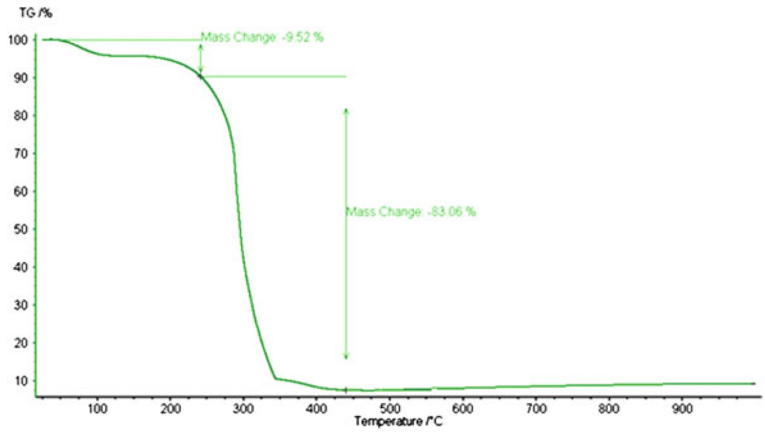

Fig. 31.2 Thermo-gravimetric curve of sugarcane bagasse

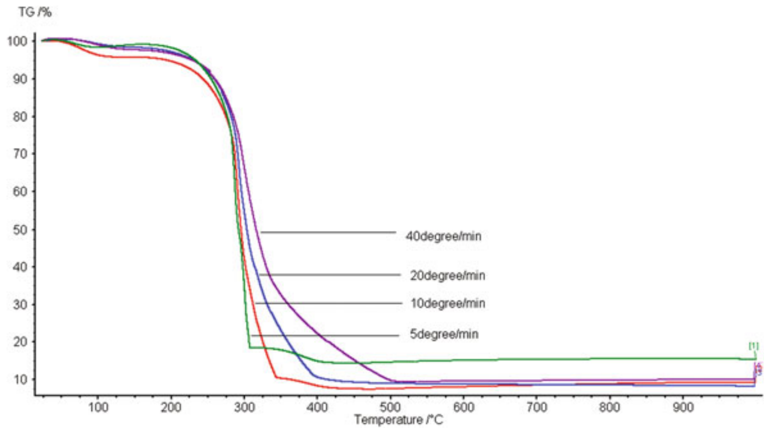

Fig. 31.3 Thermo-gravimetric analysis of sugarcane bagasse at different heating rate

described that the thermo-degradation of the sugarcane bagasse stopped. The remaining material was only char, which contains fixed carbon and ash.

The final temperature to degrade sugar bagasse increases as heating rate increases, The final temperature for weight change of sugar bagasse of 5, 10, 20 and 40 °C/min were 306, 340, 400 and 500 °C respectively. This observation gives evidence that the degradation of sugarcane bagasse a slow reaction process, it requires a low heating rate.

Figure 31.5 was obtained by plotting the natural logarithm of the ratio of heating rate and maximum temperature against the reciprocal of maximum temperature. The heating rate and the maximum temperature were obtained from Fig. 31.4. The determination of kinetic parameters was done by using Fig. 31.5.

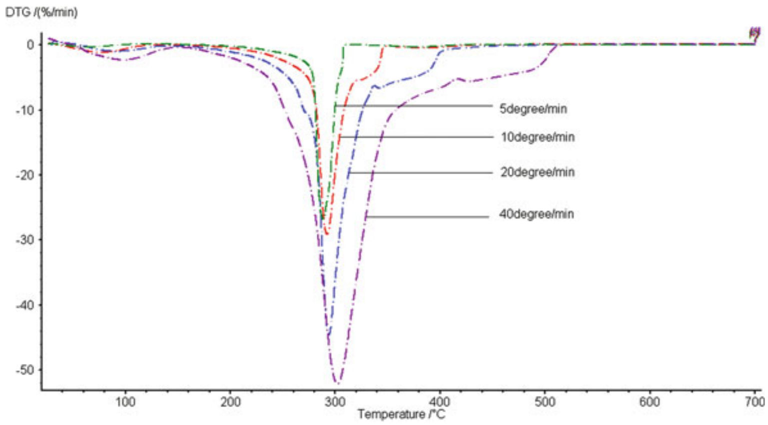

Fig. 31.4 Derivative thermo-gravimetric analysis of sugarcane bagasse

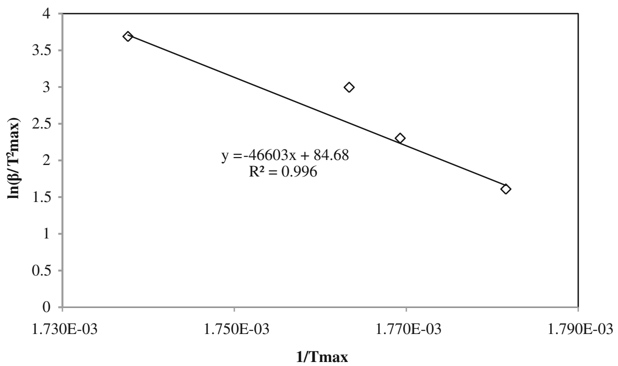

Fig. 31.5 Graph for determination of kinetic parameters

The activation energy obtained was 387.457 kJ/mol and the pre-exponential factor is 0.74 s^{-1}.

The bio-oil obtained was dark brown liquid, with a density of 1200 kg/m^3 and viscosity of 23 cP at 40 °C, the pH was 3, High Heating Value (HHV) was 23.2 MJ/kg and ash content was 0.02 wt %.

Conclusion

The overall calculations of the thermochemical kinetics of sugarcane bagasse was done by using Kissinger's method, which assume that the reaction order was one, the activation energy and frequency factor obtained were 387.457 kJ/mol and 0.74 s^{-1}.

On the other hand the liquid fuel obtained during the pyrolysis process is more suitable since it has higher calorific value than the original sugarcane bagasse; this is an advantage because a little amount of bio-oil is able to produce enough energy.

Acknowledgments The Authors would like to thank the SIDA SAREC program and the University of Dar es Salaam for financing the project.

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Chapter 32
Characterization of Pyrolysis Kinetics for the Use of Tropical Biomass as Renewable Energy Sources

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Abstract Tropical biomass such as rice husks, sugar bagasse, coffee husks and sisal waste are among typical biomass wastes abundant in most of the tropical countries. However, despite their enormous potential as energy sources, they are hardly studied and their thermal characteristics are still not well known. The purpose of this work is to determine the thermochemical characteristics and pyrolysis behavior of these selected biomasses. Proximate, ultimate and heating value analyses were carried out on the samples. Results show that all biomass have a range of, volatile contents (50–80 % w/w), fixed carbon (10–20 % w/w), ash content (<3 % w/w), carbon (50–56 % dry basis) low nitrogen (0.7–1.3 % dry basis) and sulphur (<0.1 wt % dry basis) contents with heating value (HHV 14–18 MJ/kg). The biomasses were thermally degraded through thermogravimetry analysis and their characteristics such as devolatilisation profiles and kinetics parameters (activation energy *E*, and frequency factor *A*) were determined, in an inert atmosphere. It is found that the kinetic parameters obtained can predict not only global devolatilization of biomass pyrolysis but also can predict the pyrolysis pathway of cellulose in the target biomass.

Keywords Tropical biomass · Pyrolysis · Kinetics

Short Introduction

Although typical tropical biomass wastes as rice husks, sugar bagasse, coffee husks and sisal have enormous potential as energy sources, they are hardly studied and their thermal characteristics are still not well known. The purpose of this work is to

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_32,

determine the thermo-chemical characteristics and pyrolysis behavior of these selected biomasses, where the proximate, ultimate and heating value analyses were carried out on various samples. It is found that the kinetic parameters obtained can predict not only global devolatilizationof biomass pyrolysis but also can predict the pyrolysis pathway of cellulose in the target biomass.

Introduction

Tropical biomasses are among renewable energy resource available in tropical countries. These resources are from agricultural crop residues and forestry plantation or natural. The estimate form Tanzania harvest annually is 1.2 million m^3 of forests plantation (not waste) and 12.604 million tones of agricultural waste (Kamwenda and Mkeya 2000). These resources can have high potential use as alternative source of fuel since are still not in use intensively for commercial form, regarding that the present source in the world fossil fuels are nearly exhausted, where is estimated to be able to sustain reserves availability for the next 40 years for petroleum and 60 years for natural gas (Mkilaha and John 2001). The transport sector accounts high consumption, of around 97 % of liquid fuel (Economy Watch 2010). Also importation cost and environment emission of fossil fuel is a problem. From this respect, liquid fuel need to be generated from other resources, since currently it is from non renewable sources. Pyrolysis is the promising route to produce liquid fuels from biomass.

The technology of pyrolysis of biomass has been assessed as a promising route for liquid fuel production. However, uncertainties remain related to both production and utilization of technology (Chiaramont et al. 2005). Therefore, for the design of a conversion system that suits specific characteristics of the biomass, the material need be fully characterized. Pyrolysis kinetics is among the way that can lead to a dynamic and static condition of the process. During the dynamic condition, pyrolysis temperature is progressively increased with increasing heating time using a specified heating rate, while static condition maintains a selected constant temperature in a pyrolyzing reactor (Weerachanchai et al. 2010).

Kinetics of Biomass Pyrolysis

Materials

Characteristic properties of four selected tropical biomasses listed in Table 32.1 presents the proximate and ultimate analysis found of the biomass samples using ASTM as standards. The high hydrocarbons and less oxygen content are to be highlighted, together with high heating value of both tropical biomasses, compared

Table 32.1 Biomass properties analysis for rice husks, sugar bagasse, coffee husks and sisal pole (Wilson et al. 2011)

	ASTM standard	Rice husks	Sugar bagasse	Coffee husks	Sisal pole
Proximate analysis (%)					
Moisture	ASTM E-949	8.80	9.00	6.70	10.10
Volatile matter	ASTM E-872	59.20	80.50	83.20	79.30
Fixed carbon	By difference	14.60	16.20	14.30	14.60
Ash	ASTM E-1755	26.20	3.30	2.50	6.10
Ultimate analysis (%), *dry basis*					
C	ASTM E-777	45.60	48.10	49.40	47.00
H	ASTM E-777	4.50	5.90	6.10	6.00
N	ASTM E-778	0.19	0.15	0.81	1.66
O	By difference	33.40	42.40	41.20	39.10
Cl	ASTM D-6721	0.08	0.07	0.03	0.05
S	ASTM E-775	0.02	0.02	0.07	0.13
Higher heating value (MJ/kg)		13.24	17.33	18.34	17.35
"H:C" Ratio		0.13	0.12	0.12	0.13
"O:C" Ratio		0.94	0.88	0.83	0.83

to rice husks. The carbon and hydrogen contents are a good indicative of hydrocarbons content that are to be released during pyrolysis (Tsamba et al. 2006). It was also found that, content of nitrogen, sulphur, and chlorine are very small for all biomass. On the basis of elemental composition, coffee husks exhibited high energy content due to their higher H:C ratio with relatively low O:C ratio.

Pyrolysis Kinetics

Pyrolysis kinetics provides important information for the engineering design of a pyrolyzer or a gasifier. It also shed light on the different processes in a pyrolyzer that affect product yields and composition. To optimize the process parameters and maximize desired yields, this knowledge is of key important (Basu 2010).

Typical approach to the kinetics of thermal decomposition of a biomass is dividing the volatile evolution into a few fractions—lumps, each of which is represented by a single first-order reaction. These lumps are assumed to be non-interactizng and evolved by independent parallel reactions (Ledakowicz and Stolarek 2002).

If pyrolysis is performed at a constant heating rate β (K/min), the first-order rate can be expressed in the following form.

Biomass $\rightarrow$ Volatile$_i$ $i = 1, 2, 3, \ldots$n

$$\frac{dV_i}{dT} = \frac{k_i}{\beta}\left(V_i^* - V_i\right) \tag{32.1}$$

where V_i^* is the ultimate yield of the *i*th volatile $(\tau \rightarrow \infty)$, V_i is the accumulated amount of evolved volatiles from lump *i* up to time τ, k_i is the rate constant, which depends on temperature according to the Arrhenius equation.

$$k_i = A_i \exp(-E_i/(RT)) \tag{32.2}$$

where *E* is the activation energy (kJ/mol), *R* is the common gas constant, *T* is the temperature (K), and *A* is the frequency factor (s^{-1}).

At the peak temperature at which volatile evolution reaches a maximum (T_{max}), the time derivative of the reaction rate should be equal to zero. The values of T_{max} of the volatile lumps at different heating rates will be determined from peak-resolution curves (DTG). Rearrangements the two equations, final form of equation will allows to determine kinetic parameters as follows;

$$\ln\left(\frac{\beta}{T_{\max}^2}\right) = \ln\left(\frac{RA_i}{E_i}\right) - \frac{E_i}{RT_{\max}} \tag{32.3}$$

The parameters E_i and A_i can be determined from the slope and intercept of a linear plot of $\ln(\beta/T_{\max}^2)$ vs. $1/T_{\max}$ at various heating rates.

Thermogravimetric Analysis

Themogravimetric test were performed with thermogravimetric analyzer (TGA) type NETZSCH STA 409 PC Luxx. High purity nitrogen (99.95 %) was used as the carrier gas and the flow rate was 60 ml/min. About 30 mg of sample with average particle size of less than 2 mm was put in the crucible each time and heated from 35 to 1,000 °C with different heating rate ranging from 5 to 40 K/min. Calculated thermogravimetric output from the TGA software was obtained.

Results and Discussion

Biomass Decomposition Profiles

Figure 32.1, 32.2 presents the TG and derivative TG (DTG) profiles showing the thermal degradation characteristics of rice husks, sugar bagasse, coffee husks and sisal pole at a heating rate of 10 °C/min. The TG profiles show the typical degradation profile for biomasses with well demarked regions for moisture release, devolatilization and char degradation. These differences play an important role in the pyrolysis of these materials and respective product yields.

Figure 32.1, show the weight loss observed for dried samples of rice husks, coffee husks, sisal pole and sugar bagasse, at a heating rate of 10 K/min

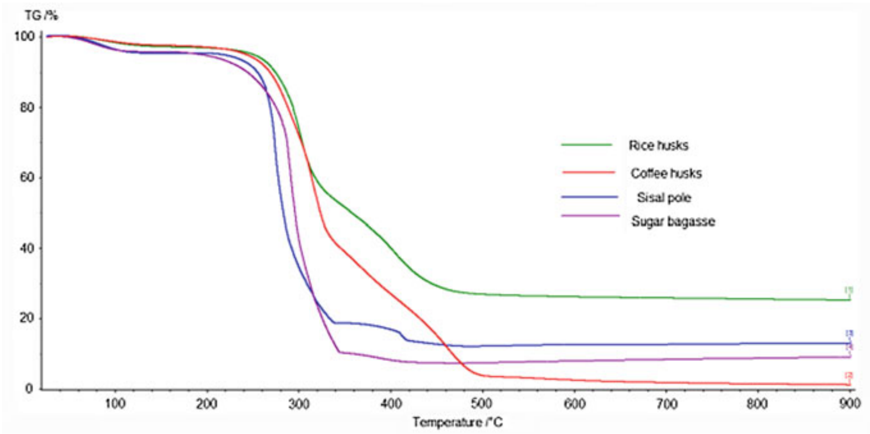

Fig. 32.1 Weight loss from the thermal decomposition of coffee husks, sugar bagasse, sisal pole and rice husks at 10 K/min

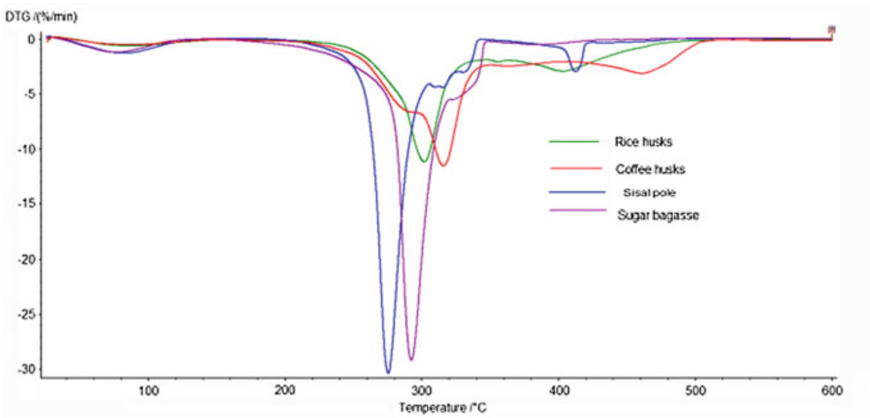

Fig. 32.2 Weight loss rate from the thermal decomposition coffee husks, sugar bagasse, sisal pole and rice husks at 10 K/min

(i,e. 5–10 K/min for pyrolysis process). The temperature interval in which each biomass sample experiences the greater mass loss is different from one to another, these intervals are 250–510, 240–440, 240–450 and 230–480 °C, where about 88.7, 83.06, 79.45 and 68.74 % of the total volatiles weight were released in coffee husks, sugar bagasse, sisal pole and rice husks, respectively. The volatiles yield is greater in coffee husks compared to both rice husks, sisal pole and sugar bagasse. Sugar bagasse have comparably much volatile matter content than sisal pole and rice husks but lower than coffee husks, the same for sisal pole than rice husks. The char yield is inversely proportional to the volatiles yield.

Figure 32.2 show the DTG profiles where, sugar bagasse have similar decomposition to sisal pole but with slightly different maximum temperature of

292 and 275 °C, and coffee husks have similar decomposition to rice husks with slightly different maximum temperature 315 and 302 °C.

Kinetic Analysis of Biomass Pyrolysis

For kinetics parameters determination, different values (as signed to the respect curve) of heating rate (β) were used (5–40 K/min) and is observed that the DTG curves for all biomasses at these various heating rates, shifts the position of the peak extreme (T_{max}) to a higher temperature region as heating rate increasing.

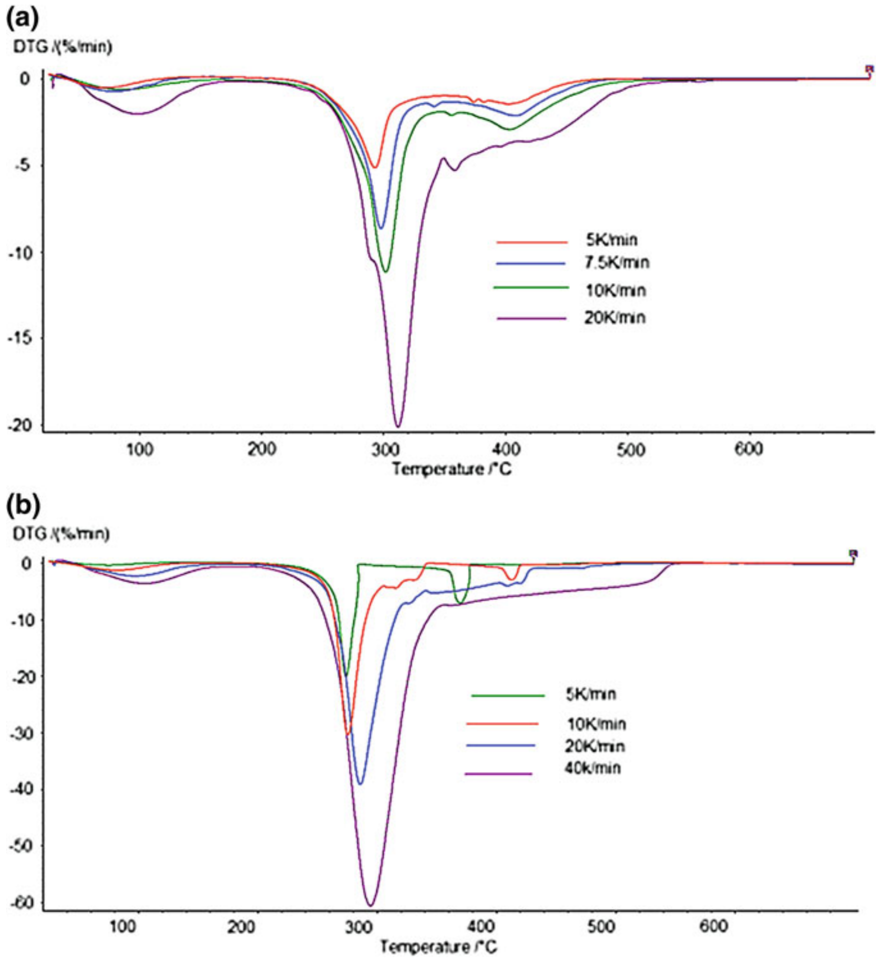

Fig. 32.3 **a** DTG of rice husks at various heating rates. **b** DTG of sisal pole at various heating rates. **c** DTG of Sugar bagasse at various heating rates. **d** DTG of coffee husks at various heating rate

Effect of these heating rates is shown in Fig. 32.3a and b. From this respect, it can be stated that the heating rate affects both location of the DTG curve and maximum decomposition rate.

According to the above mentioned DTG curves, the experimental data obtained, were processed in order to obtain kinetic parameters like the activation energy *E*, and pre-exponential factor *A*, as expressed in Table 32.2. From the set of DTG curves at different heating rates of each biomass, the T_{max} were obtained for calculation into Eq. (32.3) and the linear plot for slop determination is presented in Fig. 32.4. Because at higher temperature no significant changes in conversion occur from the biomass (Gašparovic et al. 2009).

Finding from other literatures available on establishing kinetic parameters for the studied tropical biomass are; Kinetic data obtained for mill bagasse 460.6 kJ/mol,

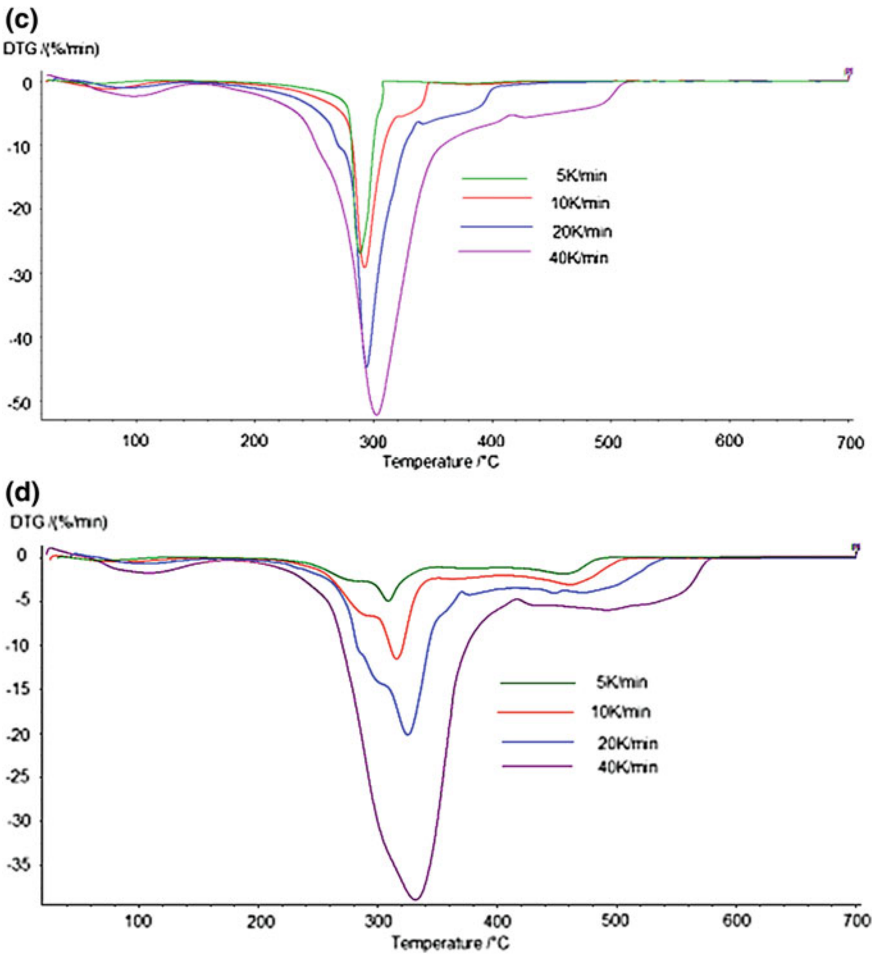

Fig. 32.3 continued

Table 32.2 Kinetic parameters of thermal decomposition of coffee husks, sugar bagasse, sisal pole and rice husks

	β (K/min)	E (kJ/mol)	A (/s)
Rice husks	5	268.98	5.28E+16
	7.5		
	10		
	20		
Sisal pole	5	267.81	2.91E+17
	10		
	20		
	40		
Sugar bagasse	5	533.11	1.62E+34
	10		
	20		
	40		
Coffee husks	5	297.05	1.14E+18
	10		
	20		
	40		

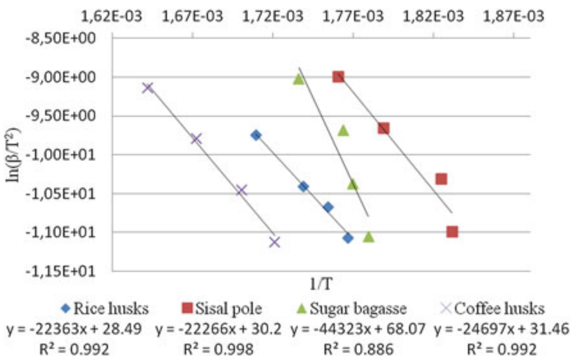

Fig. 32.4 Linear plot of $\ln(\beta/T_{\max}^2)$ vs. $1/T_{\max}$ at various heating rates for selected tropical biomasses

coffee husks 370.8 kJ/mol (Wilson et al. 2011). From this establish in respect of the method used by Ledakowicz and Stolarek (2002), the kinetic parameters obtained are 297.05, 533.11, 267.81 and 268.98 kJ/mol for coffee husks, sugar bagasse, sisal pole and rice husks respectively, for heating rates ranging from 5 to 40 K/min. The variability of the kinetic parameters is accepted on the bases of method used, originality and specific nature of the biomass materials under the study.

Conclusion

Selected tropical biomasses were successfully characterized. The proximate and ultimate analysis findings show that these materials have acceptable heating value with enough content of volatiles to be used as renewable energy sources, coffee husks highlighted with high energy content as per discussion. The content of nitrogen, sulphur, and chlorine is marginal in all biomasses.

- As regard to TGA analysis, the thermal decomposition of volatiles is mainly observed in the temperature range 240–500 °C for biomasses, where coffee husk is characterized with highest volatiles than others 88.7 %.
- From calculated kinetic parameters, is described that sugar bagasse has high values of activation energy 5.331 kJ/mol. The highest value of activation energy denotes the high temperature sensitivity of the charcoal formation reaction.

Therefore through these analyses results it is conforming that these biomasses are suitable for renewable energy source.

Acknowledgments The authors wish to acknowledge Miss. E. Kasembe, Mr. W. Lugano, Mr. P. Mashingo, and Mr. S. Mahir, PhD students at the Department of Mechanical and Industrial Engineering, University of Dar es Salaam, for the assistance rendered.

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Chapter 33
Prospects and Limitations of Biomass Gasification for Industrial Thermal Applications in Sub-Saharan Africa

Joseph Ndemere Arineitwe, Mackay Okure, Job Mutyaba and Surroop Dinesh

Abstract The paper presents an evaluation of the prospects and limitations of biomass gasification for small-scale industrial thermal applications in sub-Saharan Africa. The evaluation was done through a review of existing biomass conversion technologies that could be replaced by gasifiers and the availability of potential feedstock fuels, an economic analysis of potential gasification projects under different conditions with the use of RETScreen Clean Energy Project Analysis Software, and highlighting possible solutions to the challenges which the technology faces. The findings show a continued heavy reliance on wood fuels for thermal energy together with a high use of inefficient conversion technologies in industries. Furthermore, significant quantities of agricultural residues remain un-utilized which could substitute about 40 % of wood fuel use in industries. The economic analysis shows that the adoption of gasification technologies is economically viable, due to the high potential for revenues from fuel savings and the associated Green House Gas (GHG) emissions reductions when agricultural residues substitute or supplement the use of wood fuel. Some of the identified limitations of biomass gasification technology include liquidity constraints of the potential users, the lack of local knowledge in the design, manufacture and operation of gasifiers as well as the hazard and safety issues of gasifiers. It can be said that biomass gasification can play a major role in energy efficiency and a shift from the wood fuel dependency in small-scale industries, which is important for the environment and beneficial to the users. However, there is need for incentives such as tax holidays, tax waivers on equipment as well as reduced debt payment rates to enable industries afford the required capital investments. Institutional mechanisms for easy access to carbon credit markets are also necessary as GHG emissions reduction revenues contribute a significant portion of the annual

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_33,

revenues. Also investment in research and development of local skills in the design, manufacture and operation of gasifiers is vital to further reduce the capital investments and ensure proper management of the gasification-related hazard and safety issues.

Keywords Biomass · Gasification · Thermal energy · Small-scale industries

Symbols and units

Abbreviations

[GHG]	Green house gas
[ICSU]	International council for science
[IEA]	International energy agency
[LHV]	Lower heating value
[MGM]	Maganjo Grain Millers
[NPV]	Net present value
[REEEP]	Renewable energy and energy efficiency partnership

Symbols

[CH_4]	Methane
[CO_2]	Carbondioxide
[N_20]	Nitrous oxide
[$tCO2_{eq}$]	Ton of carbondioxide equivalent
[E_{th}]	Thermal energy output
[$\dot{m}_f$]	Fuel consumption rate
[η_{th}]	Thermal efficiency
[MC_f]	Fuel moisture content

Units

[yr]	year
[kg]	Kilogram
[kW]	Kilo watt
[Mtoe]	Mega tons of oil equivalent
[GJ]	Giga Joules
[MJ/Nm^3]	Mega Joules per normal cubic metre
[MJ/kg]	Mega Joules per kilogram
[PJ]	Penta Joules

Conversions

1 Mtoe =	11.63 TWh
1 Mtoe =	41,868 TJ

Short Introduction

The paper presents an evaluation (trough review) of the prospects and limitations of biomass gasification for small-scale industrial thermal applications in sub-Saharan Africa. The findings show a continued heavy reliance on wood fuels for thermal energy together with a high use of inefficient conversion technologies in industries. The economic analysis shows that the adoption of gasification technologies is economically viable, but still with some limitations. For that reason, investment in research and development of local skills in the design, manufacture and operation of gasifiers is vital to ensure proper management of the gasification-related hazard and safety issues.

Introduction

Sub-Saharan Africa faces many energy challenges, which have impacts on the social-economic aspects of the region. The key challenges include, high energy production-to-consumption ratio partly due to low level of industrialization; and inefficient energy conversion technologies, especially for biomass. Overcoming some of the challenges will require intensive and organized research and development activities to facilitate informed energy decision-making. Although energy research and development is still weak in sub-Saharan Africa (ICSU 2007) research effort and progress are being made in the various countries. One of the many technologies under research in the region is gasification technology. While this technology has been in existence for many years, its adoption and use in sub-Sahara Africa is still limited.

Gasification, by partial combustion, is a thermo-chemical process used for converting a solid fuel into a mixture of combustible gases known as producer gas (Knoef 2006). The generated gas is mainly composed of hydrogen, carbonmonoxide, methane, carbondioxide, nitrogen and water vapor. Condensable hydrocarbons (tars) and ash are also produced. The heating value of producer gas varies from 4 to 6 MJ/Nm^3 for air-blown gasifiers to 13–15 MJ/Nm^3 for oxygen/steam-blown gasifiers (Knoef 2006). The gas can be used for various uses, the ones more relevant to sub-Saharan Africa including provision of thermal energy, generation of electricity and as well as mechanical power through internal combustion engines.

The use of producer gas for provision of energy offers advantages over direct burning the solid fuel such as better combustion efficiency by achieving high temperatures as well as more clean combustion through the use of suitable gas burner technology. It should also be mentioned that gasification has more solid fuel conversion efficiency compared to the traditional open fire technologies that are largely employed in sub-Saharan Africa.

Potential of Biomass Gasification

While the population of the continent continues to grow annually, its energy supply remains low indicating a reduction in energy access on a per capita basis. The total energy consumption in Africa was estimated as 470 Mtoe in 2008 with biomass, mainly wood, contributing the biggest share of 60 % as shown in Fig. 33.1 (IEA 2008). It should also be mentioned that 90 % of the coal in Africa is found in South Africa alone (ICSU 2007). The biggest portion (61 %) of the total energy is used for residential purposes such as cooking, lighting and heating followed by industrial purposes as show in Fig. 33.2. Considering the industrial sector, biomass's contribution was 32.4 % (90.55 Mtoe). The reliance on biomass is highest in Sub-Sahara Africa with over 90 % of the total biomass consumption (Karekyezi 2004) which translates into 81.50 Mtoe in industries in the region.

With the increasing deforestation levels, wood fuel continues to be scarce and expensive. Hence the use of agricultural residues as sources of energy in industries to substitute wood is an important possibility. The potential of agricultural residues in Sub-Sahara Africa was estimated to be 139.5 million tons from 36 out of 48 countries (Gouvello 2008). Using the average heating value of 16.7 MJ/kg (dry fuel), the energy potential was calculated as 2,330 PJ (55.7 Mtoe). It is estimated that bagasse-based cogeneration from sugar industries could meet about 5 % of the total electricity demand in the region (Trade and Development Board 2011). Basing on the projected electricity demand of 680 TWh by 2015 at a demand increase rate of 5 % (Orvika 2009) the amount of bagasse estimate in 2011 was calculated as 2.44 Mtoe. Assuming that 50 % of the residues are used for other purposes—animal feed, cooking/heating, and soil fertility, surplus agricultural residues can be used to substitute about 40 % of wood fuel in industries.

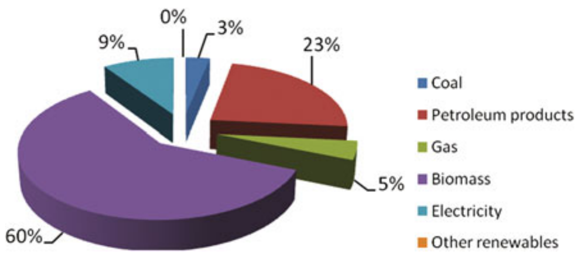

Fig. 33.1 Energy sources in Africa 2008

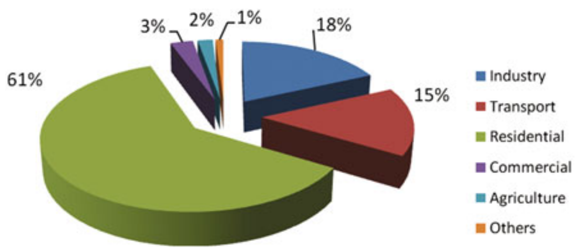

Fig. 33.2 Proportion of energy consumption in various sectors

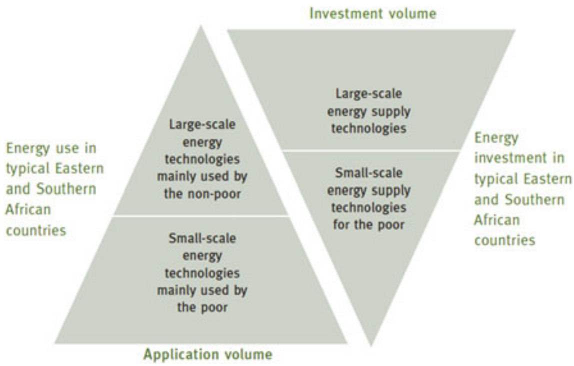

Fig. 33.3 Energy use versus energy expenditure typical in Eastern and Southern Africa

It was also found out that large energy investments are mainly concentrated on the large-scale energy technologies whose application volume is small compared to small-scale energy technologies that are mainly used by the majority of the population as illustrated in Fig. 33.3 (REEEP 2006). It is therefore important to that significant investment be made in small-scale technologies which comprise the majority of industries in the region.

Therefore the potential of gasification technologies utilizing surplus agricultural residues for industrial thermal applications is significant.

Economic Evaluation of Biomass Gasifiers

The Approach Used

The study evaluated the economics of biomass gasification technology in the provision of thermal energy in small scale industries using the RETScreen Clean Energy Project Analysis Software (Version 4) that is freely available online (RETScreen International 2011). This considered the project's fuel savings, revenues from emissions reductions trading against the capital investment and operation costs of the system.

A case study of MGM, a small-scale food processing industry in Uganda was used. MGM is engaged in agro-processing of grain to produce flour, bread and cakes. The factory produces a number of pre-cooked flour products made from maize, soy, silver fish, millet and rice. An oven of capacity of 180 kg confectioneries per day is made from brick and cement-sand mortar with steel baking compartments. The oven is fed with large logs of firewood. The factory also employs two roasters made of steel drums driven by a small electric motor to provide rotary motion along the longitudinal axis. The drums are filled in batches with grains and heated directly with an open fire. The combined total production of the roasters was reported to be 2,000 kg/day.

MGM operates 6 days a week and 8 h per day throughout the year. The wood consumption was estimated to be 97.4 t/year at the cost of US $56/t of wood. These estimates were made based on the fuel wood records as well as the actual daily wood measurement. The wood moisture content was measured as 31.4 % (wb). The wood combustion system used at MGM is similar to the inefficient 3-stone open fires, and hence its thermal efficiency was conservatively assumed to be 20 % (Umogbai 2011). The installed thermal capacity of MGM factory was calculated from Eq. (33.1) where E_{th} (kW) is the thermal output, η_{th} is the thermal efficiency(%), $\dot{m}_f$is the fuel consumption rate (kg/s), MC_f is the wood moisture content (%wb) and $LHV_f$is the wood heating value (MJ/kg). The heating value for dry wood was taken as 19.5 MJ/kg (Yorwoods 2008).

$$E_{th} = \eta_{th} \cdot \dot{m}_f \left(1 - MC_f\right) \cdot LHV_f \tag{33.1}$$

Fixed bed gasifiers, because of their suitability for small-scale use, have been suggested. The gasifier system overall efficiency of 40 % and its unit capital cost of US $200/kW (Ghost 2006) were used.

The key parameters used in the evaluation are average inflation rate of 6.2 % over the past 15 years was applied (International Monetary Fund 2011), income tax rate of 25 % and depreciation tax basis of 20 % (PKF 2011) with Straight-line method over 20 years. Other parameters assumed include fuel price escalation rate of 7 % discount rate of 12.0 % and project life of 25 years. The capital investment costs used are also summarized in Table 33.1.

The study evaluated the financial viability of the project considering that the scenario where agricultural residues substitute 40 % of the wood fuel. While the prices of agricultural residues range from US $3/t to 14/t (Ashden Award 2009) depending on the source in Uganda, the evaluation considered a conservative price of US $15 per ton. Assuming the LHV of 16.5 MJ/kg and the moisture content of 15 % (wb) for air dry agricultural residues (Bingh 2004), the amount of residues required would be 18.6 t/year in addition to 29.0 t/year of wood fuel. Without the use of agricultural residues, MGM would continue to use 48.3 t/year of wood.

The evaluation considered five cases to determine how they could affect the economic viability of the project.

- Case 1 assumes that MGM fully finances the project without getting a bank loan, incentive/grant or tax holiday.
- Case 2 assumes that MGM fully finances the capital investments but gets a tax holiday spread over 5 years.

Table 33.1 Capital investment costs

Initial costs	%	USD
Feasibility study	7.1	2,000
Development	14.2	4,000
Engineering	63.3	17,860
Balance of system and misc.	15.4	4,343
Total initial costs	100.0	*28,203*

- Case 3 assumes that MGM acquires a loan equivalent to 50 % the total investment cost at debt interest rate of 23 % (UMA 2009) over a period of 5 years.
- Case 4 assumes that MGM acquires a loan as in Case 3 and receives an income tax holiday over 5 years.
- Case 5 assumes that MGM gets incentives/grants equivalent to 20 % of the total investment cost.

The results of the evaluation were compared with the scenario where MGM continues to use 100 % wood fuel with the adoption of the gasification system.

The emission factors for CO_2, CH_4 and N_2O of 109.6, 0.03 and 0.004 kg/GJ respectively for biomass combustion (National Inventory Report 2010) were used in the calculation of GHG emission reduction that would be achieved by switching to the use of a gasifier at MGM. Other parameters assumed in the emissions analysis are shown in Table 33.2.

It should be noted that the calculation of GHG emissions reductions did not put into consideration leakages that come with the transportation and preparation of fuel, use of electricity to run the gasifier, and the possibility that the revenues from the emission reductions will be invested in activities which lead to generation of GHG emissions.

Results and Discussion

With the use of the gasifier, MGM's annual operating costs and savings/income are shown in Tables 33.3 and 33.4 respectively. In effect, it means that the annual income of MGM—excluding interest on loans or depreciation—would be US $ 3,008—and US $1,427—when using a mix of wood and agricultural residues and using wood only respectively.

The results have also shown that the project with substitution of 40 % wood fuel with agricultural residues is economically viable with significantly shorter equity payback periods and positive NPV values in comparison with the continued use of wood fuel only as shown in Table 33.5. The cumulative cash flows for both scenarios are also shown in Figs. 33.4, 33.5. A tax holiday of 5 years has more impact on the case when MGM finances all the investments costs. Given the possibility of liquidity constraints in small-scale industries, it is most likely that

Table 33.2 Emission analysis parameters

Parameter	Unit	Quantity
GHG credit transaction rate	%	2.5
GHG reduction credit rate	$/tCO2 eq	20
GHG reduction credit escalation rate	%	3.0
GHG reduction credit duration	Year	25

Table 33.3 MGM's annual operating costs

Annual costs	Amount (US$)	
	Using wood/agricultural residues	Using only wood
O&M	3,308	3,308
Fuel cost—proposed case	1,918	2,729
Total annual costs	*5,225*	*6,036*

Table 33.4 MGM's annual savings/income

Income source	Using wood/agricultural residues		Using wood only	
	Saving	Income (US$)	Saving	Income (US$)
Fuel cost—base case	97.4 t/year	5,503	97.4 t/year	5,503
GHG reduction income	136t$CO2_{eq}$/year	2,730	98t$CO2_{eq}$/year	1,960
Total		*8,233*		*7,463*

loans have to be acquired in order to finance the implementation of the gasifier projects. A lower interest rate may help to reduce the payback period. The sensitivity analysis showed that variations in the fuel cost (proposed case) and the emission reduction credit rate can significantly affect the payback period and the NPV.

The MGM gasifier project scenario presents opportunities for addressing the core challenges of sub Saharan African. Firstly, it addresses the issue of use of inefficient combustion technologies that are common in the region. This would help to reduce deforestation rate as well as reducing on emissions. Putting the project into perspective, the possible use of a gasifier by MGM would lead to annual GHG emissions reduction which is comparable to 31 acres of forest absorbing carbon every year. There would be great impact on the environment with the adoption of these technologies in many small-scale industries in the region. Specifically for thermal applications, the only modification that may be necessary to integrate with a gasifier is a properly designed gas burner/combustion chamber. The rest of the exiting system remains largely unmodified with tax holidays and reduced lending rates, small-scale industries should be able to acquire gasifiers for their thermal needs.

Secondly, the project is itself a source of income for the industries. Increasing the capital base of industries through fuel saving and GHG emission reduction

Table 33.5 Pay back periods and NPVs for the two project scenarios

Scenario	Wood and agricultural residue		Wood only	
Case	Equity payback (years)	NPV (US$)	Equity payback (years)	NPV (US$)
1	8.1	3,421	15.4	−10,998
2	6.9	6,185	14.6	−9,864
3	10.5	1,498	19.4	−12.922
4	10.2	2,244	19.4	−12.862
5	6.8	7,652	13.1	−6,768

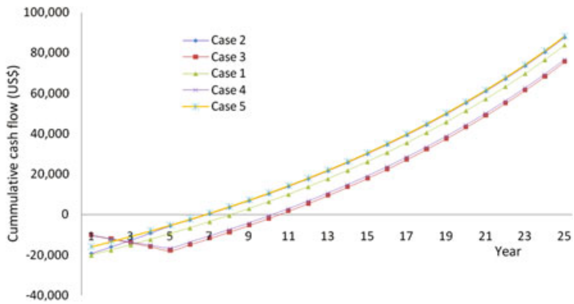

Fig. 33.4 Cumulative cash flows of with both wood and agricultural residues as fuels

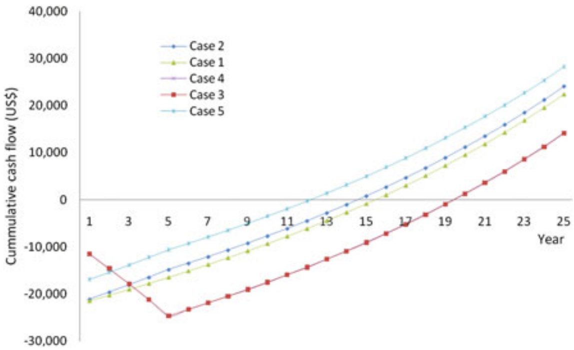

Fig. 33.5 Cumulative cash flows with wood as the only fuel

trading directly leads to economic and industrial growth. This is achieved through diversification and increased employment opportunities.

Thirdly, for industries that can have access to agricultural residues in large quantities all year around, complete substitution of wood fuel would further reduce the annual operation costs and increase the annual income hence impacting greatly on the equity payback period. It should be mentioned that there may be additional investment costs that need to be met to accommodate the large quantities of the residues. They could include storage and handling facilities and pre-treatment systems where applicable.

Limitations of Biomass Gasification Technology

Due to the diverging capacities of different small-scale industries in sub-Saharan African, biomass gasification systems need to be designed in appropriate scales according to the user demands. This remains a key challenge because of the various factors that need to be considered such properties and types of feedstock materials, energy requirement etc. At the same time, biomass gasification systems need to be made economically affordable to small-scales industries. This however risks compromising the efficiency hence leading to operation difficulties and environmental problems.

Successful adoption of biomass gasification in sub-Sahara Africa requires additional support other than the fuel savings, GHG emissions trading and the way of energy utilization. Government or institutional policies on capital cost subsidies and tax cuts or tax holidays for are necessary. There is a challenge of high interest rates on bank loans which drive away the industries that may be interested in acquiring the systems. These all remain big challenges.

There still remain significant levels of lack of awareness of gasification technology in the region. Awareness campaigns by governments and institutions need to be put in place to educate potential users about the technology and its benefits. The development of skills in the design and operation of gasifiers in the region need to be emphasized.

Conclusions

The potential of biomass gasification for provision of thermal energy in small scale industrial applications exists with the availability of agricultural residues which could substitute about 40 % of wood fuel use in industries. It has also been shown that the adoption of biomass gasifiers for provision of thermal energy in small-scale industries by replacing the traditional inefficient technologies currently in use is economically viable and has positive significant environmental and economic impacts when agricultural residues are used to supplement or substitute wood fuel.

In order to increase the rate of adoption of gasifiers, policies such as tax holidays, reduced debt payment rates, tax waivers on gasifier equipment supplies or any meaningful incentives should be put in place. With these, many small-scale industries that wouldn't ordinarily afford such high investments can be brought on board.

Given that the sources of revenue to help cover investment and operational costs are hinged around fuel savings and GHG emission reductions, governments and institutions in sub-Sahara Africa need to put in place mechanisms that can help industries access carbon credit markets relatively easily. Without the revenues from GHG emission reductions, most small-scale industries would need high incentives or subsidies and longer tax breaks in order to find adoption of gasification technology an economically sound venture.

It is also important that governments and institutions invest in research and skills development in the design and operation of gasification systems. This would go long away in reducing the high capital investments and ensuring high performance of the technologies.

Acknowledgments The authors thank the management of Maganjo Grain Millers for allowing us to collect useful data. Appreciation also goes to SIDA/Sarec for the financial support.

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Chapter 34
Anaerobic Digestion of Vegetable Wastes Using Biochemical Methane Potential Assays

Ackmez Mudhoo, Romeela Mohee, Zumar M. A. Bundhoo and Dinesh Surroop

Abstract Solid wastes generation is a major problem in Mauritius in terms of wastes disposal with vegetable wastes representing 40–46 % the organic waste stream by mass. This study focused on the anaerobic digestion (AD) of vegetable wastes using biochemical methane potential (BMP) assays to assess the performance of AD processes in treating these wastes in a sustainable manner. 2,000 mL plastic bottles were used as anaerobic digesters for the assays and the vegetable wastes comprising of carrots, potatoes, cabbage and beetroots were ground and seeded with inoculum in a ratio 4:1 (volume basis). The inoculum used was mature sludge taken from an anaerobic digester treating cattle wastes. The inoculated substrates were then fed in the digesters, purged with N_2 and sealed with rubber septum. The AD process was allowed to run over a hydraulic retention time (HRT) of 20 days. Results showed a total solids (TS) reduction of 62.1 %, volatile solids (VS) reduction of 66.4 % and COD reduction of 64.9 % which demonstrated effective degradation of the substrates during the digestion process. The biogas yield was 0.360 L/g VS fed and this value was in agreement with published data. These results hence showed that vegetable wastes can be effectively treated by AD. The next phases of the study consist in investigating the AD process of wastewater treatment sludge and the effects of sonication on AD of vegetable wastes and sludge, with special emphasis on process parameters.

Keywords Anaerobic digestion · Biogas · Biochemical methane potential assay · Chemical oxygen demand · Volatile solids

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_34,

Short Introduction

In Mauritius solid wastes generation is a major problem. In order to find better solutions how to manage the waste, this study focused on the anaerobic digestion (AD) of vegetable wastes using biochemical methane potential (BMP) assays to assess the performance of AD processes in treating these wastes in a sustainable manner. The results of this study showed that vegetable wastes can be effectively treated by AD. After the positive results on the vegetable wastes, further investigation on wastewater treatment sludge.

Introduction

Solid wastes generation is a major problem in Mauritius in terms of wastes disposal. In 2009, 415,948 t of wastes were generated and this value is expected to increase to 510,000 t by 2034 (Mohee et al. 2010). This increase in waste generation represents a major burden on the sole landfill in Mauritius. The Mare Chicose Sanitary Landfill started operation in 1997 and was originally receiving about 6,800 t of wastes but is now receiving more than 400,000 t of wastes annually (Mohee and Bhurtun 2002). This has caused the landfill at Mare Chicose to reach full capacity and since there are no other suitable sites for the construction of a new landfill for wastes disposal in Mauritius, there is a major problem of disposing about 400,000 t of wastes annually and more dramatically, this value will keep on increasing (Mohee et al. 2010; Ackbarally 2009).

Solid wastes generation in Mauritius can be classified mainly into Municipal Solid Wastes (MSW), industrial non-hazardous wastes, construction and demolition wastes, health care wastes, hazardous wastes and sludge (Mohee et al. 2010). MSW contributes the highest proportion of the solid wastes going to the Mare Chicose Sanitary Landfill and is in the order of 70 % (Mohee et al. 2010). Furthermore, the organic fraction of MSW (OFMSW) in Mauritius is 80 % (Surroop 2010) and this comprises of paper, yard, fruit and vegetable wastes and food wastes with vegetable wastes representing about 40–46 % by mass of OFMSW (Surroop 2010; Surroop and Mohee 2011). Due to the easy biodegradability of vegetable wastes and their high moisture content (Bouallagui et al. 2003), this paper is proposing and investigating the potential of Anaerobic Digestion (AD) as the treatment technique for the high amount of vegetable wastes generated in Mauritius.

AD can be defined as the breakdown and stabilisation of organic materials by microbial organisms in the absence of oxygen to produce methane, carbon dioxide and a stable, innocuous sludge that can be used as soil conditioner or fertiliser (Fantozzi and Buratti 2009; Appels et al. 2008; Chen et al. 2010; Ward et al. 2008). AD has long been used for treatment of domestic wastewater (Foresti et al. 2006), treatment of Waste Activated Sludge (WAS) (Appels et al. 2008; Dewil et al. 2006), application to agricultural wastes (Ward et al. 2008; Paepatung et al. 2009) and treatment of primary and secondary sludges (Show et al. 2007; Mao et al. 2004). It is now being used for the treatment of vegetable wastes. With AD, biogas is produced and this can be burnt to produce energy and electricity which is in line with the Maurice-Ile-Durable concept. Furthermore, with the reduction in the volume of wastes possible with AD, this will decrease the burden on the Mare Chicose sanitary landfill and provide the solution to the waste problem in Mauritius.

Anaerobic digestion, as stated previously, involves the breakdown of organic materials by microorganisms in the complete absence of oxygen. This breakdown takes place through 4 phases which are hydrolysis, acidogenesis, acetogenesis and methanogenesis (Fantozzi and Buratti 2009; Appels et al. 2008; Ward et al. 2008; Show et al. 2007). In the hydrolytic phase (1st phase), insoluble organic materials and high molecular weight compounds like polysaccharides, carbohydrates, proteins and fats are hydrolysed or cracked by exoenzymes of facultative and obligatory anaerobic bacteria into monomers or water-soluble components such as amino and fatty acids (Appels et al. 2008; Deublein and Steinhauser 2008). During acidogenesis, the monomers obtained from the hydrolytic phase are further broken down by acidogenic (fermentative) bacteria into short-chain organic acids C_1–C_5 molecules (e.g. butyric acid, propionic acid, acetic acid), alcohols, hydrogen and carbon monoxide (Appels et al. 2008; Deublein and Steinhauser 2008). In the acetogenic phase (3rd phase), the higher organic acids and alcohols produced in the acidogenesis phase (2nd phase) are further digested by acitogens into mainly acetic acid, carbon dioxide (CO_2) and (H_2) (Fantozzi and Buratti 2009) and during methanogenesis, methanogens, which are strict anaerobes, convert the acetic acid, CO_2 and H_2 from the 3rd phase to methane (CH_4) and carbon dioxide (CO_2) (Fantozzi and Buratti 2009; Deublein and Steinhauser 2008). For AD to perform properly, there are some process parameters that need to be monitored and these are the concentration of microorganisms and retention time, the type of substrate used, pH, volatile fatty acids (VFA), alkalinity, temperature, nutrients, particle size and disintegration and inhibitors.

Approach and Methodology

Substrate

The substrate used for this research study was vegetable wastes obtained from a nearby market comprising of carrots, potatoes, cabbages and beetroots. All these vegetable wastes were shredded and characterised in terms of total solids (TS) and moisture content, volatile solids (VS) and ash content and pH in accordance with the procedures recommended in the Standard Methods for the Examination of Water and Wastewater (APHA et al. 1998). The shredded vegetable wastes were then mixed in equal proportions and tested for pH, VFA and alkalinity according to the above standard procedures (APHA et al. 1998). The alkalinity was adjusted by adding $NaHCO_3$ until it reached the maximum permissible value of 5,000 mg/L $CaCO_3$ (Nguyen 2008; Tchobanoglous et al. 1993; Bougrier et al. 2008) required for proper AD. This substrate was then ready to be used for the AD process.

Inoculum

The inoculum used was mature sludge taken from an anaerobic digester treating cattle wastes. The inoculum was tested for pH, TS and moisture content, VS and ash content, chemical oxygen demand (COD), VFA and alkalinity according to the procedures recommended in the Standard Methods for the Examination of Water and Wastewater (APHA et al. 1998).

Biochemical Methane Potential Assays

Biochemical methane potential (BMP) assays serve as a good method to evaluate the performance of AD processes. The BMP test consisted of two 2,000 mL plastic bottles placed in dark plastic bags to prevent light from affecting the AD process (Deublein and Steinhauser 2008). One plastic bottle served as the anaerobic digester for biogas collection and measurement while the second anaerobic digester was used for sampling purposes during the AD process. The inoculum and the ground vegetable wastes were mixed in a volume ratio (1:4). 1,000 mL of this inoculated substrate was placed in each of the 2,000 mL anaerobic digesters which were purged with N_2 to ensure anaerobic conditions. The digesters were then sealed with rubber septum which consisted of drilled holes and tubing systems to allow for biogas collection and for sampling purposes. The biogas from the digester was bubbled through an acidified solution to ensure that all the biogas generated was collected during the downward displacement of water as illustrated in Fig. 34.1. The anaerobic digestion process was allowed to run over a hydraulic retention time (HRT) of 20 days at room temperature and pressure (RTP). At regular intervals during the AD process, sampling was done from one of the digesters and the sample was tested for pH, TS and moisture content, VS and ash content, VFA and alkalinity and COD in accordance with the procedures recommended in the Standard Methods for the Examination of Water and Wastewater (APHA et al. 1998).

Statistical Analysis

For each of the parameters tested during the AD process (TS, VS, VFA, alkalinity, pH, COD and biogas yield), the error bars inserted in Figs. 34.2, 34.3, 34.4, 34.5, 34.6, 34.7 were computed based on absolute and relative errors. For those

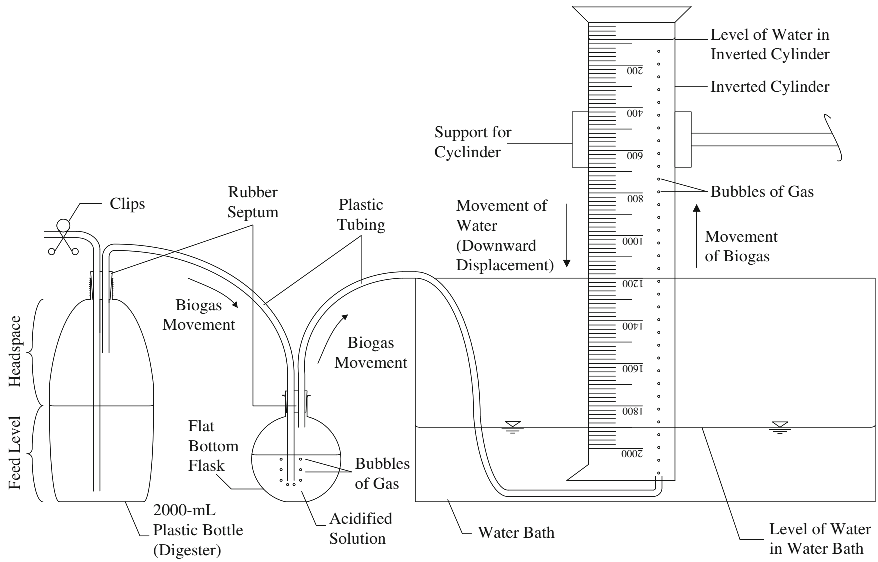


Fig. 34.1 Anaerobic digestion set-up

Fig. 34.2 TS and VS variation during AD

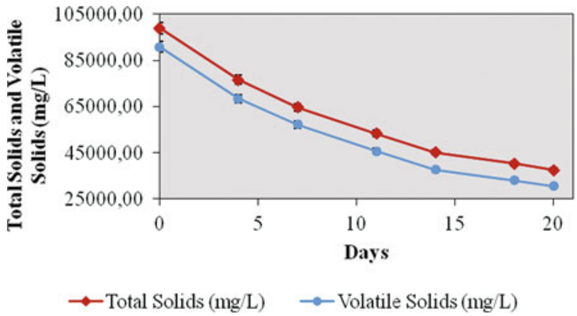
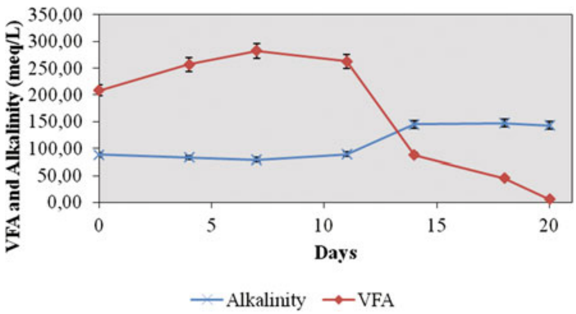


Fig. 34.3 Alkalinity and VFA variation during AD



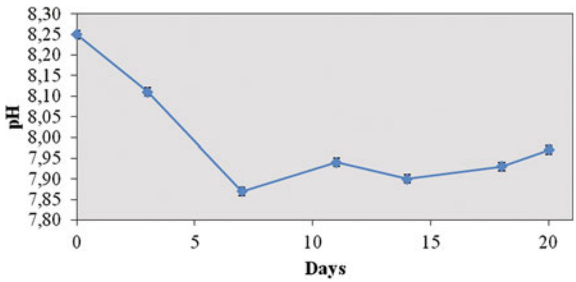


Fig. 34.4 pH variation during AD

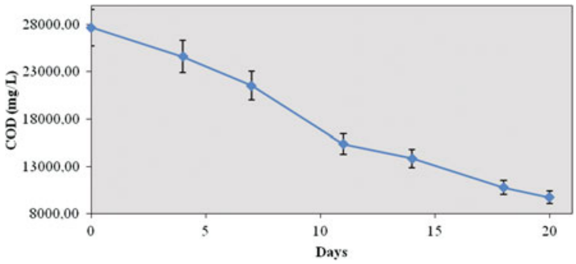


Fig. 34.5 COD variation during AD

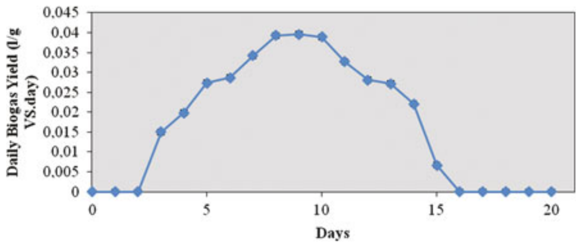


Fig. 34.6 Daily biogas production

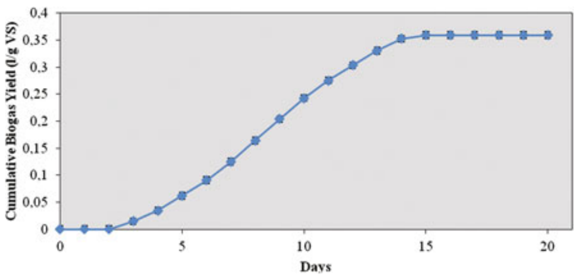


Fig. 34.7 Cumulative biogas production

parameters involving mathematical equations such as TS, VS, VFA, alkalinity, COD and biogas yield, the relative errors (±ΔE/E) were calculated and used to estimate the error bars. As for those parameters not involving mathematical equations such as pH, the absolute errors (±ΔE) were used to work out the error bars.

Results and Discussions

Characterisation of Vegetable Wastes, Inoculum and Inoculated Feed

The different characteristics of the vegetable wastes, inoculum and feed to the digesters are presented in Table 34.1.

It can be observed from Table 34.1 that the total solid content of the feed was 10.12 %. Hence, the AD process was performed at a medium solid content (Nguyen 2008; Tchobanoglous et al. 1993). The pH of the feed was 8.25 and this was slightly above the specified limit for AD processes (Deublein and Steinhauser 2008). However, the alkalinity was 88 meq/L (4,400 mg/L $CaCO_3$) and this was within the permissible range for anaerobic digestion (Nguyen 2008; Tchobanoglous et al. 1993; Bougrier et al. 2008). It can also be observed that the COD of the feed was quite high indicating the high amount of organic matter available for degradation.

Total Solids and Volatile Solids

The total solids and volatile solids variation during the AD process are illustrated in Fig. 34.2.

From Fig. 34.2, the total solids decreased from 99,000 to 37,500 mg/L representing a TS reduction of 62.1 %. Total solids are normally classified as fixed solids (ash) and volatile solids. During AD, the fixed solids remained unchanged while the volatile solids were converted into biogas (Tchobanoglous et al. 1993). During the hydrolytic phase of AD, the microorganisms break down the large molecules in the substrate and dissolve the resulting smaller molecules into solution (Show et al. 2007; Velmurugan and Ramanujam 2011). Consequently, the total solid content was reduced due to the large amount of molecules going into solution by hydrolysis. Additionally, the conversion of volatile solids into biogas in the methanogenic phase of AD also contributed to the reduction in total solids. It can also be observed from Fig. 34.2 that the volatile solids decreased from 90,765 mg/L to 30,500 mg/L

Table 34.1 Characterisation of vegetable wastes, inoculum and inoculated feed

	Vegetable wastes	Inoculum	Feed
Total solids (%)	11.98	3.88	10.12
Volatile solids (%)	93.93	69.29	91.77
pH	7.88[a]	7.85	8.25
Alkalinity (meq/L)	253	8.3	88
Volatile fatty acids (meq/L)	179.4	10	208.5
Chemical oxygen demand (mg/L)	33,846	3,759	27,692

[a] Before adjusting for alkalinity, pH was 6.19

representing a VS reduction of 66.4 %. The decrease of volatile solids, as explained previously, was due to the conversion of the volatile solids into biogas. However, not all of the VS were converted into biogas. The main reason for this was due to the fact that volatile solids can be divided into biodegradable volatile solids (BVS) and refractory volatile solids (RVS). Only part of the BVS could be degraded by the acidogens, acetogens and methanogens under the operating conditions of this research study while the RVS did not degrade at all.

Alkalinity and VFA Variation

The alkalinity and VFA variation during the AD process are shown in Fig. 34.3.

The general trend of the VFA concentration in Fig. 34.3 was an increase and then a decrease during the AD process while the trend of the alkalinity was completely opposite. The initial increase of the VFA concentration could be attributed to the acidogenetic and acetogenetic phases of AD. During these two phases, the acitogens convert the monomers from the hydrolytic phase into short-chain organic acids and subsequently, acetogens convert these short-chain acids into acetic acid, CO_2 and H_2 (Fantozzi and Buratti 2009; Appels et al. 2008; Deublein and Steinhauser 2008). Since the acidogenesis and acetogenesis were initially dominant over methanogenesis, the production of the short-chain organic acids and acetic acid caused an increase in VFA concentration as illustrated in Fig. 34.3. The subsequent decrease of the VFA concentration was due to the methanogenetic phase of AD which started to dominate over acidogenesis and acetogenesis. During methanogenesis, methanogens convert the acetic acid, CO_2 and H_2 to CH_4 and CO_2 (Fantozzi and Buratti 2009; Deublein and Steinhauser 2008). As this CH_4 and CO_2 escaped from the system and were collected as biogas, the VFA concentration decreased as depicted in Fig. 34.3. As for the alkalinity, the general trend was a decrease followed by an increase. The decrease in the alkalinity values coincided with the increase in the VFA concentrations. As the VFA concentrations increased, the H^+ ions generated in the system increased. To counter this effect and prevent any major pH change in the AD process (so that the methanogens are not suppressed), the alkalinity present in the system provided the buffering capacity. The HCO_3^- reacted with this excess of H^+ ions and buffered the system against this pH change as illustrated in Eq. (34.1). Subsequently, the HCO_3^- ions concentration decreased and this caused the alkalinity to decrease (Tchobanoglous et al. 1993). Another reason for the decrease in the alkalinity was due to the escape of CO_2 in the biogas collected. As soon as the CO_2 was produced in the system, it escaped immediately with the biogas collected. To counter this decrease in CO_2, the HCO_3^- had to react with H^+ ions to generate more CO_2 so as to maintain the equilibrium in the system as shown in Eq. (34.1) and this caused the alkalinity to decrease. As for the increase in the alkalinity, this was mainly due to the breakdown of organics present in the digesters (Appels et al. 2008; Deublein and Steinhauser 2008). The breakdown of organic-nitrogen compounds such as proteins and amino acids and the production of CO_2 from organic compounds contributed to an increase in alkalinity due to the formation of HCO_3^- (Nguyen 2008).

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \quad (34.1)$$

pH Variation

The pH variation during the AD process is illustrated in Fig. 34.4. The pH variation during the AD process was quite erratic as illustrated in Fig. 34.4. This variability was due to various factors such as VFA concentrations, alkalinity and the buffering capacity of the system. The pH decreased initially during the acidogenesis and acetogenesis phases of anaerobic digestion. During these phases, the concentration of volatile fatty acids increased causing an increase in H^+ ions generated in the system and a decrease in pH. At that point, the acidogenesis and acetogenesis phases were dominant over the methanogenesis phase. The rate of VFA formation was much higher than the rate of degradation of these VFA into CH_4 and CO_2. This led to an accumulation of VFA in the system and a decrease in pH (Bougrier et al. 2008). However, the alkalinity initially present in the system did provide the buffering capacity against this pH change and that was why the pH did not drop too low but was maintained well above the minimum permissible limit of 6.2 for proper AD (Nguyen 2008). Eventually, as the rate of methane formation started to increase, the pH then stabilised and stayed almost constant towards the end of the AD process. This was due to the buffering capacity of the system and the degradation of the VFA into CH_4 and CO_2. Furthermore, at some points during the AD process, the pH was observed to increase. This was due to the degradation of the organics present in the system increasing the alkalinity, decreasing the VFA concentration and increasing the pH as discussed previously.

COD

The COD variation during the AD process is depicted in Fig. 34.5.

Chemical Oxygen Demand is an indication of the amount of organic matter present in a particular system. When there is high organic matter, the oxygen demand is high and the COD gets a high value. It can be observed from Fig. 34.5 that the COD decreased during the BMP assay representing a net COD reduction of 64.9 %. This degradation of COD occurred due to methanogenic activities whereby the methanogens degraded and converted the solubilised organic matter into CH_4 and CO_2 (Appels et al. 2008). However, not all the COD could be degraded by the methanogens as indicated by the 64.9 % COD reduction. COD is classified into soluble and particulate COD. During AD, only soluble COD is easily degraded by the microorganisms while particulate COD which consists of inert COD, slowly biodegradable COD is hard to degrade unless solubilised during hydrolysis. Due to the presence of particulate COD in the system, the net COD reduction was 64.9 %. It can also be observed from Fig. 34.5 that the highest rate of COD reduction occurred between days 7–11. The main reason for this was due to a larger amount of solubilised organic matter present. From Fig. 34.3, the maximum VFA concentration occurred during the same period as the maximum rate of COD reduction from Fig. 34.5. The high VFA concentration can be correlated to a large amount of solubilised organic matter in a system (Raposo et al. 2006). Due to a larger amount of solubilised organic matter, the methanogens had a more easily degradable feed to digest and hence, the COD reduction rate was higher during that period. Finally, it can be observed that the VS reduction and COD reduction were quite close. Since both VS and COD gave an indication of the amount of organic matter present, it seemed logical that both the VS and COD reduction were quite close due to degradation of organic matter during anaerobic digestion.

Biogas Production

The individual and cumulative biogas yield during the AD process are illustrated in Figs. 34.6, 34.7.

Biogas production started as from day 2 as illustrated in Figs. 34.6, 34.7. During the initial 2 days of the BMP assay, the inoculum used was getting acclimatised to the new environment and the substrates were being hydrolysed while the acidogenetic and acetogenetic phases of AD were also starting. During those 2 days, the methanogens did not have any feed to digest and convert into biogas. This was the reason for the delay in biogas production. As from day 2, the biogas production started to increase achieving its peak on day 9. It can be observed from Fig. 34.3 that the maximum VFA concentration was around the same period. With a high concentration of VFA, the methanogens had higher feed to digest and convert into biogas and hence, the biogas production was highest by day 9. As from day 9, the biogas production decreased due to the lower amount of VFA produced and due to the lower amount of organic matter remaining to degrade in the BMP assay. Eventually, by day 16, the biogas production ceased. The anaerobic digestion process was completed in terms of the available organic matter to degrade. From Fig. 34.7, it can be observed that the cumulative biogas yield obtained was 0.360 L/g VS fed. This was in accordance with published data from literature indicating that the biogas yield for AD of vegetable wastes lie in the range 0.3–0.6 L/g VS (Ward et al. 2008; Bougrier et al. 2008). The biogas yield obtained for this research study was on the lower limit with reference to the above range since this research was performed at RTP (below mesophilic temperatures). The higher limit of biogas yield referred to those anaerobic digestion set-ups performed under mesophilic or thermophilic conditions whereby it has been observed that biogas yield is higher under those two operating temperature conditions due to higher solubilisation of organic matter (Appels et al. 2008; Deublein and Steinhauser 2008).

Conclusions

BMP assays were used to evaluate the performance of AD of vegetable wastes under an HRT of 20 days at RTP. The pH and alkalinity remained above the minimum limit required for stable AD while a TS reduction of 62.1 %, VS reduction of 66.4 % and COD reduction of 64.9 % were achieved. These results showed that vegetable wastes can be effectively treated by AD. With a biogas yield of 0.360 L/g VS, vegetable wastes were a potential source for energy production.

Future Works

The next phases of this study consist in investigating the AD of wastewater treatment sludge. The effects of sonication on AD of vegetable wastes and sludge will also be investigated, with special emphasis on process parameters. These will help evaluate the feasibility of using sonication as a pretreatment technique prior to anaerobic digestion.

Acknowledgments The authors would like to thank the Mauritius Research Council for their financial assistance for funding and supporting this research study (Ref. No.: N4 2011 0755) and the University of Mauritius for their technical support.

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Chapter 35
Viability of Using Cassava as Feedstock for Bioethanol Production in Fiji

Pritika Bijay and Anirudh Singh

Abstract Ethanol production from renewable resources has received attention due to increasing petroleum shortage. One such renewable resource that has been identified is cassava starch. Cassava starch is extracted from root crop, cassava (*Manihot esculenta* (*Crantz*)) and is readily available in Fiji. Many countries such as China, Thailand and India are already having success in producing high starch yielding cassava varieties that can be used for ethanol production. The current paper investigates the viability of producing ethanol from locally available cassava varieties in Fiji. Starch was extracted from the roots of ten different cassava varieties available at two different research stations in Fiji. The sedimentation technique was used to extract starch from cassava roots and some properties of the extracted starch were also determined. In the case of Koronivia Research Station (KRS) the variety Nadelei had the highest starch yield (23.1 %) whereas Coci had the highest starch yield (23.3 %) for Dombuilevu Research Station (DRS). The paper discusses and compares starch yield obtained from Fiji cassava varieties with some other countries and make recommendations on how starch yield from Fiji cassava varieties can be increased. Finally, the paper provides recommendations on enhancing the viability of cassava as a source of bioethanol in Fiji. It also assesses the resources available in Fiji currently to make cassava bioethanol in Fiji a viable proposition.

Keywords Cassava · Starch · Ethanol yield · Bioethanol

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_35,

Short Introduction

Recently, cassava starch (extracted from root crop) has received a lot of attention in ethanol production. Many countries such as China, Thailand and India already started to produce ethanol from cassava starch successfully. The current paper investigates the viability of producing ethanol from locally available cassava varieties in Fiji. Additionally, the paper discusses and compares starch yield obtained from Fiji cassava varieties with some other countries and make recommendations on how starch yield from Fiji cassava varieties can be increased.

Introduction

Cassava, *Manihot esculenta* (*Crantz*) is a perennial plant widely grown in many tropical countries including Fiji Islands. The importance of cassava is derived from its diverse use for human consumption, animal feed and industrial application. It is currently the sixth world food for more than 500 million people in the tropical and the sub-tropical Africa, Asia and Latin America (El-Sharkawy 2004).

Cassava generally grows in many soil types. However, cassava does not tolerate saline or persistent water-logged conditions and it also does not tolerate temperature at or below 10 °C (O'Hair 1990). It is usually propagated vegetatively from mature woody stem cuttings however, cassava can also be propagated from seeds. According to Ceballos et al. (2004) seeds are generated through crossing in breeding programs and this result in creating new genetic variation. The use of seeds in commercial cassava production is a promising option to obviate constrains, particularly diseases associated with vegetative propagation (Iglesias et al. 1994).

The roots of cassava typically consists of moisture (70 %), starch (24 %), fibre (2 %), protein (1 %) and other substances which also includes minerals (3 %) (Tonukari 2004). Starch is an important source of carbohydrate that is synthesised by cassava roots and can not only be used as food but also as a source of chemical reagent, feedstock for fermentation processes and adhesive substance. The use of cassava starch as feedstock for ethanol production as fuel is already being exploited and the results shown by many researchers are quite promising.

Therefore, it becomes essential that high starch yielding cassava varieties are identified. The classification of cultivars (variety) is usually based on pigmentation and shape of the leaves, stems and roots (Rogers and Appan 1973). The cassava varieties in Fiji are also identified using these classifications.

Currently, Koronivia Research Station (KRS) in Fiji have identified the following twenty-eight cassava varieties; Vulatolu, Vulatolu 2, Merelesita, Merelesita 2, Yabia Damu,Yabia Vula, Niumea, Coci, Sokobale, Aikavitu, Kasaleka, Katafaga,, Belesilika, Manioke, Yasawa Vulatolu, Malaya (Macuata), Ro Tubuanakoro, Coci (selection), Vulatolu (Dalip Singh), H.165, H.97, Tilomuria No.3, Tavioka Falawa, Navolau, New Guinea, Lomaivuna, Beqa, Hawaii and Kadavu [Nauluvula 2009, pers. Comm.].

The objective of this study was to identify the starch yield from ten different varieties of cassava found in Fiji and to determine some properties of the starch obtained from these varieties. Another objective was to compare starch yield of Fiji cassava with cassava starch yield in other countries.

Materials and Methodology

The cassava varieties that were used for ethanol production were obtained from two different research stations of the Ministry of Primary Industries in Fiji. One was KRS situated 18° 32′811″ S and 178° 32′133″ E and the other was Dombuilevu Research Station (DRS) situated 17° 33′620″ S and 178° 14′736″ E. These two locations are indicated in the map of Fiji in Fig. 35.1.

The ten cassava varieties obtained were; Niumea, Sokobale, Beqa, New Guinea, Coci, Vula Tolu, Yabia Damu, Merelesita, Nadelei and Navolau. The variety Sokobale was not available at DRS therefore; only nine varieties were used for ethanol production from this location. The cassava varieties obtained from KRS

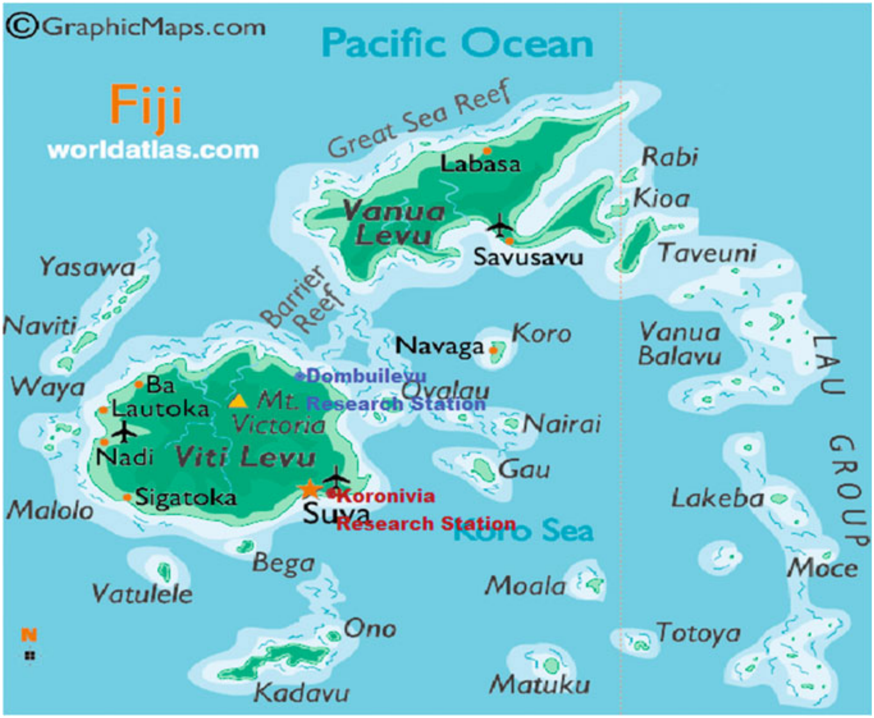

Fig. 35.1 Map of Fiji showing the collection points of cassava varieties (*Source* Fiji Map: http://www.worldatlas.com/)

and DRS were approximately 12 months old. The two sites were chosen to determine whether geographical location played a part in determining starch yield which will then influence the ethanol yield.

Dry Matter Content of Cassava Roots

Dry matter content of cassava roots has become an important character for the acceptance by researchers and consumers who boil or process them (Teye et al. 2011). The percentage of starch and starch yield are closely related to dry matter percentage. Therefore, this is one of the factors that need to be determined in order to identify the best cassava variety for starch and ethanol yield.

Dry matter content was determined according to the procedure described by Benesi (2005). The roots of different cassava varieties were analyzed for dry matter content within 12 h of harvesting. The roots were peeled, cleaned and then shredded into fine slices before 100 g of these were weighed in a Petri dish (w_1). The Petri dish was then placed in an oven at a temperature of 65 °C for 72 h. The samples were removed after 72 h and weighed immediately (w_2). Dry matter content was calculated using the Eq. (35.1):

$$\text{Dry matter content } (\%) = \frac{w_2}{w_1} \times 100\% \tag{35.1}$$

Starch Extraction from Cassava Roots

The extraction of starch from cassava was done according to the method described by Birse and Cecil (1980). However, some parts of the method were modified. A flowchart of starch extraction is shown in Fig. 35.2. Cassava roots were washed, peeled then washed again before the roots were chopped into approximately 1 cm cubes. The weight of the chopped cassava (w_3) was taken before pulverizing it in a high speed blender for 5–10 min. The pulp was then suspended in ten times its volume of water, stirred for about 5 min before filtering using a double fold cheese cloth. The filterate was left to stand for about 6 h before the starch settled and the liquid portion discarded. The water was then added to the sediment and the whole process was repeated. The starch was then dried at 50 °C for 24 h and its weight measured (w_4).

The starch yield was determined using the Eq. (35.2):

$$\text{Starch Yield } (\%) = \frac{w_4}{w_3} \times 100\% \tag{35.2}$$

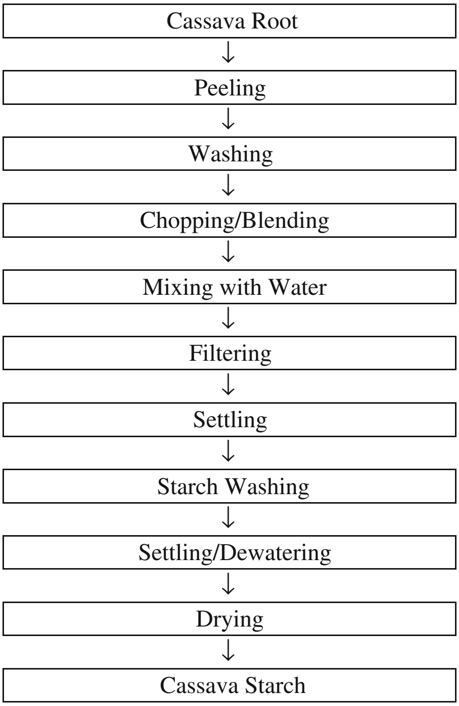

Fig. 35.2 Flowchart for Cassava starch production

Moisture Content of Starch

Moisture content of the extracted starch was determined according to the method described by Benesi (2005). However the quantity of cassava starch to be analyzed was increased.

Approximately 10 g of cassava starch (w_5) was dried in an oven at 105 °C for 24 h. After 24 h the samples were cooled in a desiccator and weighed immediately (w_6). The moisture content was determined using Eq. (35.3):

$$\text{Moisture content }(\%) = \frac{w_5 - w_6}{w_6} \times 100\% \tag{35.3}$$

Ash Content of Starch

Ash content was determined according to the method described by International Starch Institute (1999a). Clean ashing crucibles were heated in the furnace for approximately half an hour at 900 °C. The crucibles were cooled in a dessicator to room temperature and weighed (w_0). Approximately 5 g of the starch sample was uniformly distributed in the ashing crucible and weighed (w_7). The samples were then incinerated on a bunsen burner until it completely carbonised before placing the ashing crucibles in the furnace for 5 h at 900 °C. After incineration the samples were cooled to room temperature in a dessicator and weighed (w_8). Ash content of starch was determined using Eq. (35.4):

$$\text{Ash content } (\%) = \frac{w_8 - w_0}{w_7 - w_0} \times 100\% \qquad (35.4)$$

pH determination of Starch

The pH of starch was determined according to the method described by International Starch Institute (1999b). Approximately 5 g of starch was mixed with 20 ml of distilled water. The starch was then allowed to settle for 15 min before the pH of the water phase was measured using a calibrated pH meter.

Results and Discussion

The starch yield from different cassava varieties obtained from two different locations in Fiji is shown in Table 35.1. The starch yields for cassava varieties obtained from both the stations ranges from 17 to 23 %.

The results show that the yields are dependent on the sites of the plantations. They show that Beqa, New Guinea, Yabia Damu, and Nadelei are more suited to the Koronivia site with regard to their starch yields. On the other hand Niumea, Coci, Vula Tolu and Navolau performed better at the Dombuilevu site for their starch yields. The Merelesita starch yield did not show much variation with site. Therefore, it is seen that location is one of the factors that influence starch yield.

Table 35.1 Starch yield from cassava varieties

Cassava variety	Koronivia	Dombuilevu
	Starch yield (%)	Starch yield (%)
Niumea	18.3	19.9
Sokobale	17.7	
Beqa	21.9	17.0
New Guinea	20.9	19.5
Coci	20.5	23.3
Vula Tolu	17.3	18.1
Yabia Damu	19.6	17.9
Merelesita	18.6	18.8
Nadelei	23.1	22.1
Navolau	17.0	19.8

Table 35.2 Dry matter content of cassava varieties

Cassava variety	Koronivia	Dombuilevu
	Dry matter content (%)	Dry matter content (%)
Niumea	37.9	36.2
Sokobale	36.3	
Beqa	41.2	32.2
New Guinea	41.5	32.3
Coci	37.0	36.8
Vula Tolu	31.1	35.6
Yabia Damu	35.7	36.0
Merelesita	40.9	35.6
Nadelei	40.8	38.0
Navolau	33.7	33.8

Benesi's (2005) result indicated that the genetic constitution of the plant is the most influential factor. However, sites, rounds of starch extraction and their interaction also have appreciable influence. Similar observations were also made by Ngendahayo and Dixon (2001) who found that after six months, the starch content in plants are influenced by genotype, harvesting time and rainfall pattern.

The dry matter content obtained from two different locations is shown in Table 35.2. The cassava from Koronivia had a dry matter content as high as 41 % (New Guinea and Beqa) whereas the ones from Dombuilevu had a maximum of 38 % (Nadelei).

Dry matter content is very much related to rainfall during six to eighteen months of plant growth (Ngendahayo and Dixon 2001). This suggests that the difference in dry matter content between the sites could be contributed to the rainfall received during plant growth. However, Benesi et al. (2004) have reported that the root dry matter content of cassava in Malawi is in the range 38.24–46.48 % and that dry matter content was not as much influenced by the environment as by the genetic differences.

The mineral elements and inorganic salts present in starch are referred to as ash. Table 35.3 shows that the ash content for cassava varieties obtained from Koronivia is 0.10 to 0.17 % and for Dombuilevu it was 0.1 to 0.21 %.

According to Thomas and Atwell (1999) ash content is typically less than 0.5 % of dry mass and this agrees with the results obtained for all the cassava varieties obtained from Koronivia and Dombuilevu. Variations in ash content depend upon source of raw material, agronomic practices, extraction and milling procedures and types of chemical modifications (Benesi 2005).

The pH of cassava starch as reported in Table 35.4 ranged from 4.07 to 5.23 for the varieties obtained from Koronivia and 5.03 to 6.20 for those varieties obtained from Dombuilevu. Benesi (2005) indicated a pH range of 5.0–5.5 for the native starch obtained from ten elite Malawian cassava genotype. The recommended pH range stated by the National Starch and Chemical Company is between 4.5 and 7.0 (National Starch and Chemical Company 2002).

Table 35.3 Ash content of cassava varieties

Cassava variety	Koronivia	Dombuilevu
	Ash content (%)	Ash content (%)
Niumea	0.17 ± 0.01	0.19 ± 0.03
Beqa	0.17 ± 0.03	0.21 ± 0.02
Sokobale	0.11 ± 0.02	
New Guinea	0.09 ± 0.01	0.15 ± 0.04
Coci	0.14 ± 0.02	0.13 ± 0.01
Vula Tolu	0.10 ± 0.02	0.12 ± 0.02
Yabia Damu	0.10 ± 0.02	0.17 ± 0.03
Merelesita	0.12 ± 0.02	0.13 ± 0.01
Nadelei	0.10 ± 0.02	0.10 ± 0.02
Navolau	0.14 ± 0.02	0.16 ± 0.04

Means of three replicates (±SD)

Table 35.4 pH of Cassava varieties

Cassava variety	Koronivia (pH)	Dombuilevu (pH)
Niumea	4.07 ± 0.02	5.98 ± 0.05
Sokobale	4.18 ± 0.02	
Beqa	4.89 ± 0.01	5.81 ± 0.04
New Guinea	5.23 ± 0.02	5.03 ± 0.02
Coci	4.47 ± 0.01	5.04 ± 0.03
Vula Tolu	4.63 ± 0.03	5.17 ± 0.01
Yabia Damu	4.44 ± 0.01	6.20 ± 0.02
Merelesita	4.53 ± 0.03	5.21 ± 0.03
Nadelei	4.53 ± 0.02	5.48 ± 0.03
Navolau	4.37 ± 0.01	5.34 ± 0.02

Means of three replicates (±SD)

Table 35.5 Moisture content of Cassava varieties

Cassava variety	Koronivia	Dombuilevu
	Moisture content (%)	Moisture content (%)
Niumea	12.6 ± 0.5	12.9 ± 0.9
Sokobale	14.7 ± 0.6	
Beqa	14.1 ± 0.8	14.5 ± 0.4
New Guinea	13.9 ± 0.6	13.6 ± 0.9
Coci	13.1 ± 0.5	12.5 ± 1.0
Vula Tolu	13.9 ± 0.6	13.7 ± 1.2
Yabia Damu	12.9 ± 0.3	12.8 ± 0.5
Merelesita	12.4 ± 1.0	13.0 ± 0.4
Nadelei	13.7 ± 0.4	13.6 ± 0.9
Navolau	12.5 ± 1.0	12.0 ± 1.2

Means of three replicates (±SD)

The moisture content for Koronivia cassava variety as shown in Table 35.5 ranged from 12.4 to 14.7 % whereas for Dombuilevu it was from 12.0 to 14.5 %. The results obtained are consistent with the results reported by Nuwamanya et al. (2008)

and Benesi (2005). Nuwamanya et al. (2008) reported moisture content ranged from 14.09 to 16.49 % for the parental lines and 14.80 to 16.11 % in the progenies. The native cassava starch moisture content that Benesi (2005) found for the ten varieties investigated ranged from 10.47 to 12.83 %. High moisture content in cassava starch is not a desired property. High moisture content in cassava starch leads to growth of micro-organisms that are capable of degrading starch (Nanda et al. 2010). Moorthy (2001) reported that high moisture content affects the pasting properties of cassava starch and Willett and Doane (2002) stated that the tensile properties and overall granular structure of starch are also affected by high moisture content.

Comparison of Starch Yields from Fiji Cassava with Other Countries

In Fiji, cassava has primarily been cultivated for food. More recently, cassava has gained importance as a possible fuel commodity in countries such as China, Thailand, Indonesia, and other countries which have more advanced national biofuel programs. The Fiji government is also looking at improving the country's energy security by developing biofuels to reduce the dependence on diesel and petrol. Some renewable resources that have been identified for bioethanol production in Fiji include sugarcane, molasses and cassava.

Cambodia (Jie 2002)

In Cambodia cassava is mostly used for human consumption while little is used for animal feed and industrial purposes. Cassava is usually harvested 6–8 months after planting in flood plain regions. Farmers usually plant the cassava stems into the soil during November and harvest the crop before flooding in June. In the upper lands cassava is planted during wet season and harvested 9–12 months later. Results obtained from major cassava factories in Cambodia showed an average starch content of 24–28 % in roots. Most provinces in Cambodia plant cassava for human consumption therefore cultivation practices are limited to minimum land preparation, weeding and fertilizer. However, there are provinces where farmers earn money by selling cassava and cultivation is intensive giving high average yield and production.

China (Wang 2002; Yinong and Kaimian 2002)

In China more than 60 % cassava is used for industrial purposes, 30 % for animal feed and 10 % for human food. Planting of cassava is usually done in the tropical/subtropical extremes of the southeast corner of the country (Onwueme 2002).

The mean temperatures in this region are 20–24 °C with clay Oxisols or Alfisols soil of low fertility and pH of 4.5 to 6.6 being used (Onwueme 2002). Crops are grown on flats or ridges and usually intercropped with groundnut or rubber. Stem cutting are placed horizontally (Onwueme 2002). The roots can be processed to make different products due to their high starch content of 28–35 %. Over the past years China has been successfully able to introduce new varieties to replace older ones. These new varieties have high starch content and high yield fulfilling the most important breeding objectives in response to China's fast development of cassava processing industry. Most owners of starch factories in China have recognized the importance of raw materials supply. Therefore, they have started to support cassava cultivation with farmers by signing contracts and introducing farmers to varieties that have high starch content and high yield.

India (Edison 2002; Unnikrishnam et al. 2002)

India has a unique status on the cassava map for its high yield per hectare among the Asian countries. This has been made possible due to the availability of high yielding varieties, willingness of farmers to adopt these varieties and improved management practices. A large number of varieties are grown in different regions of India and the starch content for these varieties range from a minimum of 22 % to as high as 48 %. Cassava is grown in India under varying agro-climatic conditions and different soil types. In most states it is grown as rain-fed crop but in some districts like Tamil Nadu it is grown as irrigated crop. Previously, cassava was mostly grown in uplands either on open slopes or in coconut-based cropping systems. However, in the recent years it has shifted to lowland rice-based cropping systems.

Thailand (Sarakarn et al. 2002)

Thailand over the years has been trying to look for varieties that are most suitable to the environment and with good traits. The desired varieties should have high yield capacity, high harvest index, high root starch content and early harvest time. Thailand had limited cassava genetic diversity therefore, to improve those local varieties and to widen the genetic base, the country introduced many varieties from abroad. Varieties that are present in Thailand have a high starch content of 27.6 %. Most of these varieties have other good characteristics such as high fresh root yield, can be planted in late rainy season and more.

Cassava in Thailand is mostly grown as a sole crop (Howeler 1988). However; occasionally it is intercropped with maize, groundnut, rubber or coconuts. Planting occurs during May to November with most planting done between May to June (Onwueme 2002). Planting is done on flat or ridges by placing the stems vertically in soil. The soil in which cassava is grown is mostly Ultisols of loamy sand or sandy loam texture (Onwueme 2002). Temperatures are usually 27 °C with rainfall of 1,100–1,500 mm in central plain and 900–1,400 mm in the northeast region (Onwueme 2002).

Vietnam (Bien et al. 2002)

Vietnam is one of the major exporters of cassava. This has been made possible due to their extensive research in identifying varieties that are suitable to the agro-climatic condition and varieties that are high yielding as well as adopting sustainable production practices. The use of farmer participatory research in development and transfer of new technologies to cassava households have been a success. With introduction of high yielding cassava varieties and improved or sustainable production practices have raised the economic effectiveness of cassava production especially in Southeastern region of Vietnam. Several cassava cultural practices have been developed which include, (1) erosion control by growing vetiver grass and other plant species, (2) balanced fertilizer application, (3) intercropping cassava with peanut and/or mungbeans, (4) planting new high yielding varieties, (5) using the herbicide Dual, (6) using silage of cassava leaves and roots to feed animals. All these practices are supported by farmers. In most areas cuttings are planted vertical however, in sandy soils horizontal planting is practiced. Cassava roots in Vietnam can give high starch contents of 25–30 %.

Fiji

In Fiji cassava is predominantly grown for human consumption. There is almost no processing of cassava into dried form for human or animal use. However, apart from food cassava is exported to Australia and New Zealand as frozen tubers. Cassava is grown in most parts of Fiji. As it is tolerant to a range of climatic conditions as well as growing in marginal land, limited effort is currently being placed in improving conditions for planting. There is minimum land preparation, weeding is hardly done and limited fertilizer applied. In 2007 cassava yield was 13.80 t/ha (Krishna et al. 2009). This yield can be increased with sustainable cultivation practices and also by identifying high yielding varieties. Cassava research in Fiji is mostly done by KRS and other stations of the Ministry of Agriculture, Fisheries and Forest. The maximum starch yield obtained from cassava available in Fiji was 23.3 % and a minimum of 17 %.

Bioethanol is produced by fermenting sugars or substances that contain sugar. Cassava roots contain starch that can be converted to sugar. As seen in the starch results obtained, cassava in Fiji can be used for bioethanol production. The Fiji Government has plans to produce bioethanol from agricultural sources available in

Table 35.6 Comparison of ethanol yield made from various energy crops (Rao 1997)

Crop	Yield (t/ha/year)	Conversion rate to sugar or starch (%)	Conversion rate to ethanol (L/t)	Ethanol yield (kg/ha/year)
Sugarcane	70	12.5	70	4,900
Cassava	40	25	150	6,000
Carrot	45	16	100	4,500
Sweet sorghum	35	14	80	2,800
Maize	5	69	410	2,050
Wheat	4	66	390	1,560
Rice	5	75	450	2,250

Fiji namely sugarcane, molasses and cassava. Experts have pointed out that cassava is the best crop to be used for bioethanol production. The reason being that ethanol yield of cassava per unit land area is higher than any other known energy crop as seen in Table 35.6, it is also much cheaper to set up a cassava ethanol factory because of lower investment and much simple processing technology due to special characteristics of starch (Wang 2002). The cost of cassava ethanol can be lowered due to production of useful by-products from different parts of cassava plant (Wang 2002).

However, since cassava is primarily produced in Fiji for food by the people, an approach needs to be taken that would balance out the use of agricultural land for food and fuel. The use of food crops for fuel usually drives the prices of these crops. For this reason governments in many countries are now ensuring that biofuels do not increase the price of staple foods. The Fiji Government has dismissed the threat to food security on the grounds that more than half of Fiji's almost 2 million hectares of land is idle according to FAO 2006 figures (Krishna et al. 2009). As stated in the FAO report (Krishna et al. 2009), promoting diversification and setting aside land for food production is one strategy. However, governments need to make a national-level decision as to what extent staple crops should be used for biofuel production.

Conclusions

Cassava roots have a number of end-uses, such as for food and feed processing, starch industry, bioethanol production and for export. The ten varieties of Fiji cassava showed difference in starch yield and dry matter content suggesting that high starch yields could be obtained by selecting suitable varieties for starch extraction. Cassava can be grown in poor soil conditions and in many areas. However, with suitable farming practices cassava root yields as well as starch yield can be increased.

Further research on starch yield and dry matter content needs to be carried out on the other varieties of cassava that are available in Fiji and from various other locations. Also other possible root crops such as yams should be considered for starch and bioethanol production. The Ministry of Agriculture in Fiji should do research on new and better varieties of cassava that are more suitable to the climatic condition and are high yielding. They should also monitor the new varieties released on large scale farming and promote the use of the superior varieties of cassava to farmers.

Finally, in order to consider cassava for bioethanol production a comprehensive feasibility study needs to be conducted. Bioethanol production should only be considered if food versus fuel crisis does not arise.

Acknowledgments The authors would like to show there sincere gratitude to Mr. Poasa Nauluvula and Mr. Basdeo of Koronivia Research Station as well as Mr. Fillimone of Dombuilevu Research Station for providing the cassava samples for analysis and helping with relevant information regarding the various cassava varieties.

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Chapter 36
Feasibility of Using Solar Energy as a Source of Renewable Energy in Mauritius Under Collaboration of DIREKT

Pratima Jeetah, Dinesh Surroop, Romeela Mohee, Walter Leal Filho, Veronika Schulte and Julia Gottwald

Abstract With limited indigenous conventional energy resources, Mauritius imports over 80 % of its energy supply from foreign countries, mostly from the Middle East. Developing independent renewable energy resources is thus of priority concern for the Mauritian government. Mauritius, being a tropical island surrounded by the Indian Ocean has enormous potential to develop various renewable energies, such as solar, biomass, wind power and geothermal energy. In order to reduce external dependency of fuel the Mauritian Government introduced attractive policies and invited investors of the homeland and abroad to invest in renewable energy technologies. Thus, the aim of this study was to determine the feasibility of implementing solar photovoltaic panels at institutional and organizational level and determine its economical feasibility. The study also consisted of determining the extent to which Mauritians are ready to accept such technologies. A research was thus carried out in collaboration with DIREKT and was found that Mauritians are eager to accept and invest in the solar photovoltaic technology provided that they are given sufficient information on how the system works. Moreover, the economic evaluation for the implementation of the photovoltaic technology revealed that the payback period for such technologies will be around 4.3 years which is very much acceptable.

Keywords Solar · Photovoltaic

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_36,

Short Introduction

Mauritius imports over 80 % of its energy supply from foreign countries, and in order to reduce external dependency of fuel the Mauritian Government introduced attractive policies and invited investors of the homeland and abroad to invest in renewable energy technologies. Thus, the aim of this study was to determine the feasibility of implementing solar photovoltaic panels at institutional and organizational level and determine its economical feasibility. As Mauritians are eager to accept and invest in the solar photovoltaic technology, the economic evaluation for the implementation of the photovoltaic technology has been done and revealed the payback period of 4.3 years.

Introduction

Mauritius is a tropical country that has a very good solar regime with an average annual solar radiation of around 6 kWh/m^2/day. With emerging awareness about protection of the environment during the twenty-first century, the Government of Mauritius is focusing on broadening its energy supply, improving energy efficiency and adapting its energy infrastructure through modernization in order to meet the challenges ahead. To achieve this, Mauritians needs to adapt to a rapid shift in the practices of a low carbon, efficient and environmentally benign system of energy supply. As a result, the Government together with the Ministry of Renewable Energy and Public utilities have drafted a Long Term Energy Strategic plan based on practices of Renewable energy and has given it the name of Maurice Ile Durable vision. The Government also has a long-term vision of transforming Mauritius into a sustainable Island. One important element towards the achievement of this vision is to increase the country's renewable energy usage and thereby reducing dependence on fossil fuels. Democratization of energy production is determined to be the way forward. In line with the government's vision on renewable energy, the University of Mauritius has been working as a partner with DIREKT team to promote renewable energy infrastructure locally. The DIREKT (Small Developing Island Renewable Energy Knowledge and Technology Transfer Network) is a teamwork scheme that involves the participation and collaboration of various universities from Germany, Fiji, Mauritius, Barbados and Trinidad & Tobago. The aim of the DIREKT project is to reinforce the science and technology competency in the domain of renewable energy through technology transfer, information exchange and networking, targeting ACP (Africa, Caribbean, Pacific) Small Island developing states. A step in this direction is to transfer citizens the ability and motivation to produce electricity via small-scale distributed generation (SSDG), i.e. wind and photovoltaic.

Primary Energy Requirement in Mauritius

The total primary energy requirement of Mauritius is around 16,328 GWh per year. In 2010, the non renewable fuels imported (petroleum products and coal) accounted for 81.2 % of the energy demand. The remaining 18.8 % were supplied by locally available renewable resources. The local renewable energy supply comes from bagasse (90.1 %), hydro electricity (3.5 %), solar thermal (3.1 %) fuel wood (2.9 %) and wind energy (0.4 %) (Ministry of renewable energy & public utilities 2009).

Targets for Renewable Energy Over Period 2010–2025

On the basis of the Long term Energy Strategic plan set by the Government of Mauritius and the Ministry of RE and Public Utilities, it is expected that by 2015 the local renewable energy supply will amount to 24 % and by 2025 it will increase to 35 %.

Solar Energy Practices in Mauritius

Mauritius receives between 8 and 10 h of sunshine daily and the average annual solar radiation is 6 kWh/m^2. To promote the development of solar energy, the Government issued tenders for the supply and installation of 125 units of photovoltaic systems for street lighting and lighting of Government offices as a pilot project in early 1998.

However, this form of energy is not sufficiently tapped, though the potential is very high. But, one of the means actually used to take advantage of this source of energy is through the use of solar water heaters. Due to the abundance of the solar energy resource in Mauritius, some 35,000 solar water-heating units have been installed all over Mauritius, which represents an 8 % penetration of the household market. Solar water heating is the most common form of solar energy conversion, used in Mauritius.

With the setting up of the MID Fund in July 2008, the solar water heater loan scheme controlled by the Development Bank of Mauritius has been increased to Rs. 10,000 so as to double the number of solar water for domestic use by end 2011. The outcome of this new scheme has been above expectations with some 49 thousand applications received by the Bank. Based on the constructive experience, the Government is now planning another scheme to encourage wider use of solar energy in terms of photovoltaic in household and other sectors of the economy.

The Government of Mauritius has also anticipated the production of 300 kW of electricity via solar photovoltaic to displace the diesel fuelled Mauritian generation.

To lessen the impacts from new road and power line construction, the project will be constructed near the existing diesel generation plant. This project is expected to reduce greenhouse gas emissions by 470 metric tonnes per year. It is also projected to reduce around 16,000 metric tonnes of CO_2 over a period of 35-year which is expected to be the life- time of the project.

Moreover, the Government of Mauritius and the Central Electricity Board, with the help of the UNDP have set out a grid code which has been designed for small-scale distributed generators in order to allow the integration of small-scale renewable energies in the power system of Mauritius mainly through the use of photovoltaic panels and wind turbines.

Methodology

This research tries to find out the extent to which private and public sectors have implemented or are ready to invest on renewable energy technologies in Mauritius and what are the views of stakeholders to implement these technologies in the future. To measure the effectiveness, both quantitative and qualitative data have been used. All organizations and Institutions throughout Mauritius which are in some ways or the other involved in renewable energy were identified.

Data were collected using the Questionnaire based survey approach over a period of two months. Questionnaires were sent to the targeted groups by post, electronic mails, faxes and some were also delivered in person. The informal personal interview that is face-to-face approach was also used to some of the target groups due to the nature and content of the questionnaire. Prior meeting was arranged with the directors, managers and employees via the phone and emails one week before. Each face-to-face interview lasted for approximately 15 min. The face-to-face method provided an opportunity to probing (i.e. asking for addition information) if the answers given by the respondents were incomplete or ambiguous. Furthermore, it provides rich and descriptive data. Some filled questionnaires were returned by post while others forwarded by emails.

Results and Discussions

Interest in Renewable Energy Sectors

To determine the feasibility of using Solar Energy as a source of renewable Energy in Mauritius, a survey form was sent to stakeholders, governmental organizations, non- governmental organizations, private sectors and tertiary institutions involved in Renewable energy. The response obtained is shown in Table 36.1.

Table 36.1 Types of renewable energy organizations in Mauritius are interested in

Field of interest	% interested
Biofuels	16
Biomass	24
Biogas	24
Wind power	48
Hydropower	16
Geothermal	12
Solar thermal	52
Photovoltaic	56
Hydrogen fuel cell	8
Hybrid system	40
Ocean energy	12

It can be found that most organization are very much interested in Photovoltaic (56 %) followed by solar thermal energy (52 %), Wind Power (48 %), Hybrid systems (40 %), Biomass (24 %), Biogas (24 %), Bio-fuel (16 %), Hydropower(16 %), Geothermal (12 %), Ocean Energy (12 %) and Hydrogen fuel cells (8 %). It must be noted that in the surveys, most organizations specified a hybrid system of wind/photovoltaic and solar thermal/Photovoltaic. The objective of this question was to determine the interest and in turn the most appropriate renewable energy technologies to be applied in Mauritius in the coming future. Using this definition the sample surveyed reveals that stakeholders and organizations are mostly interested in Solar Photovoltaic technologies.

Market Oriented Service Expected from Tertiary Institution

To be able to implement such practices, the same group of people were asked about their interest in terms of services they want to get from tertiary institutions. It was found that the types of market oriented services that the organizations prefer to have from tertiary institutions included among others; trainings to put RE practices into practice, providing information related to funding grants by international organizations for RE projects and partnership with private firms in consultancy. Moreover, many organizations are very much interested in getting training in construction and installation of RE devices mainly in the field of wind and solar energy and to get international and regional market surveys. Concern among targeted group were also diverted towards carrying out feasibility studies and to have complete assessment of sites in terms of RE sources up to implementation of project, including installation, testing and commissioning. The sample results show that the organizations are very much willing to be well informed and guided on the RE technologies to the extent of installation and commissioning.

Economics of Photovoltaic Panels

Based on the results obtained regarding the interest in Renewable energy in Mauritius, It was found that respondents are much more willing to adopt the photovoltaic system as a source of producing electricity than any other type of renewable energies. Furthermore, with the motivating scheme provided by the government for citizens to produce electricity via small-scale distributed generation, most organization, stakeholders and businesses are willing to converge towards photovoltaic panels rather than wind turbines because of two main reasons; firstly due to the better aesthetic of PV and secondly sunshine insolation is much higher in all parts of Mauritius as compared to wind resource. So taking this into consideration, the economics of the installation and commissioning of solar photovoltaic was performed.

Sunshine Availability in Mauritius

Data on amount of sunshine in Mauritius was collected by the meteorological station showed that there is a very good potential for exploiting solar energy in Mauritius. Sunshine is available in abundance all year round in Mauritius, be it summer or winter. This is shown in the table below in terms of hours of sunshine that yields the amount of insolation per m^2 per day: (Table 36.2).

Costing for Solar Panel

For the costing, quotations were taken from different solar companies in Mauritius and the Solar Electricity's Company quotation was selected since it was at a lower

Table 36.2 Yearly sunshine data in Mauritius

Month	Sunshine		Insolation KW/m²/day
	Daily hrs per day	Mean monthly	
January	7.0	216.3	6.80
February	6.6	186.1	6.48
March	6.7	209.4	6.08
April	6.0	179.1	5.07
May	6.3	193.9	4.45
June	6.1	182.8	4.17
July	6.1	187.6	4.30
August	6.1	187.7	4.99
September	6.3	189.5	6.01
October	6.8	210.1	6.89
November	7.3	219.8	7.47
December	7.0	216.8	7.10

price. The quotation was as follows for various delivery capacities for a grid tied inverter all in Mauritian rupees (1 Euro = 40 MUR):

	1,000 W/Hr	2,000 W/Hr	3,000 W/Hr	4,000 W/Hr	5,000 W/Hr	6,000 W/Hr
Solar panel (monocrystalline)	103,941	197,992	280,946	323,927	448,967	519,882
Inverter	33,020	52,960	80,840	92,682	117,714	142,948
Wiring + installation fee	41,300	44,700	51,257	52,956	63,754	76,300
Total excluding VAT	178,261	295,652	413,043	469,565	630,435	739,130
+Vat (15 %)	26,739	44,348	61,957	70,435	94,565	110,870
Total	**205,000**	**340,000**	**475,000**	**540,000**	**725,000**	**850,000**
Units saved monthly	**120**	**240**	**360**	**480**		

The Independ Power producer (IPP) was taken as example for the costing. It has been found that the IPPs produce around 10 MW of electricity per year which amounts to 1,141.55 W/Hr. Thus from the available quotation, we can opt for the 2,000 W/Hr solar panel since taking the 1,000 W/Hr will deliver less than the actual demand. Thus the installation and production cost for 10 MW/year of electricity will cost 340,000 Mauritian rupees (MUR) amounting to 8,500 euro (1 euro = 40 Mauritian rupees). However, this cost excludes the profit when sold to grid. In Mauritius, the units of electricity are sold according to the amount of units consumed. This is shown in the table below: (Table 36.3).

Since 1 unit of electricity means 1 kWh, thus IPPs produces 10,000 units. Using the above table, the selling price for the 10,000 units amounts to 78,948 Mauritian rupees (1974 euro).

With a production of 10,000 units per year at a selling price of 78,948 rupees the payback period is found to be 4.3 years as shown in the graph (Fig. 36.1).

However, it must be noted that the payback period will be slightly higher as this quotation is based on the price of watt produced per hour and on the assumption that everyday there is availability of sunshine.

Table 36.3 Price of units of electricity in Mauritius (*Source* CEB utility bill)

Unit (KW/Hr)	Price (Rs)	Price (Euro)
First 25	2.87	0.07
Next 25	3.98	0.1
Next 25	4.31	0.11
Next 25	4.95	0.12
Next 100	5.59	0.14
Next 50	6.38	0.16
Next 50	7.18	0.18
Remaining	7.97	0.2

Fig. 36.1 Payback period for the installation of PV panel to produce 10 MW of electricity/year

Conclusion

It has been found that a high number of tertiary institutions are actually running most of the market oriented issues. Nevertheless, these form part of a module only, thus the required in-depth knowledge may not be achieved by the targeted group. Thus, these institutions can make further provision in running these issues as a whole course in itself.

The surveys revealed that the renewable energy that is most in use in Mauritius is the solar energy, followed by wind, a hybrid of wind and solar technologies, hydro and biomass. But, the implementation of all the renewable energy sources at a time is not feasible for a small island like Mauritius. We should explore each and every aspect of the Renewable energy sources before embarking on them. However, the type of renewable energy which is most known to the Mauritian population and which is most ready to be accepted at household as well as at business and Organization level is the solar energy through the use of photovoltaic panels.

Based on another survey carried out by Doolaree (2010), the findings tallied with this study revealing that among all the renewable energy sources, 45 % of the respondents firmly believed that Mauritius should invest in solar while 21 % suggested to invest in wind energy. Thus PV is expected to be the most prosperous RE in the long term due to the presence of sunlight everywhere. Moreover, with the introduction of net metering and awareness campaign, the use of PV will certainly be improved and well accepted at all levels.

The main reason behind this shift in the mindset might be probably due the interesting incentive schemes launched out in 2009 by the Government in collaboration with the Central Electricity Board, with the help of the UNDP.

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Chapter 37
Optimization of Biogas Production to Use in Cooking Stove

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Abstract The objective of this project is to enhance the biogas production from anaerobic digestion of resources, like organic wastes, which are readily available on the island. The project laid emphasis on the optimization of the process which includes methods available up to date to enhance the biogas production. Anaerobic Digestion is the biological treatment of biodegradable organic waste in the absence of oxygen, utilizing microbial activity to break down the waste in a controlled environment. Anaerobic digestion results in the generation of biogas; which is rich in methane, were used to generate heat in a cooking stove. The digestate which is nutrient rich can potentially be used as a soil conditioner or as fertilizer. The digestion process took place in a sealed airtight container (the digester) which was the ideal conditions for the bacteria to ferment the organic material in oxygen-free conditions. A pilot anaerobic digester of 1 m3 was designed proposed whereby cow dung was used as feed to operate the digester. The digester consisted of a mixing unit integrated inside. The digester was then connected to a holder whereby it was used as a biogas storage system. From there on, the biogas was sent to a stove for cooking purposes. Plastics tank were selected as the main material for the design since it was easily available on the market and had low investment cost. This kind of project would be implemented at farmers or lower middle class people who reared cows, since the feed is readily available. This project was feasible for typical Mauritian family in terms of technical, social and economical factors.

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_37,

Short Introduction

This paper describes the optimization process of the anaerobic digestion (biological treatment of biodegradable organic waste in the absence of oxygen, utilizing microbial activity to break down the waste in a controlled environment) used in biogas production. Biogas is rich in methane, and can be easily used to generate heat in a cooking stove. This project has been found feasible for typical Mauritian family in terms of technical, social and economical factors, and has a good potential to be implemented in the farmers' households.

Introduction

Controlled anaerobic digestion is by no means a radical or new concept. Large scale industrial digesters and small domestic digesters are in operation in many places around the world. The purpose of all these digesters is to produce combustible biogas which can be burned to provide energy for a whole range of uses. Here in Mauritius, there is quite a bit of ideological interest in anaerobic digestion and biogas production, particularly from intensive farmers, but there are not many examples of digesters in operation. These farmers are interested in this topic primarily as an alternative energy source (biogas), and secondly, as part of an efficient effluent waste disposal system for the farm.

Somehow there seems to be a problem in finding ways to put controlled anaerobic digestion into practice on the average Mauritian farm. The reasons why this concept is not being realized more could be a number of possible reasons such as the capital cost of setting up an anaerobic digester project, a lack of working models and/or a lack of a source of ideas to base individual projects on, i.e.—trouble shooting and project development at a technical 'on farm' level.

A given amount of volatile solids of a particular waste can be converted to a maximum amount of biogas at a given temperature provided optimum conditions are prevalent. This conversion can be accounted by two factors i.e. biodegradability at a specified temperature and operating conditions that depend on kinetics, reactor configuration, the flow pattern within the digester, digestion stage as well as the presence of the inhibitory substances.

This project is definitely not supposed to be revolutionary or radically new, but rather to be a starting point for further research and development in this area.

Methodology

Objectives

The purpose of this project was to develop a small scale working prototype possibly suited to operate on the average farm. The focus of this project was the production of combustible biogas. The main objective of this research is to employ anaerobic digestion process as a sustainable technology for minimizing the animal solids waste and to provide the renewable source of energy as well as to reduce the potential greenhouse gases emission. The specific objectives of this study are; to construct a pilot-scale anaerobic digester, to optimize the methane yield of substrate with different techniques, to analyze the operational parameters for the stability of Anaerobic Digestion system, to investigate the optimization of the anaerobic digestion system and to analyze biodegradability of organic materials.

Design

The methodology adopted was firstly the digester was designed and constructed using locally available materials. The design and construction phase is consisted of selecting the basic parameters to be assumed during the construction of the biodigester. The biodigester being the main part of the stand alone system has similar features as the fixed dome digester. It is typically a high density polyethylene plastic tank. This tank was chosen since it is normally readily available in the local market and it is cost effective. Considering the low budget criteria of this project, the mixing part cannot be run with a motor installed with the biodigester. It is going to be very expensive. Thus to design a manual mixing system, Archimedes's screw principle is proposed. The biogas purification is another phase in this project. The scrubbing of the biogas in order to remove impurities that are generated during the digestion process such as CO_2 (carbon dioxide) and H_2S (hydrogen sulphide) is very important. The scrubbing is viewed as very important as hydrogen sulphide is highly corrosive to the cooking and heating systems that would utilize the biogas, and the presence of carbon dioxide makes the gas more difficult to compress and store, although it does not increase the volatility. A simple method for hydrogen sulphide utilizing steel wool in a glass bottle is modelled and to remove carbon dioxide from biogas, 1 M sodium hydroxide is used for scrubbing.

After scrubbing, the can be directed to the cooking stove via pipelines. To measure the biogas releasing from the biodigester, the method of an inverted measuring cylinder is proposed.

Analysis

Following the construction phase was the analysis phase which comprised of testing the parameters concerned during the anaerobic digestion process. Most of the lab works were performed either in the UOM Chemical Engineering laboratories found in phase 2 building or on the sixth floor of Engineering tower. The samples, from feed, sludge and biogas streams were collected for analytical tests. Parameters such as chemical oxygen demand, total solids, volatile solids, carbon to nitrogen ratio, moisture content, ash content, pH, volatile fatty acids, volume of biogas produced daily and heating value of biogas were analyzed using standard laboratory techniques.

Construction

Biodigester

The mechanism of system included the biodigester, mixing system, scrubbing system, gas measuring system and the cooking stove for the combustion purpose of biogas. The biodigester is mainly a plastic tank in which a mixing unit is integrated in it. The feed and output system will be also mounted. The plastic tank is a high density polyethylene plastic water tank having dimensions of 110 cm by 96 cm by 92 cm (Table 37.1).

Mixing System

The design of the mixing unit is derived from the principle of working of the Archimedes screw. The Archimedes 'screw consists of a screw inside a hollow pipe. The screw is turned usually by manual labour. As the bottom end of the tube turns, it scoops up a volume of liquid. This amount of liquid will slide up in the

Table 37.1 Characteristics of the HDPE tank

Characteristics	Value
Type	Plastic
Material	High density polyethylene
Volume	1,050 L
Weight	70 kg
Pressure	100 kPa
Volume of gas occupied	0.2 m3
Volume of substrate mixture	0.8 m3

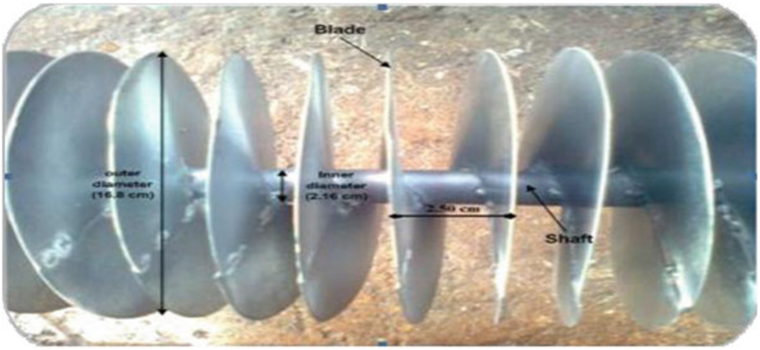

Fig. 37.1 Labeled view of the mixing unit

Fig. 37.2 Three-bladed propeller

spiral tube as the shaft is turned, until it finally pours out from the top of the tube. Based on the handbook of the design and operation of Archimedes screws, the geometry of the mixing unit is calculated (Nagel 1968; Rorres 2000) (Fig. 37.1).

At the end of the screw, a three-bladed propeller is fixed to enable mixing of the substrate found at the bottom of the digester. The figures below show picture of the final construction of the digester (Figs. 37.2, 37.3 and 37.4).

Fig. 37.3 Side view of digester

Fig. 37.4 Front view of digester

Materials of Construction

The selection for the materials of construction was done keeping in mind that this project is to be implemented in farms or in at houses of low income. The table summaries the different materials selected for the different parts of digester and reasons (Table 37.2).

Table 37.2 Summary of the materials of construction

Components		Material of construction	Reason(s)
Tank		HDPE (high density polyethylene)	The plastic material is found to be able to meet the stringent demands of the chemical compability of digestion process
			The plastic tank is virtually impervious to acids and alkalis, flexible, and durable
			Low cost
Mixing unit	Inner part	Galvanized steel	Zinc coatings prevent corrosion of the protected metal by forming a physical barrier
			Low cost compared to other materials locally available
	Outer part	PVC (polyvinylchloride)	Resistant to chemicals
			Offers high quality standards
Fittings and piping		Reinforced flexible hoses	Suitable due to their strength and inertness towards fluids

Results and Discussion

Substrate Characteristics

The physical and chemical characteristics of the organic waste are important for the design and operation of anaerobic reactors as they have an effect on the biogas production and process stability during anaerobic digestion (Garcia-Pena et al. 2011). The parameters analysed for the characterization of dairy manure and agricultural residues were: moisture content, total solid content, volatile solid, pH, chemical oxygen demand and C/N ratio. All these analytical determination for the characteristic of the dairy manure were performed according to the standard method (Begue 2011).

The findings as per the survey are displayed in this paper together with some pictures taken on site. Results obtained from burning of the biogas is also discussed and the carbon dioxide emissions avoided are discussed in this paper.

The physical and chemical characteristics of cow manure were analysed according to the standard method (Begue 2011). The result obtained for the total solid, volatile solid, pH, chemical oxygen demand and C/N ratio are summarized in Table 37.3.

The value for C/N ratio reported in the literature review for stable and better biological conversion of organic waste to biogas during anaerobic digestion lies within the range of 20–30. The carbon to nitrogen ratio for cow manure was found to be 26.57 and this ratio can be considered appropriate for the anaerobic bacteria as stated in the literature review. It was found that the total solid content of cow manure was 9.7–13 but from the table above the total solid content of the cow manure was slight higher due to a lower moisture content and higher organic

Table 37.3 Substrate characteristics

Parameters	Value
Moisture content (%)	85.0
Volatile solids (%)	84.6
Total solids (%)	15.0
Chemical oxygen demand (g/ml)	78,125
pH	6.79
C/N ratio	26.57

content present in the cow manure (Wang et al. 2010). Various studies reported that the volatile solid of cow manure was 83.0 and the result obtained during the experiment was almost similar at 84.6 (Stafford et al. 1980).

The chemical oxygen demand of the dairy manure was also investigated and it was found to be 78,125 mg/l. However, other studies found that the COD of cow manure was 129,400, 38230 and 165,000 mg/l (Stafford et al. 1980; Wang et al. 2010; Yilmaz 2007). These different values confirmed that the COD depends on the solid content present in the cow manure.

The cow manure has pH of 6.79, as it is slightly acid by nature.

Biogas Production

The performance of the experimental digester was monitored for 34 days. Initial the anaerobic reactor was fed with 540 kg of substrate. The volume of the biogas produced was measured four to five times a week through the water displacement method using a measuring cylinder of 2,000 ml. The samples were also removed from the digester twice a week from the digester and were analysed for moisture content, volatile solid, pH and chemical oxygen demand according as per the standard method (Begue 2011).

The graph shows the rate of biogas production throughout the experimental period of 34 days. The degradation of the organic waste by the methanogenesis bacteria started as from the first day of the set–up of the anaerobic reactor. The biogas production was monitored four to five times per week and the volumetric biogas production for the experimental period (Figs. 37.5, 37.6).

The graphs indicate the biogas production and cumulative biogas production for the 34 days. The reactor was operated in batch mode for 34 days from the start up process. On the fourth day the first volume of biogas production was noted. As from day 6, the volume of biogas produced showed a decreasing trend due to the abrupt decrease in the pH. After the biogas production continues to increase daily and it reaches its maximum percentage on day 14. This occurred due to the fact that the digester was left on purpose for two days so as biogas would build up and have enough pressure for it to have a constant flame during ignition. On day 14, 38 min of burning of the biogas was recorded and still 62 L of biogas remaining in the digester was measured.

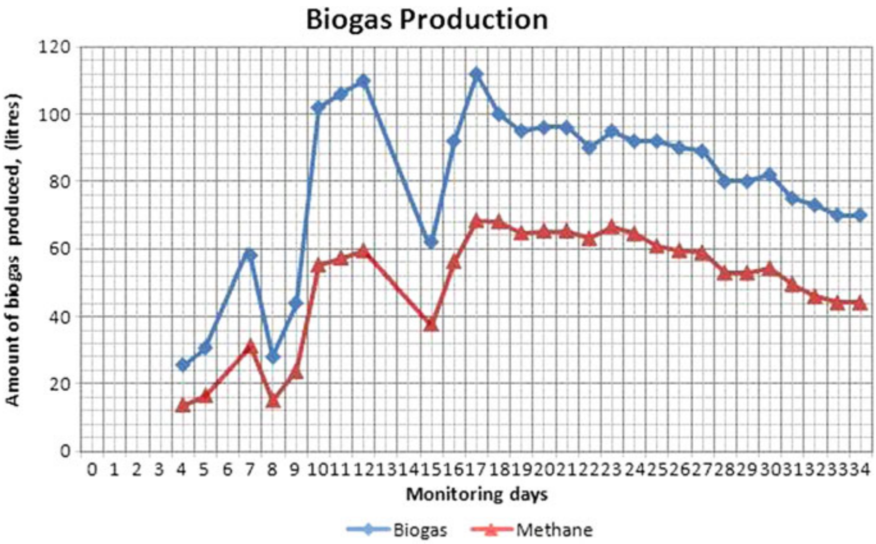

Fig. 37.5 Biogas production through out the project

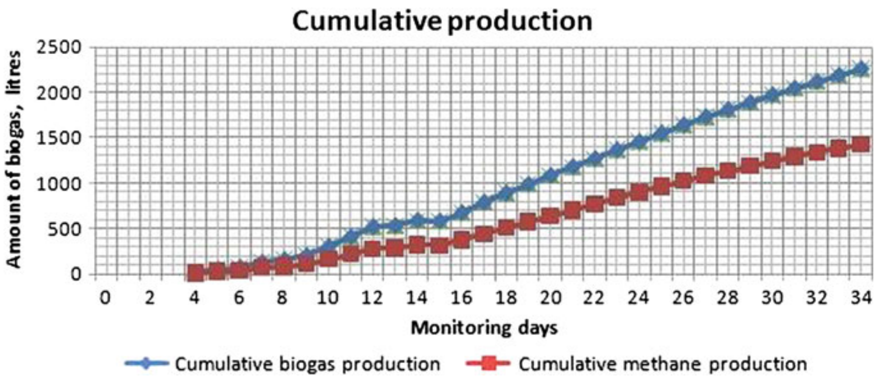

Fig. 37.6 Cumulative production of biogas and methane

As from day 16, the biogas production rate fell indicating exhausting of readily accessible substrate for biogas production as some of the organic substrate in the reactor was already converted to biogas by the methanogenesis bacteria. After that gradual decrease but constant of biogas production was recorded. The second graph indicates the trend of accumulative biogas production for the 34 days retention time. The total amount of methane noted at the end of the 34 days was 2,179 L.

pH and Volatile Fatty Acids Variation

pH is one of the most useful parameter that indicates process stability and proper activities of methanogens in the anaerobic reactor. The accepted pH range for optimal growth of methanogens for anaerobic digestion is between 6.5 and 8.5. The pH of the experimental reactor was carefully monitored every two days for a period of 23 days.

At the start of the process, the composition of the substrate was slightly acidic as the pH in the reactor was below seven during the first 6 days. This was due to the formation of volatile fatty acid and this indicates that the digestion process had undergone the hydrolysis stage and reached the acidogenesis stage. To provide a stable medium for optimal activity of methanogenic bacteria, the digester was mixed well thoroughly thrice a day for days 7 and 8. On day 8 the pH of the reactor was 6.7 and compared to day 6 there was a significant increase in the amount of methane collected. Keeping in mind everyday, the digester was to be manually mixed at least twice a day. The increase in pH and biogas yield, indicate that the methanogenesis phase was taking place inside the reactor. After the pH was more or less constant through out the whole process; indicating a rather stabilized process as shown in Fig. 37.7.

The significance study showed that VFA is generally a good parameter for predicting process instability. In mesophilic conditions, the production of VFA decreased from 522.35 mg/L within 25 days of retention time to 243 mg/L. After 25 days VFA is increased by 24 %; which can be explained due to the increase in pH at that period of time. This also explains the increase in alkalinity within the same period of retention days. Below shows the different graphs of pH and alkalinity trend through out the process (Figs. 37.8 and 37.9).

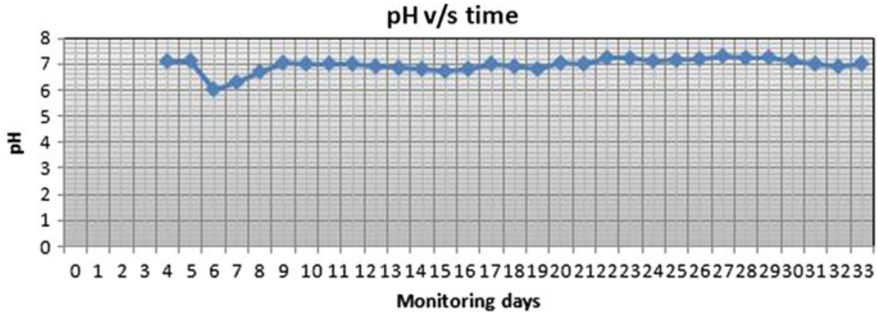

Fig. 37.7 Graph of pH variation with time

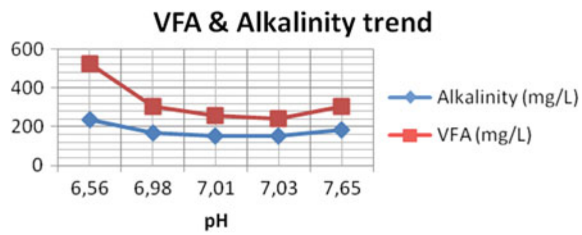

Fig. 37.8 Graph of VFA and alkalinity against pH

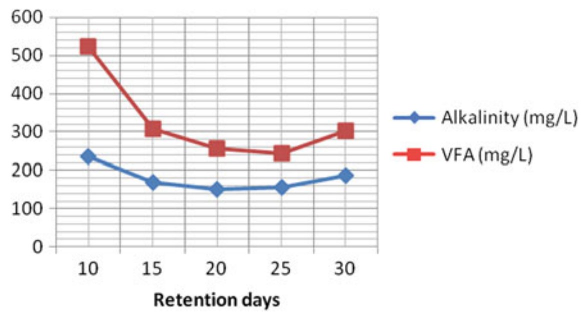

Fig. 37.9 Graph of VFA and alkalinity against retention days

Chemical Oxygen Demand

The chemical oxygen demand was used to measure the degree of decomposition of organic material present in the digester for the experimental period of 23 days. Chemical oxygen demand is a general measure of the amount of soluble organic compounds, which give an indication of the amount of soluble carbon compound that can be converted to methane during the process of anaerobic digestion (Fig. 37.10).

The graph depicts the variation of COD for the experimental period of 35 days. At the beginning of the experiment the COD content of the organic substrate was 78,125 mg/L and a significant decrease was observed during the start–up of the process. On day 5 the value of COD decreased to 64,500 mg/l and this result indicates that 82.56 % of the COD content was removed during the anaerobic reaction. The significant removal of the chemically oxidizable organic compound was due to an increase in the conversion of organic matter into biogas production. The COD of the organic substrate was found to decrease significantly by same percentage of around 80–85 % from day 5 to day 12. There was a larger fall in COD concentration after 16 days of anaerobic digestion. It could mean that there was a higher microbial activity during that period.

From day 22 till day 35, a constant decrease in the COD concentration is observed. On day 35 the COD was recorded to be 9986 mg/L.

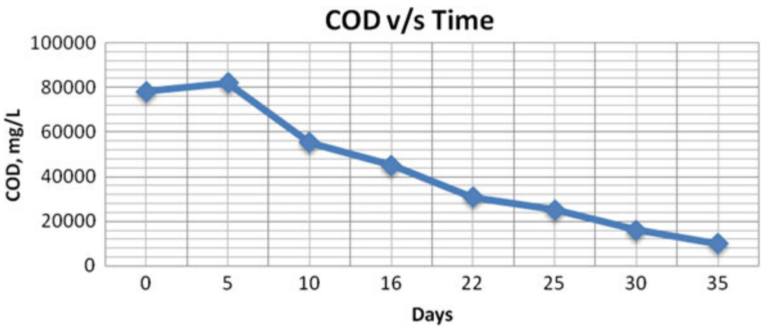

Fig. 37.10 COD variation with time

Total Solids and Volatile Solids

During the process of anaerobic digestion, volatile solids of the organic material in the reactor are degraded to a certain extent and converted to biogas. Volatile solid is an important parameter for measuring the biodegradation of organic substrate, which indirectly indicates the metabolic status of the microbial groups in the anaerobic digester (Elango et al. 2007). The percentage of solid destroyed during anaerobic digestion is a measurement of system performance and the removal efficiency of the organic matter during the process.

The degradation of the organic matter for the experimental period of 23 days is illustrated in the graph of percentage volatile solids and total solids against retention time as shown in Fig.37.11.

It can be observed that volatile solids concentration decreases gradually as the retention time approaches. The total solids reduction and volatile solids destruction are 83.97 and 64.14 % respectively (Fig. 37.11).

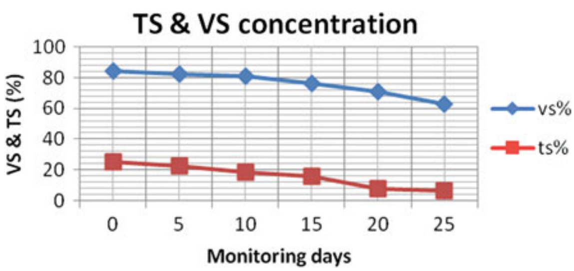

Fig. 37.11 Solid concentration variation with time

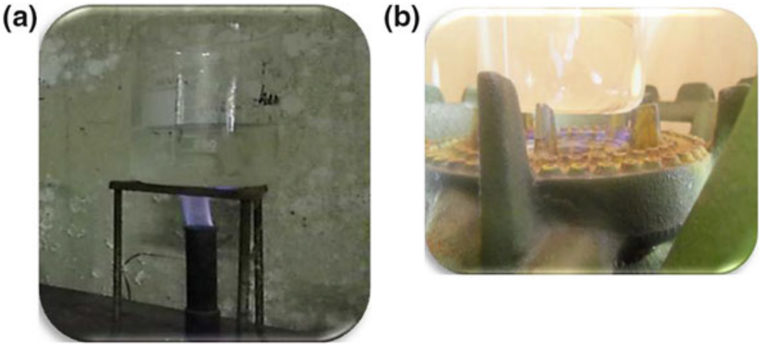

Fig. 37.12 **a** Bunsen burner, **b** Cooking stove

Biogas Combustion

A premixed cooking stove model and Bunsen burner were used to burn the biogas and heat water in a beaker. A blue flame can be observed from the figures below (Fig. 37.12).

On Day 13 and day 14, the biogas was left to build up enough pressure in the digester so as on day 15, it was decided to burn the biogas. This building of pressure was done so as the biogas travel easily in the gas pipes thus giving a nice blue flame.

First, the Bunsen burner was used to combust the biogas. The flame heated the beaker of water for 8 min giving a water temperature difference of 29 °C. Then the gas pipe was connected to the cooking stove which same beaker of water for 30 min giving a temperature difference of 57 °C. Still 62 L of biogas were collected until no more could be obtained.

Based on these values, efficiency of the Bunsen burner and cooking stove were found to be 88.26 and 46.26 % (Table 37.4).

Table 37.4 Temperature change with time

Specifications	LPG	Biogas	
		Bunsen burner	Stove
Initial temperature (°C)	24	29	29
Final temperature (°C)	94	58	86
Temp. difference	70	29	57
Time taken (mins)	17	8	30

Table 37.5 Summary of cost investment

Specification	Cost, Rs
Estimation of total capital investment	
Purchased equipment cost	10,325
Total direct cost	19,101.25
Total indirect cost	3216.00
Fixed capital investment	22,317.25
Working capital	2479.70
Total capital investment	24796.95

Economic Analysis

The economic analysis of the AD project was performed by extrapolating methods, allowing the total capital investment to be found as summarised in the following tables (Table 37.5).

Conclusion

Anaerobic digestion (AD) is a proven technique and technology to treat solid waste to produce methane gas which generates a clean and green energy. AD will offer Mauritius the opportunity to take the lead in sustainable waste and energy management which will contribute in the concept of Maurice Ile Durable (MID) and will help to substitute fossil fuels by renewable resources.

From this investigation it is concluded that source sorted organic fraction of municipal solid wastes can be anaerobic ally digested, producing a biogas containing 60.5 % CH4 at a daily rate of approximately 0.158 L/kgVS. The rate of biogas production observed in the pilot scale digester declined with increasing influent volatile solids concentration and this decline was due to the limited ability of the digester to thoroughly mix the contents and thus avoid the production of scum layer. The mixing capability of the pilot scale digester far exceeded the mixing ability of commonly designed sludge digesters, indicating that new developments in digester mixing are needed for successful digestion of animal wastes.

In this study, pilot scale anaerobic digestion of cow dung was conducted. A 1m3 anaerobic reactor was designed and operated under semi-continuous mode during first 10 days and for the remaining days on batch mode. An attempt to optimize the process was done by constructing an Archimedes's screw type mixer together with a three-bladed propeller attached to the end of the mixing unit. The following conclusions can be drawn from this study.

An effective start-up of the anaerobic digestion with inoculum and substrate acclimatization was done successfully. A constant temperature from mesophilic condition was observed per day reaching a condition of room temperature which was found satisfactory. A volatile solid reduction of 59.39 % was obtained during the process and the pH was more or less stable lying in the range 6–8.

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Chapter 38
Efficiency Optimisation of Three-Phase Induction Motor Using Swarm Intelligence

M. Asraf Ally Jubokawa and Robert T. F. Ah King

Abstract Renewable energy is becoming more and more important with the current environmental issues. Many research projects are being conducted to implement the renewable technologies mainly in developing countries and small island developing states. Another way of reducing the environmental impact is to increase efficiency at the energy utilization end. More than half of the world's electrical energy generated is consumed by electric machines. Thus, improving the efficiency in electrical drives brings along two benefits as economic saving and reduction of environmental pollution. Efficiency optimisation of three-phase induction motor can be achieved through optimal control and design techniques. Optimal control is more practical because the motor efficiency cannot be improved for every operating point by optimising machine design. A three-phase induction motor can be controlled via indirect field orientation which offers an improvement in the dynamic response of the system. However, it is observed that in many applications, the field orientation operate under constant flux for different amount of load torque and this reduces the efficiency of this control scheme. In this study, a loss model equation is developed for the three-phase induction motor to establish the relationship between the rotor flux and total electrical losses. Imperialist Competitive Algorithm (ICA) is compared to Particle Swarm Optimisation (PSO) to evaluate the optimal rotor flux that minimizes the motor losses at specific load torques. Simulation results show the effectiveness of using field orientation control with swarm intelligence and the superiority of ICA over PSO.

Keywords Energy efficiency · Optimization · Induction motor · Motor losses

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
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Short Introduction

It is well known that more than half of the world's electrical energy is consumed by electric machines. For that reason, improving the efficiency in electrical drives could bring two important benefits: economic savings and reduction of environmental pollution. Efficiency optimisation of three-phase induction motor can be achieved through optimal control and design techniques. In this study, a loss model equation is developed for the three-phase induction motor to establish the relationship between the rotor flux and total electrical losses. Simulation results show the effectiveness of using field orientation control with swarm intelligence and the superiority of Imperialist Competitive Algorithm over Particle Swarm Optimisation.

Introduction

In order to reduce electrical energy consumption, the efficiency of utilization can be increased. This means can reduce the burden on renewable energy production as electrical energy demand keeps increasing. The induction motor is widely used in industrial practice since they are more rugged, require less maintenance and are less costly than their counterpart, the dc motor. The wide range of motor ratings available coupled with advancement in torque and speed control technologies have further contributed to its success (Hubert 1991). Achieving energy efficient control is important in the induction motor. It is estimated that more than around 50 % of the world electric energy generated is consumed by electric machines and so improving efficiency in electric drives is important (Kim 2007). That is mainly, for two reasons: economic saving and reduction of environmental pollution (Kim 2007).

A lot of developments have been made in the field of efficiency optimisation of three-phase induction motor through optimal control and design techniques. Optimal control is more important because the motor efficiency cannot be improved for every operating point by optimising machine design (Thanga Raj et al. 2009).

In many applications of constant speed operation, the induction motor operates under partial load for long periods such as mine hoist load (Thanga Raj et al. 2009) and spinning drive in textile industry. In these applications making the induction motor to operate at reduced flux is important so as to maintain a balance between iron (core) and copper losses.

In this paper a loss model controller (LMC) is developed for the three-phase induction motor based on the two-phase controller described in (Amin et al. 2009). Then for different load torque the value of optimal flux is determined by using swarm intelligence.

Modelling the Induction Motor

The dynamic model of an induction motor considers transients that occur during load variations and frequency changes. This model of induction motor also considers the instantaneous effects of variations in voltage, current, stator frequency, torque disturbances (Krishnan 2001).

Normally the direct-quadrature transformation is used to model the induction motor so as to obtain constant inductance matrix terms (Krishnan 2001). The relationship between abc parameters and qd0 parameters is as follows (Ong 1998):

$$\begin{bmatrix} f_q \\ f_d \\ f_0 \end{bmatrix} = \left[T_{qd0}(\theta)\right] \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} \tag{38.1}$$

where f can represent the phase voltages, current or flux linkages and

$$\left[T_{qd0}(\theta)\right] = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \tag{38.2}$$

The voltage flux equations (Ong 1998) in arbitrary frame (ω) is given by

Stator Voltages

$$V_{qs} = R_s I_{qs} + p\lambda_{qs} + \omega\lambda_{ds} \tag{38.3}$$

$$V_{ds} = R_s I_{ds} + p\lambda_{ds} - \omega\lambda_{qs} \tag{38.4}$$

$$V_{0s} = R_s I_{0s} + p\lambda_{0s} \tag{38.5}$$

Rotor voltages

$$V_{qr} = R_r I_{dr} + p\lambda_{dr} + (\omega - \omega_r)\lambda_{qr} = 0 \tag{38.6}$$

$$V_{dr} = R_r I_{dr} + p\lambda_{qr} - (\omega - \omega_r)\lambda_{dr} = 0 \tag{38.7}$$

$$V_{0r} = R_s I_{0r} + p\lambda_{0r} = 0 \tag{38.8}$$

Stator flux

$$\lambda_{qs} = L_s I_{qs} + L_m I_{qr} \tag{38.9}$$

$$\lambda_{ds} = L_s I_{ds} + L_m I_{dr} \tag{38.10}$$

$$\lambda_0 = L_0 I_{0s} \tag{38.11}$$

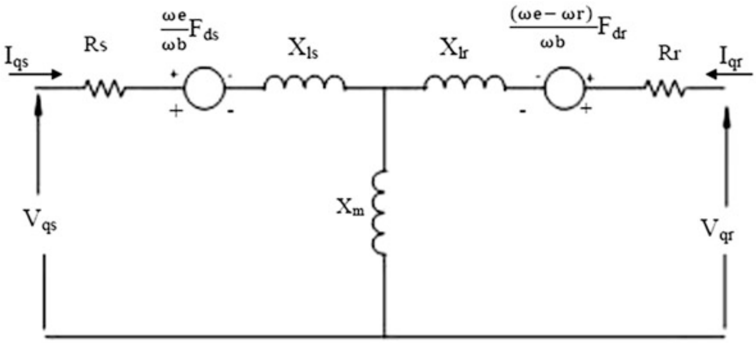

Fig. 38.1 Q-axis of induction motor

Rotor flux

$$\lambda_{qr} = L_m I_{qs} + L_r I_{qr} \tag{38.12}$$

$$\lambda_{dr} = L_m I_{ds} + L_r I_{dr} \tag{38.13}$$

$$\lambda_{0r} = L_0 I_{0r} \tag{38.14}$$

The torque equation of the motor is

$$T_e = \frac{3}{2}\frac{P}{2}\left[\lambda_{ds} I_{qs} - \lambda_{qs} I_{ds}\right] \tag{38.15}$$

In terms of base quantities

$$F = \omega_b \lambda \tag{38.16}$$

$$X = \omega_b L \tag{38.17}$$

The final circuit of the three-phase balanced induction motor in the synchronous frame where $\omega = \omega_e$ are given in Figs. 38.1 and 38.2.

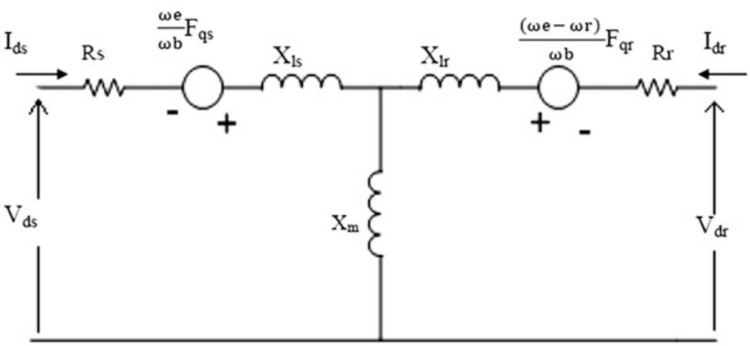

Fig. 38.2 D-axis of induction motor

Simulink Model of the Induction Motor

The three-phase induction motor can be simulated via Simulink using Krause model (Krause et al. 2002). The equations describing this model are as follows:

$$I_{qs} = \frac{1}{X_{ls}}(F_{qs} - F_{mq}) \tag{38.18}$$

$$I_{ds} = \frac{1}{X_{ls}}(F_{ds} - F_{md}) \tag{38.19}$$

$$I_{qr} = \frac{1}{X_{lr}}(F_{qr} - F_{mq}) \tag{38.20}$$

$$I_{dr} = \frac{1}{X_{lr}}(F_{dr} - F_{md}) \tag{38.21}$$

where F_{mq} is the q-axis saturation and is given by

$$F_{mq} = X_m(I_{qs} + I_{qr}) \tag{38.22}$$

F_{md} is the d-axis saturation and is given by

$$F_{md} = X_m(I_{ds} + I_{dr}) \tag{38.23}$$

Equations (38.18–38.21) are then substituted in Eqs. (38.22) and (38.23) as well as in the voltage equations (base form) Eqs. (38.3), (38.4), (38.6) and (38.7) in order to eliminate the current terms. The resulting voltage equations are then solved for flux linkages per second. The equations are as follows.

$$F_{qs} = \omega_b \int \left[V_{qs} - \frac{\omega_e}{\omega_b} F_{ds} + \frac{R_s}{X_{ls}}(F_{mq} + F_{qs}) \right] dt \tag{38.24}$$

$$F_{ds} = \omega_b \int \left[V_{ds} + \frac{\omega_e}{\omega_b} F_{ds} + \frac{R_s}{X_{ls}}(F_{md} + F_{ds}) \right] dt \tag{38.25}$$

$$F_{qr} = \omega_b \int \left[V_{qr} - \frac{(\omega_e - \omega_r)}{\omega_b} F_{dr} + \frac{R_r}{X_{lr}}(F_{mq} - F_{qr}) \right] dt \tag{38.26}$$

$$F_{dr} = \omega_b \int \left[V_{dr} + \frac{(\omega_e - \omega_r)}{\omega_b} F_{qr} + \frac{R_r}{X_{lr}}(F_{md} - F_{dr}) \right] dt \tag{38.27}$$

Equations (38.22) and (38.23) can be expressed as

$$F_{mq} = X_{ms}\left[\frac{F_{qs}}{X_{ls}} + \frac{F_{qr}}{X_{lr}}\right] \tag{38.28}$$

$$F_{md} = X_{ms}\left[\frac{F_{ds}}{X_{ls}} + \frac{F_{dr}}{X_{lr}}\right] \tag{38.29}$$

where

$$X_{ms} = \left(\frac{1}{X_m} + \frac{1}{X_{ls}} + \frac{1}{X_{lr}}\right)^{-1} \tag{38.30}$$

$$T_e = \frac{3}{2}\frac{P}{2\omega_b}\left[F_{ds}I_{qs} - F_{qs}I_{ds}\right] \tag{38.31}$$

$$\omega_r = \int\left(\frac{P}{2J}\right)(Te - T_L)dt \tag{38.32}$$

These equations are then implemented in Simulink as described in (Ozpineci and Tolbert 2003).

Indirect Field Oriented Control

Field oriented control (FOC) is basically a software algorithm that utilises the position of the rotor combined with two-phase currents to generate a means of instantaneously controlling the torque and flux. Field-orientated controllers control both the magnitude and phase of the AC quantities and are thus referred to as vector controllers. FOC produces controlled results that have a better dynamic response to torque variations in a wider speed range compared to other scalar methods (Roberts 2001).

The Indirect FOC (IFOC) scheme requires as input the rotor speed, the d axis rotor flux and the desired operating speed. From these data the required control currents are generated.

Some equations derived for rotor flux orientation (Ong 1998) are as follows:

$$I_{qr} = -\frac{L_m}{L_r}I_{qs} \tag{38.33}$$

$$\lambda_{dr} = L_m I_{ds} \tag{38.34}$$

$$I_{ds} = \frac{R_r + pL_r}{R_r L_m}\lambda_{dr} \tag{38.35}$$

$$I_{qs} = \frac{4T_{em}L_r}{3PL_m\lambda_{dr}} \tag{38.36}$$

$$\omega_{sl} = \frac{R_r L_m I_{qs}}{L_r \lambda_{dr}} \tag{38.37}$$

The value of ω_{sl} is integrated to find the slip angle, θ_{sl}.

$$\theta_{sl} = \int \omega_{sl} \tag{38.38}$$

The synchronous angle θ_e is found by adding θ_{sl} with θ_r.

$$\theta_e = \theta_r + \theta_{sl} \tag{38.39}$$

where

$$\theta_r = \int \omega_r = \text{ rotor angle} \tag{38.40}$$

From these equations the control scheme is implemented in Simulink.

Hysteresis Current Controller

In order to generate the pulses to drive the voltage inverter, hysteresis modulation (HM) is used. Hysteresis modulation is a feedback current control method where the motor current tracks the reference current within a hysteresis band. The IFOC generates sinusoidal reference currents of desired magnitude and frequency that is compared with the actual motor line current (Simulating an AC Motor Drive 2008).

The DC-to-AC Voltage Inverter

A voltage inverter receives dc voltage at the input and converts it to ac at appropriate frequency and voltage. Fig. 38.3 shows a three-phase inverter circuit with the switches in each diode (Lange 1996).

Depending on the state of the switches, the output of the inverter in the phase A, B and C will change. The switches are controlled from the output of the hysteresis current controller.

Loss Model Controller

In this section, a formula to determine the losses of the three-phase induction motor from the speed, torque, flux and other motor parameters is derived.

The equation for a three-phase system is derived in a similar way to the two-phase system in reference (Amin and Hegazy 2006). However, the formula has been adapted to a three-phase balanced system.

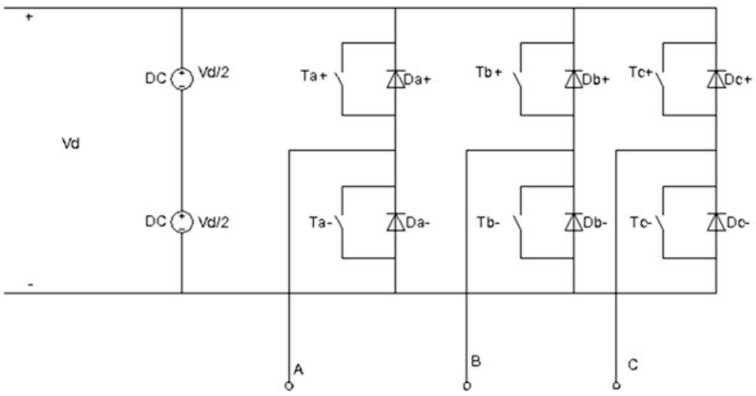

Fig. 38.3 Three-phase inverter circuit

From reference (Amin and Hegazy 2006):
The d axis magnetising voltage:

$$V_{dm} = \frac{\omega_e L_{rl} L_m}{L_r} I_{qs} \tag{38.41}$$

The q axis magnetising voltage:

$$V_{qm} = \omega_e L_m I_{ds} \tag{38.42}$$

Total losses of the induction motor are stator copper losses, rotor copper losses and core losses.

The total electrical loss formula can written as follows

$$P_{losses} = \underbrace{R_s I_{qs}^2 + R_s I_{ds}^2}_{\text{Stator losses}} + \underbrace{R_r I_{qr}^2 + R_r I_{dr}^2}_{\text{Rotor losses}} + \underbrace{\frac{V_{qm}^2}{R_c} + \frac{V_{dm}^2}{R_c}}_{\text{core losses}} \tag{38.43}$$

When using field-oriented control, $I_{dr} = 0$
Using Eqs. (38.33, 38.34) and (38.36)

$$I_{qs} = \frac{4T_{em} L_r}{3PL_m \lambda_{dr}} \tag{38.44}$$

$$I_{qr} = -\frac{L_m}{L_r} I_{qs} = -\frac{L_m}{L_r} \frac{4T_{em} L_r}{3PL_m \lambda_{dr}} \tag{38.45}$$

$$I_{ds} = \frac{\lambda_{dr}}{L_m} \tag{38.46}$$

Equations (38.41, 38.42), (38.44–38.46) are substituted in Eq. (38.43) and the resulting equation is simplified as follows:

$$P_{losses} = \frac{16}{9} R_s \left[\frac{T_{em} L_r}{P L_m \lambda_{dr}}\right]^2 + R_s \left[\frac{\lambda_{dr}}{L_m}\right]^2 + \frac{16}{9} R_r \left[\frac{L_m}{L_r} \frac{T_{em} L_r}{P L_m \lambda_{dr}}\right]^2 + \frac{16}{9 R_c} \left[\frac{\omega_e L_m L_{rl} T_{em} L_r}{L_r P L_m \lambda_{dr}}\right]^2 + \frac{[\omega_e L_m]^2}{Rc} \left[\frac{\lambda_{dr}}{L_m}\right]^2 \tag{38.47}$$

Simplifying,

$$P_{losses} = \frac{16}{9} \left[R_s + R_r \frac{L_m^2}{L_r^2} + \frac{\omega_e^2 L_m^2 L_{rl}^2}{R_c L_r^2}\right] \left[\frac{T_{em} L_r}{P L_m \lambda_{dr}}\right]^2 + \left[R_s + \frac{[\omega_e L_m]^2}{Rc}\right] \left[\frac{\lambda_{dr}}{L_m}\right]^2 \tag{38.48}$$

where

$$\omega_e = \omega_r + \omega_{sl} \tag{38.49}$$

$$\omega_{sl} = \frac{4 R_r T_{em}}{3 P \lambda_{dr}^2} \tag{38.50}$$

Efficiency (n) is given by

$$n = \frac{P_{out}}{P_{out} + P_{losses}} \tag{38.51}$$

where P_{out} is the output power of the induction motor:

$$P_{out} = T_e * \omega_r \tag{38.52}$$

In the above equations T_e represent the applied load torque and ω_r the rotor speed. By replacing these values together with the machine parameters in Eq. (38.48) the optimum value of the d-axis rotor flux, λ_{dr}, can be searched by using nature inspired algorithms like ICA and PSO. The value of λ_{dr} is optimum when the sum of copper and core losses is a minimum as shown in Fig. 38.4.

Imperialist Competitive Algorithm

Imperialism is the policy of extending the power of a government beyond its boundaries. The state may try to dominate others by direct rule or by control over market goods. Briefly, imperialism can be described as a political control over other countries in order to exploit their resources. Imperialist states compete with each other to increase their colonies and to spread their empire over the world and this competition results in the development of powerful empires and collapse of weaker ones. Imperialist states have also the tendency to assimilate colonies they have conquered by spreading their culture with the natives of the colony.

Imperialist Competitive Algorithm (ICA) (Atashpaz-Gargari and Lucas 2007) is modelled by an initial population of countries. Some of the countries in the population are selected to be the imperialist and the rest form the colonies of these

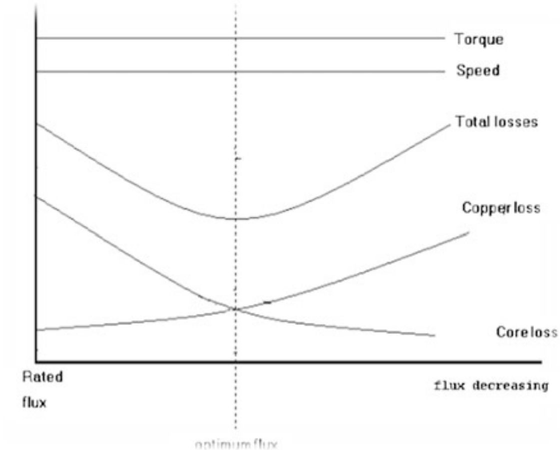

Fig. 38.4 Losses variation of the motor with varying flux (Lange 1996)

imperialists. The distribution of colonies is based on the power of the imperialist country and the power of an imperialist is inversely proportional to its cost. That is, if an imperialist has a lower value of the cost function then it is more powerful and will have a larger share of colonies. After the distribution of colonies among imperialists, colonies start to move in search space towards their relevant empire state. The total power of an empire depends on both the power of the imperialist country and the power of its colonies.

Any empire that cannot increase its power (or prevent it from decreasing) in imperialistic competition is eliminated. This competition will gradually increase the power of powerful empires and decrease the power of weaker ones. If a colony has more power than an imperialist then the relevant imperialist swap position with this colony. The movement of colonies and position swapping towards their relevant imperialist and the collapse mechanism will cause all countries to converge to a state where there is just one empire in the world and all other countries are its colonies. The minimum cost function can then be extracted from the most powerful empire (Atashpaz-Gargari and Lucas 2007).

Modelling Imperialist Competitive Algorithm

Based on reference (Atashpaz-Gargari and Lucas 2007), the countries in ICA are modelled by an array as follows:

$$\text{Country} = [P_1,\ P_2,\ P_3 \ldots P_{Nvar}]$$

where N_{var} = dimensional optimisation problem

A country is $1{*}N_{var}$ array.

Cost

The cost of a country is found by evaluating the cost function f at the variables [P_1, P_2, $P_3 ... P_{Nvar}$]

$$\text{Cost} = f\ (\text{country}) = f(P_1,\ P_2,\ P_3 \ldots P_{Nvar})$$

Population

The initial population size is N_{pop} and the most powerful empires population is N_{imp}. The remaining population is N_{col} representing the colonies.

The colonies are divided amongst the empires based on their power. The normalised cost of the imperialist is defined by

$$C_{n+1} = C_n + \max_i\{C_i\}$$

C_i is the cost of the ith imperialist
C_n is the cost of nth imperialist
C_{n+1} is the normalised cost
The normalised power of each imperialist, P_n, is given by

$$P_n = \left| \frac{C_n}{\sum_{i=1}^{N_{imp}} C_i} \right| \tag{38.53}$$

The initial number of colonies an empire will have is NC_n where

$$NC_n = \text{round}\ (Pn^*Ncol)$$

The value of (Pn*Ncol) is rounded because population cannot have decimal values.

Movement of the Colonies of an Empire Toward the Imperialist

The colony then moves towards the empire by X units. X is a random variable with uniform distribution. The variable X is a function of the distance between the colony and the empire and β. Normally β is a constant greater than 1.

While moving toward the imperialist, a colony might reach a position that has a lower cost than the imperialist. In such a case the imperialist change position with the empire.

Total Power of an Empire

The total power of an empire is determined mainly by the power of the empire itself and to a small extent by the power of the colonies. The total cost TC is given by:

$$\mathrm{TC} = \mathrm{Cost}\ (\mathrm{imperialist}) + \mu^{*}\mathrm{mean}\ \{\mathrm{cost}\ (\mathrm{colonies\ of\ empire})\}$$

where $\mu = 0.1$

Imperialistic Competition

This competition is modelled by picking some of the weakest colonies in the weakest empires and making a competition among the powerful empires to possess these colonies. The model is developed as follows:

$$\mathrm{NTC_n} = \mathrm{TC_n} - \max_i\{\mathrm{TC_i}\}$$

where $\mathrm{NTC_n}$: normalised total cost of the nth empire.

The possession probability of the nth empire is given by $\mathrm{PP_n}$

$$\mathrm{PP_n} = \left| \frac{\mathrm{NTC_n}}{\sum_{i=1}^{N_{imp}} \mathrm{NTC_i}} \right| \tag{38.54}$$

The colonies are divided among empires with greater values of D, where D is a vector defined as follows:

$$\mathrm{D} = \mathrm{PP} - \mathrm{R} \tag{38.55}$$

where

$$\mathrm{PP} = \left[\mathrm{PP_1},\ \mathrm{PP_2}, \mathrm{PP_3}, \mathrm{PP_4} \ldots,\ \mathrm{PP_{Nimp}}\right] \tag{38.56}$$

$$\mathrm{R} = \left[\mathrm{R1},\ \mathrm{R2},\ \mathrm{R3}, \mathrm{R4},\ \mathrm{R5} \ldots,\ \mathrm{R_{Nimp}}\right] \tag{38.57}$$

R1, R2…$\mathrm{R_{Nimp}}$ are random numbers between 0 and 1.

Collapse of an Empire and Convergence

Once an empire has no colonies it will collapse. After some time all the colonies will be under control of one unique empire and ideally they will have the same cost and position as the imperialist itself. In such a condition the imperialistic competition stops and the final optimum cost can be retrieved from the algorithm.

Figure 38.5 demonstrate the operation of ICA.

Results and Discussion

The model developed is simulated and the following results were obtained.

The equation derived in section Hysteresis Current Controller is plotted for a range of λ_{dr} from 0.1 to 8 and a torque of 0.5 pu. The graph obtained is shown in Fig. 38.6.

The parameters required are substituted in the formula and the optimum flux is calculated for load torques of 0.25, 0.5, 0.75 and 1 pu respectively. The parameters of the Imperialist competitive algorithm are (Number of Countries = 200; Number of Initial Imperialists = 8; Number of decades or iterations = 30; Revolution Rate = 0.3; Assimilation Coefficient = 2; Assimilation Angle Coefficient = 0.5; Zeta = 0.02; Damp Ratio = 0.99; Uniting Threshold = 0.02). For comparison, the simulation results are also presented for a Particle Swarm Optimisation algorithm (PSO) (Liu et al. 2008) with the following parameters (Iterations = 30; Inertia = 1.0; Correction factor = 1.44; Swarm size = 64).

Figures 38.7 and 38.8 show for ICA and PSO respectively how the swarm moves in the search space to look for the value of flux that will give the minimum loss for a load torque of 0.5 pu.

The minimum power loss is found to be 339.4 kW occurring at a flux of 1.4333.

Table 38.1 summarises the minimum losses and optimum flux for several load torques.

It can be concluded that Imperialist competitive algorithm is faster and more consistent than PSO. This is shown in Fig. 38.7 whereby the optimum solution has already been reached within 5 iterations whereas PSO takes more than 20 iterations (Fig. 38.8). Furthermore there is no need to adjust the parameters of ICA as opposed to PSO in order to cause the algorithm to converge to the local optima. Hence, ICA is more consistent than PSO in finding the optima in different simulation runs.

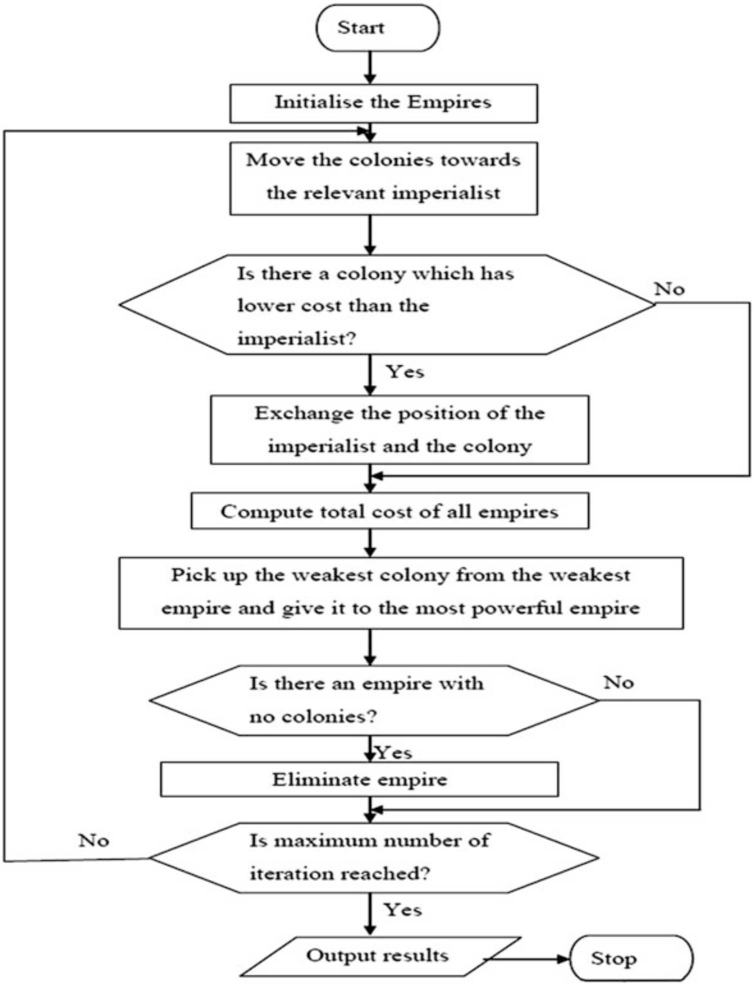

Fig. 38.5 Flow chart demonstrating operation of ICA

The optimum flux is fed into the IFOC block and the results obtained are shown in Table 38.2. The formula derived in section Hysteresis Current Controller for efficiency is used to determine the efficiency of the motor at various level of flux.

As can be seen from Table 38.2, running the motor with rated flux at reduced torque is not optimum. Up to 5 % of energy can be saved at a load torque of 0.25 pu using this method.

Figures 38.9 and 38.10 shows respectively the stator currents of the motor without optimum flux and with optimum flux for a load torque of 0.25 pu. Without optimum flux, stator current is about 60 A whereas with optimum flux, stator current is reduced to about 31 A when the load torque of 0.25 pu is applied at 2 s.

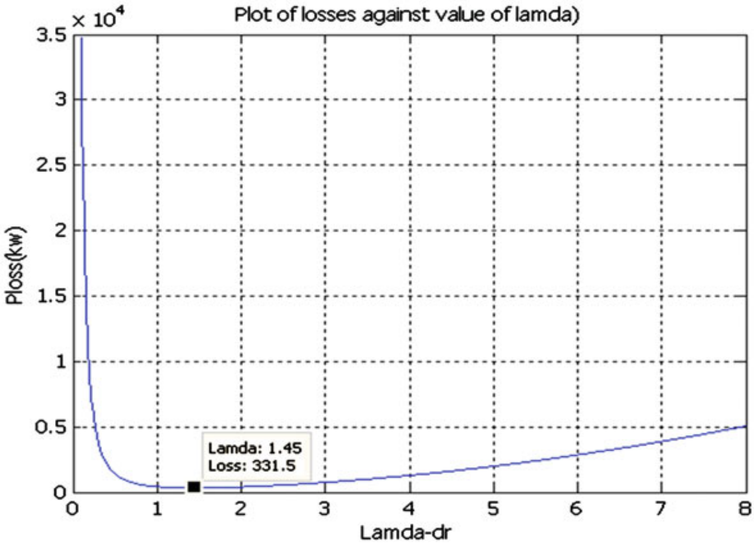

Fig. 38.6 Losses variation with variation in λ_{dr}

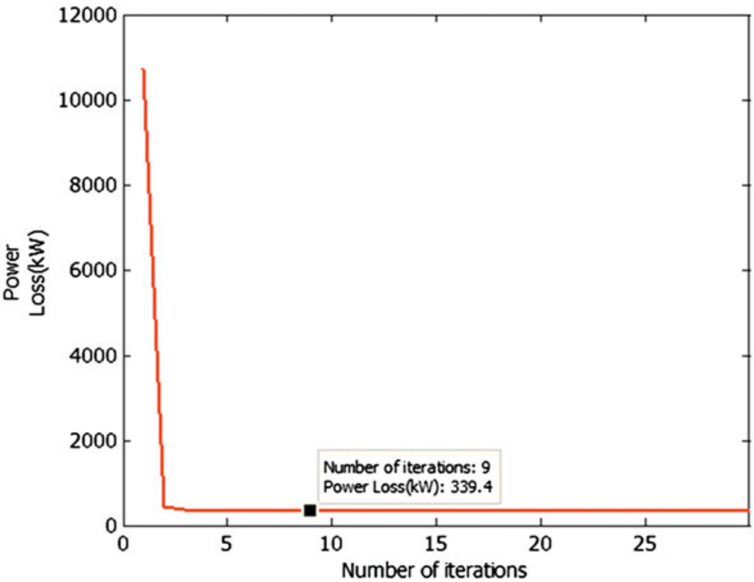

Fig. 38.7 Best position of imperialist against decades or number of iterations

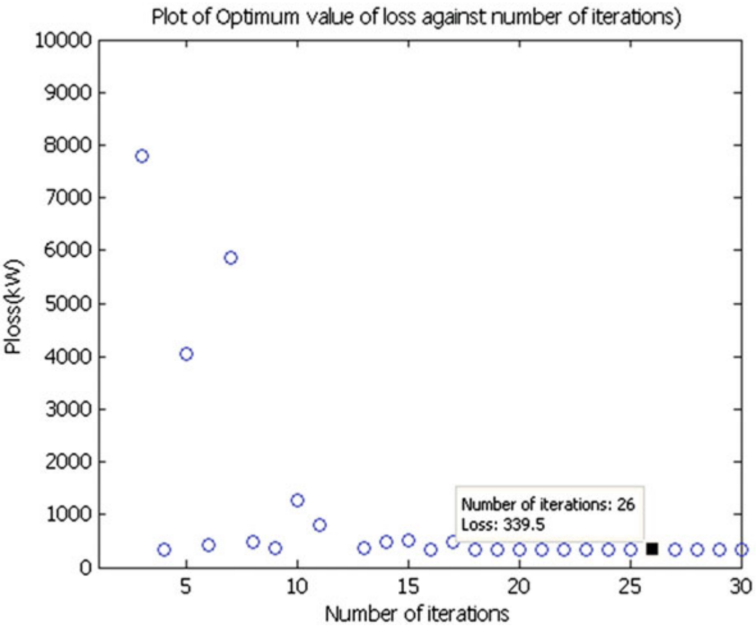

Fig. 38.8 Best swarm position against number of iterations

Table 38.1 Losses and optimum flux for different load torque with ICA and PSO

Load torque (pu)	Losses (kW)	Optimum flux (Wb) ICA	Optimum flux (Wb) PSO
0.25	169.7	1.0135	1.0050
0.5	339.4	1.4333	1.4346
0.75	509.2	1.7554	1.7554
1	678.9	2.0269	2.0261

Table 38.2 Comparison of efficiency with and without optimum flux

Load torque (pu)	Efficiency without optimum flux	Efficiency with optimum flux
0.25	0.8798	0.9371
0.5	0.9246	0.9371
0.75	0.9354	0.9371
1	0.9370	0.9371

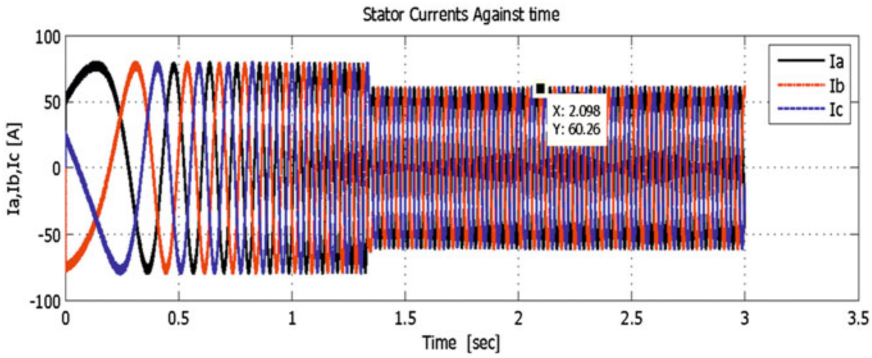

Fig. 38.9 Stator currents without optimum flux

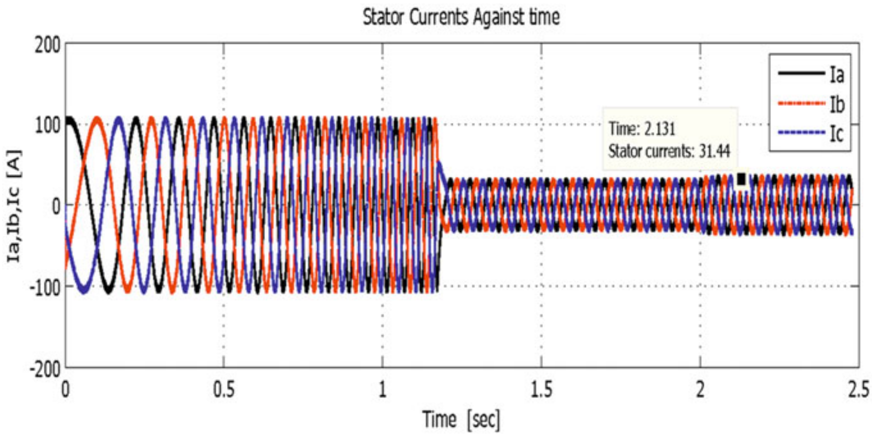

Fig. 38.10 Stator currents of the motor with optimum flux

Conclusion

The proposed LMC scheme for the three-phase system effectively improves the efficiency of the motor at small amount of applied torque by finding the optimum flux. This was demonstrated by the reduction in the stator current which in turn reduces the copper and core losses. The torque and speed being produced by the motor stills remains the same. Simulation results show that ICA has faster convergence and is more consistent than PSO in finding the optimum flux.

The proposed FOC based on LMC with ICA would mean a little added cost to the controller. This cost will be for an extra memory integrated chip (IC) to hold the look up table (LUT) where the pre-calculated optimal operating points are stored (Amin et al. 2009).

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Chapter 39
Energy Use in Manufacturing Industries Evidence from Sweden

Clara Inés Pardo Martínez and Semida Silveira

Abstract This study analyses energy use and CO_2 emissions in the Swedish manufacturing industries between 1993 and 2008. The performance of this sector is studied in terms of CO_2 emissions, energy consumption, energy intensity, energy sources, energy prices and taxes. The results show that energy consumption, energy intensity and CO_2 emission intensity have reduced significantly. The decomposition analysis evidenced that decrease in the aggregate energy intensity and the aggregate CO_2 emission intensity was caused by a decrease of energy intensity and substitution fuels. The factors that have influenced the results in energy intensity and CO_2 emission intensity in Swedish manufacturing industries have been mainly the increase of energy price, energy taxes, investments and inter-fuel substitution.

Keywords Small developing island · Renewable energy knowledge · Technology transfer

Short Introduction

The growing population, industrialization and increasing standard of living and quality of life across the globe have substantially increased our dependence on energy. This study analyses energy use and CO_2 emissions in the Swedish manufacturing industries between 1993 and 2008, where the results show that energy consumption, energy intensity and CO_2 emission intensity have reduced significantly. The decomposition analysis evidenced that decrease in the aggregate energy intensity and the aggregate CO_2 emission intensity was caused by a

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_39,

decrease of energy intensity and substitution fuels and the factors that influenced have been mainly increase of energy price, energy taxes, investments and inter-fuel substitution.

Introduction

Energy is a basic factor for production in the manufacturing industry. The growing population, industrialization and increasing standard of living and quality of life across the globe have substantially increased our dependence on energy. As a result, the development of conventional energy resources, the search for new or renewable energy sources, energy conservation (using less energy), energy efficiency (having the same service or output with less energy usage) and decreasing CO_2 emissions have become unavoidable topics in global politics.

However, to improve the analysis, design and evaluation of adequate energy polices, it is necessary to achieve a better understanding of the trends in energy use, energy efficiency and CO_2 emissions while considering the factors that could determine these trends. Gaining this understanding implies obtaining detailed data at various aggregation levels to apply suitable indicators and using models and methods that generate reliable and consistent information (International Energy Agency 2008a). This paper describes the trends in energy consumption and CO_2 emissions in Swedish manufacturing industries between 1993 and 2008 and analyses several factors that have influenced these trends such as investments, inter-fuel substitution, energy price and energy taxes as a starting point for broader analysis.

Researchers in many fields have used various approaches to measure energy efficiency in the industrial sector with the aim of determining the specific effects of energy policies, new technologies or energy prices on energy efficiency changes and improvements, among other things. Decomposition analysis has been widely used in several studies to decompose the energy consumption and to aggregate energy intensity or CO_2 emissions into the change in intensities at the disaggregated sectoral level and the impact of changes in structural composition of the industrial sector (Ang and Zhang 2000; Asia Pacific Energy Research Centre 2000; Choi and Ang 2003). For example, (Reddy and Ray 2010), in the context of Indian manufacturing industries, showed that improvements in energy efficiency are primarily achieved by structural changes. Weber (2009) analysed energy use in the US and found that improvements in energy efficiency were caused principally by structural changes in the economy. Diakoulaki and Mandaraka (2007) studied EU manufacturing industries with an emphasis on CO_2 emissions and found relevant progress in the decoupling of the growth in manufacturing industries and carbon emissions.

The studies on energy efficiency and CO_2 emissions in Sweden have included a variety of topics.

(a) Löfgren and Muller (2010), Kander and Lindmark (2006) applied decomposition analyses to energy consumption and CO_2 emissions, demonstrating that fuel substitution, improvement in the energy system and processes and changes in consumption patterns have led to the decrease in CO_2 emissions in Sweden.
(b) Sandberg and Söderström (2003), Svensson and Berntsson (2010) analysed the relationship between investments, CO_2 emissions and energy efficiency; additionally, they demonstrated that CO_2 emissions and energy efficiency influence investment decisions in Swedish industries.
(c) Henriksson and Söderholm (2009), Linden and Carlsson-Kanyama (2002) studied energy policy and its effects on improvements in energy efficiency and identified several strategies such as energy prices, carbon and energy taxes, voluntary agreements, the application of energy management systems, audits and incentives for emission reductions facilitated by fuel substitutions.
(d) Other studies have analysed barriers to the implementation of energy efficiency measures and the effects of some energy programs on small and medium-sized enterprises (Thollander et al. 2007).

However, despite the important results of the previous analyses, these studies have not assessed the specific effects of energy efficiency on energy consumption and CO_2 emissions over time, nor have they analysed other variables that could determine the trends of these variables. Therefore, the main contribution of this study is an analysis of the role of energy efficiency in the trends in energy use and CO_2 emissions in the Swedish manufacturing industries that have demonstrated important improvements in energy efficiency, which should allow for the establishment of adequate strategies in the design of effective energy policy.

The results of this study show that Swedish manufacturing industries improved their energy efficiency during the sample period and that output growth has not required higher energy consumption. This led to a decrease in CO_2 emission intensity. The factors that influenced these results were mainly the increase in energy prices, energy taxes, investments and inter-fuel substitution, indicating the importance of a suitable energy policy that strengthens sustainable development in this industrial sector.

The remainder of this paper is organised as follows: third section describes the Methods and Data used in this study; section Results and Discussion the results are shown and discussed; the Conclusions are stated in last section.

Methods and Data

In this analysis, energy and CO_2 emission intensity are defined as the energy used or CO_2 emissions generated per unit of economic production, respectively. In this study, value added is used to measure economic production to analyse trends in these indicators for Swedish manufacturing industries. Moreover, we use decomposition analysis at the manufacturing industry level to estimate and evaluate energy use and CO_2 emissions. This method examines several factors, such as the activity, structure, energy intensity and energy carbon index, which have influenced the trends in energy use and CO_2 emissions with respect to production value. This technique involves the division and decomposition of energy and emissions in the explanatory variables from aggregate data (Ang and Zhang 2000; Asia Pacific Energy Research Centre 2000).

The technique applied is the Multiplicative Log-Mean Divisia Method explained by Ang and Liu (2001), which allows an adequate decomposition at different levels of aggregation. This method is used to determine the effects of a structural change in manufacturing industrial production on total energy consumption, which can establish several causes of a change in energy use in this sector.

Two approaches are used in this analysis: energy intensity and CO_2 emissions. The relative changes *(L)* are explained using the log percentage change where $Ln(x,y)$ is the logarithmic mean of two positive numbers, i.e., $L = Ln(x,y) = (y - x)/Ln(y/x)$ (Tornqvist and Vartia 1985). These two approaches are:

The energy intensity method: In this approach, the total change in aggregate energy intensity is decomposed into a structural effect (S) representing manufacturing industrial composition, and an intensity effect representing changes in the sector's energy intensity (EI) [for more details see Ang and Zhang (2000)].

$$EI_{agg} = \mathring{a}_i S_{i,t} * E_{i,t} \tag{39.1}$$

$$F_{tot} = F_{str} * F_{int} \tag{39.2}$$

$$F_{str} = exp\left\{\sum\nolimits_i \frac{L(\omega_{i,t}, \omega_{i,o})}{\sum_i L(\omega_{i,t}, \omega_{i,o})} \ln\left(\frac{S_{i,t}}{S_{i,o}}\right)\right\} \tag{39.3}$$

$$F_{\text{int}} = exp\left\{\sum\nolimits_i \frac{L(\omega_{i,t}, \omega_{i,o})}{\sum_i L(\omega_{i,t}, \omega_{i,o})} \ln\left(\frac{EI_{i,t}}{EI_{i,o}}\right)\right\} \tag{39.4}$$

Note: EI_{agg}: aggregate energy intensity, F_{tot}: Total change in aggregate energy intensity, F_{str}: structural effects, F_{int}: Intensity effects, w_x: energy share of sector i in year t.

The CO_2 emission method: This method explains changes in the level of CO_2 emissions through three factors: activity as measured in terms of production, structure and the energy carbon index [for more details see Ausubel (1995) and Lise (2006)].

$$COI_{agg} = \mathring{a}_i S_{i,t} * COI_{i,t} \tag{38.5}$$

$$TC_{tot} = F_{str} * F_{CE} \tag{38.6}$$

$$F_{str} = exp\left\{\sum_i \frac{L(\psi_{i,t}, \psi_{i,o})}{\sum_i L(\psi_{i,t}, \psi_{i,o})} \ln\left(\frac{S_{i,t}}{S_{i,o}}\right)\right\} \quad (38.7)$$

$$F_{ce} = exp\left\{\sum_i \frac{L(\psi_{i,t}, \psi_{i,o})}{\sum_i L(\psi_{i,t}, \psi_{i,o})} \ln\left(\frac{CE_{i,t}}{CE_{i,o}}\right)\right\} \quad (38.8)$$

Note: COI_{agg}: aggregate CO_2 emission intensity, TC_{tot}: Total change in aggregate CO_2 emission intensity, F_{str}: structural effects, F_{ce}: Energy carbon index changes, CE: energy carbon index effect, y_x: CO_2 emissions share of sector i in year t.

The main limitation of this study is the degree of analysis (aggregate manufacturing sub-sectors) because it is only for one country and is insufficient for a full examination of the changes that took place into each Swedish sub-sector separately.

Database

Data to conduct the analysis are provided by SCB (Statistics Sweden) through the Swedish Environmental Accounts and Statistical database. These organizations use data at 2-digit levels of disaggregation, according to International Standard Economic Classification (ISEC). All monetary data are converted to 2000 euro values. The time period selected in this analysis is determined by the availability of data for the inter-sectoral Swedish manufacturing industries over the period 1993–2008.

Results and Discussion

Energy Intensity and CO_2 Emission Intensity in Swedish Manufacturing Industries

The trends in energy intensity and CO_2 emission intensity are shown in the Fig. 39.1; both indicators display the same tendencies. Energy intensity and CO_2 emission intensity have decreased by 28 and 29 %, respectively as average of whole manufacturing industries. All Swedish manufacturing industries have decreased these indicators, especially in the last few years.

Decomposition Analysis

To estimate and analyze the trends in energy use and CO_2 emissions in the Swedish manufacturing industries, we apply the Multiplicative Log-Mean Divisia

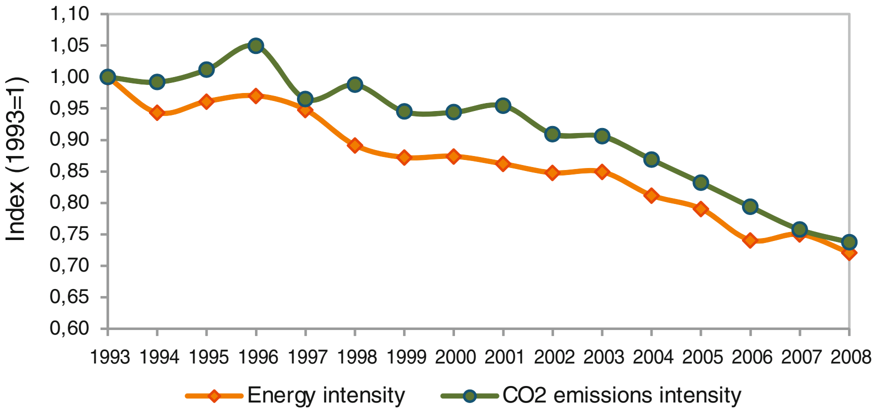

Fig. 39.1 Trends of energy intensity and CO_2 emission intensity for the Swedish manufacturing industries *Source* SCB (Statistics Sweden)

Method I explained in the section Methods and data. The results of the decomposition analysis are shown in Figs. 39.2 and 39.3 where a value of one indicates that the variable had no effect on aggregate intensity, energy consumption or CO_2 emissions and values greater than one indicate a contribution to greater aggregate intensity, energy consumption or CO_2 emissions, whereas values less than one indicated a decrease, which implies an increase in energy efficiency and a decrease in CO_2 emission intensity.

Energy intensity approach. Figure 39.2 shows the results for the decomposition of aggregate energy intensity, electricity intensity and fossil fuel intensity, where value added is the economic measures of output in the Swedish manufacturing industries. The aggregate of the energy intensity decreased considerably during the sample period. Structural and intensity effects show similar trends, indicating that both contributed to the decrease in aggregate energy intensity. However, intensity effects dominated structural effects, signifying that the decrease in aggregate energy intensity was primarily caused by a decrease in the energy intensity, which could be due to changes or improvements in technology.

The results should also demonstrate that the decrease in fossil fuel consumption has improved energy efficiency and decreased energy consumption through fuel substitution or a change in the mixture of fuels from inefficient, dirty or fossil fuels with a high carbon content (such as coal or several petroleum products) towards more efficient, clean or non-fossil fuels with a low carbon content (such as natural gas or hydroelectric energy); these trends are required for sustainable development. Moreover, achieving adequate fuel substitution to decrease the CO_2 emissions and energy consumption implies a change in economic conditions (fuel prices), a technological change (new technologies and innovation with adequate cost-benefits) and regulations that promote energy efficiency and clean production through the use of technologies that require less energy consumption and fewer pollutant-generating fuels (Hoeller and Wallin 1991; Steinbuks 2010).

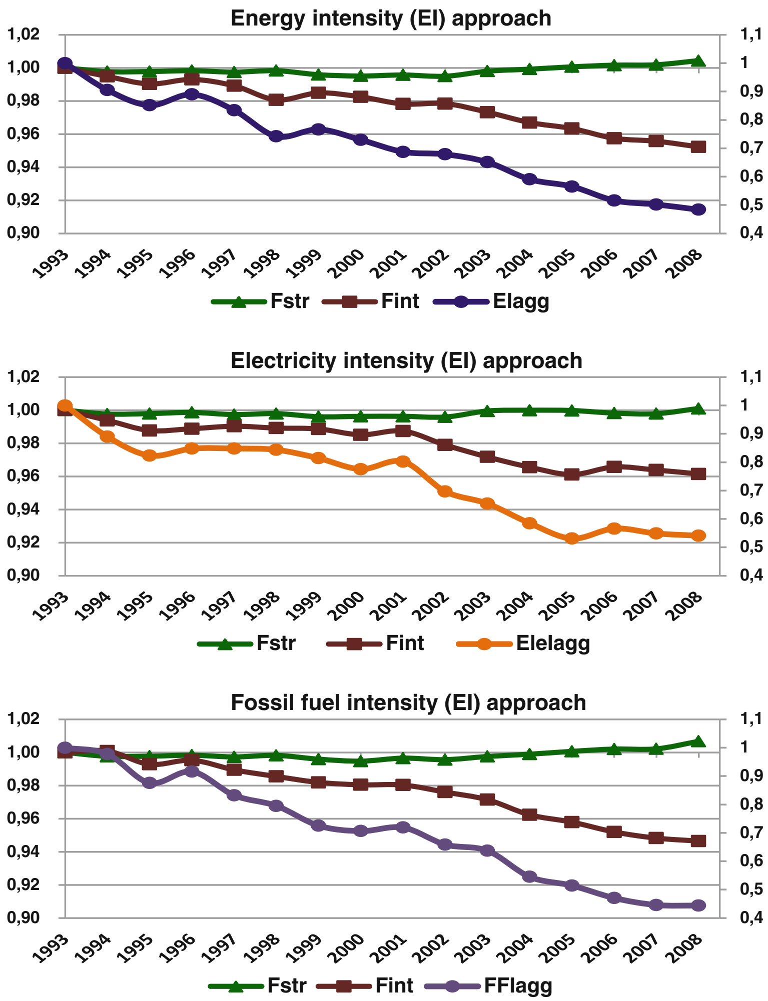

Fig. 39.2 The results of the decomposition analysis of aggregate energy intensity (*EIagg*), electricity intensity (*EIeIagg*) and fossil fuel intensity (*FFIagg*) into structural (*Fstr*) and intensity (*Fint*) effects for the Swedish manufacturing industries

CO_2 emissions approach. Figure 39.3 depicts the results of decomposition analysis from the CO_2 emissions approach. The results are similar to those obtained from the previous method, indicating the close relationship between the improvements in energy efficiency and the decrease of CO_2 emission intensity, which is consistent with several studies that have identified energy efficiency as a major energy issue because it is the most cost effective way of improving energy use and increasing both energy security and productivity and plays a role in the achievement of a carbon emission reduction target (Boyd and Pan 2000; United Nations Foundation 2007).

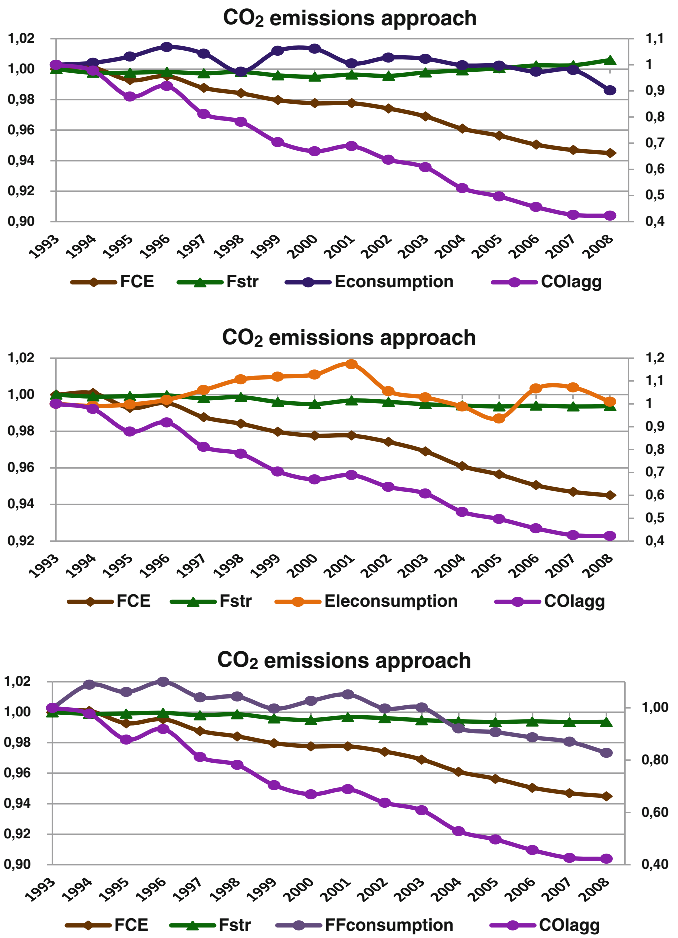

Fig. 39.3 The results of the decomposition analysis of CO_2 emissions for the Swedish manufacturing industries (structural effects (*Fstr*), energy carbon index changes (*FCE*), aggregate CO_2 emission intensity (*COIagg*), energy consumption (*Econsumption*), electricity consumption (*Eleconsumption*) and fossil fuel consumption (*FFconsumption*))

The results of the decomposition analysis from this approach indicate that the decrease in energy consumption has contributed to a lower aggregate CO_2 intensity. Similarly, structural and intensity effects had a minor role in the decrease in CO_2 emission intensity. These results highlight the fact that the Swedish manufacturing industry has increased its output while decreasing energy consumption, maintaining its production structure and decreasing its effects on climate change. Therefore, the results have demonstrated that clean production is possible within the framework of sustainable development.

Discussion of Results

Thus far, the results show that the Swedish manufacturing industries have decreased their energy consumption and output growth has not required higher energy consumption, making it possible to decrease energy and CO_2 emission intensity. The role of structural changes has been minor, and the trends of energy efficiency and CO_2 emissions were similar during the sample period. To understand the possible factors that have influenced these trends, we analyse the following issues: investments, inter-fuel substitution, energy price and energy taxes.

Investments. Multiple studies have demonstrated that higher investments generate higher energy efficiency or decrease energy intensity. Currently, investments in energy efficiency and clean energy are necessarily business decisions, and the greatest investment priorities are, in this case, based on regulatory requirements, decreased production costs or increases in productivity while maintaining or increasing product quality (Environmental Protection Agency 2007; Ramos and Ortege 2003). Moreover, the results of this study are consistent with several programs of the Swedish Energy Agency (SEA), which promotes investments to improve energy efficiency through standardised energy management systems and energy audits and identifies measures to decrease energy use and energy intensity. The Swedish long-term agreement program for energy efficiency in energy intensive industries (PFE), launched by the Swedish government in January 2005 and implemented and operated by the Swedish Energy Agency, has become a successful voluntary program. It has achieved an annual reduction in energy use of 2.909.33 TJ and a 2.5 % increase in electricity intensity through the application of 872 measures and increased investments by companies (Ottosson and Petersson 2007; Stenqvist et al. 2009). Moreover, investments in clean technologies have grown significantly in the Swedish manufacturing industries, mainly in renewable electricity production, bio-fuels and techniques for increasing energy efficiency supported by different emission-reducing subsidies from the Swedish government (Stenqvist et al. 2009). This demonstrates that an adequate energy and climate change policy require government support and the interest of the industrial sector in improving environmental performance, pursuing increased productivity and economic growth with a goal of clean production with low carbon emissions.

Inter-fuel substitution. During the sample period, the manufacturing sector in Sweden increased its use of electricity and bio-fuels, whereas the use of other fuels has decreased (see Fig. 39.4), indicating that, in this sector, electricity consumption has grown at a higher rate. However, fossil fuels declined during the sample period, demonstrating a shift in the structure of energy sources from lower efficiency or more polluting fuels (e.g., coal or petroleum products) to greater efficiency or cleaner fuels (e.g., electricity or bio-fuels). This is consistent with other studies (United Nations 1976; Pardo Martinez 2011) in the context of manufacturing industries. Moreover, the decline in the energy intensity in the manufacturing industries has been due to the ability to expand the use of higher quality fuels (Swedish Energy Agency 2009).

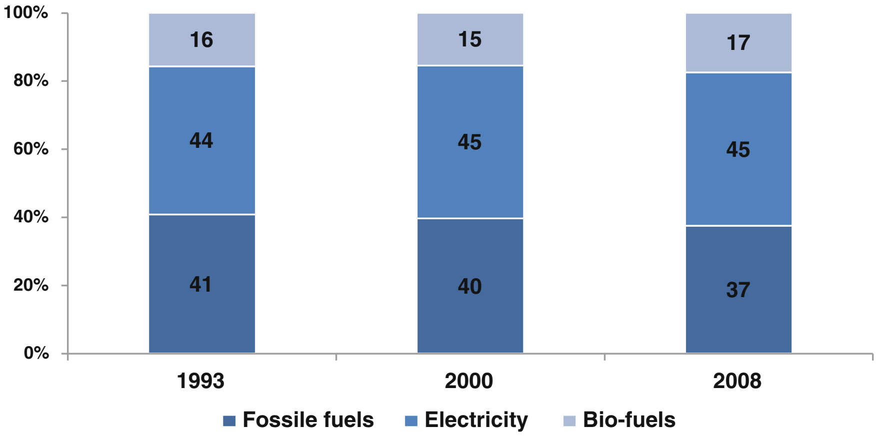

Fig. 39.4 Inter-fuel substitution in Sweden manufacturing industries *Source* SCB (Statistics Sweden)

Energy prices. In the literature, it is accepted that energy efficiency becomes important during periods of high energy prices from a cost minimisation of outputs perspective. This may encourage improvements in the process and appropriate substitution of other inputs for energy (Mukherjee 2008). Hence, increases in the prices of fossil fuels generated the substitution of these fuels for electricity and bio-fuels. Moreover, energy prices influenced energy efficiency results because decreases in aggregate energy intensity occurred during the years in which energy prices increased e.g., from 2000, Swedish manufacturing industries decreased the aggregate energy intensity while energy prices increased (see Figs. 39.2 and 39.5). Therefore, an increase in energy prices over time leads to a decrease in energy

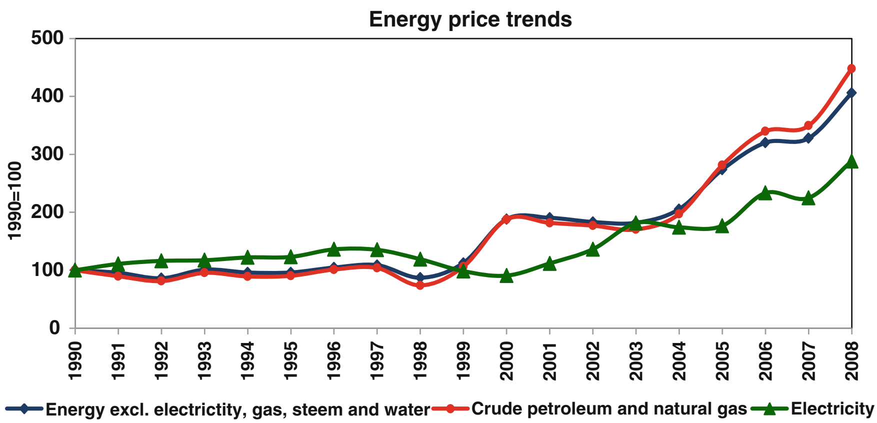

Fig. 39.5 Energy price trends (energy, electricity, crude petroleum and natural gas) in Sweden manufacturing industries *Source* SCB (Statistics Sweden)

intensity, which concurs with (Holdren 2001; Cornillie and Fankhauser 2002; Pardo Martínez 2009).

Energy Taxes. Another factor analysed were the taxes, represented by energy and CO_2 taxes. This mechanism has been used in Sweden as both a fiscal tax source and as a policy instrument to motivate and strengthen incentives to save energy by increasing energy prices and carbon taxes. The taxes also make lower-carbon fuels substitutes. These taxes have been integrated with a variety of instruments and mechanisms that were designed to make them effective and maintain the competitiveness of Swedish manufacturing industries. A permanent substantial dialogue between all of the stakeholders, but mainly with industry, has generated higher applicability and effectiveness (Price et al. 2008; Ptak 2010). Moreover, results from decomposition analysis may demonstrate that adequate energy taxation reduces CO_2 emissions, improves the efficiency of energy use, promotes renewable energy production and use and provides incentives for sustainable development established by the green tax shift. Therefore, higher taxes should be applied to environmentally harmful activities to generate an increase in the use of biomass in district heating systems, investments in new technologies and the application of energy management systems and audits (Fouquet and Johansson 2005; International Energy Agency 2008a, b).

Conclusions

This study analyses the trends in energy consumption and CO_2 emissions in Swedish manufacturing industries between 1993 and 2008. This sector has achieved important advances in energy use, simultaneously increasing its output while decreasing its energy consumption. Similarly, energy and CO_2 emission intensity decreased during the sample period, demonstrating that it is possible to produce economic growth while using fewer energy resources and controlling the amount of CO_2 emissions.

The results of the decomposition analysis showed a decrease in aggregate energy intensity and aggregate CO_2 emission intensity, which was caused by a decrease in energy intensity and substitution fuels; the role of structural changes has been minor. Moreover, the growth in production did not lead to increases in aggregate energy intensity and CO_2 emission intensity, indicating that this sector produced more with less energy consumption and fewer emissions.

These trends could be explained by the energy policies and strategies applied in Sweden that include energy prices, energy taxes and technological change that encourage investments in new technologies, encourage fuel substitution and energy management in the manufacturing industries.

The findings of this study indicate that it is possible to achieve improvements in energy efficiency and decrease CO_2 emissions while increasing production and competitiveness through a suitable energy policy that encourages the importance of energy efficiency in the manufacturing process through technological change and policy strategies.

The results found in this analysis are a valuable source of information because they suggest several strategies to make significant improvements in the energy efficiency of manufacturing industries, especially in developing countries where it is very important to increase the efforts of industry and policy makers to achieve energy savings that contribute significantly to the reduction of greenhouse gas emissions.

Finally, the results of this study are particularly relevant for the formulation, development and strengthening of energy policies for manufacturing industries that are based on Swedish experience, where economic instruments (energy prices and energy taxes) and technical instruments have driven substantial improvements in energy efficiency and decreases in CO_2 emissions through clean technology investments and fuel substitution. These results demonstrate that it is possible to achieve economic growth and sustainable development through a steady advancement towards a low-carbon economy. Future research should scrutinise data on other sectors, countries and aggregation levels to improve the understanding of the trends of energy efficiency and CO_2 emissions.

Acknowledgments The authors are grateful for the financial support provided by the Swedish Energy Agency and KTH for the development of this research. We also thank the support of the University of La Salle. The research has been developed independently.

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Chapter 40
Assessing the Potential of Torrefaction for Locally Available Biomass in Mauritius

Surroop Dinesh and Mooloo Devina

Abstract Mauritius is highly dependent on fossil fuel imports for its own energy provision with only a minor contribution of renewable energy sources. Mauritius has however got potentials to increase its renewable energy share through increased biomass use. Conversely, there are several problems associated with biomass which reduces its appeal as a fuel compared to conventional fossil fuels. Pre-treatment technologies can nevertheless help valorise biomass. Torrefaction is known to be a mild pyrolysis process during which the lignocellulosic material in the biomass is decomposed and moisture and volatiles are eliminated. In this paper, the effect of torrefaction on the energy content and the chemical composition of four different locally available biomass feedstocks in Mauritius namely: Elephant grass (Napier grass), cane tops and leaves, wood wastes and palm trunks have been investigated. Samples of the biomass were treated at varying temperatures in the range of 200–300 °C in an inert atmosphere with a residence time of 1–3 h. The optimum residence time and temperature for each of the different biomass feedstock were determined. Enhancement ratios in the energy content of the torrefied biomass varied from 1.01 to 1.42. It was found that 1 kg of torrefied biomass could displace 0.776–0.855 kg of coal and reduce emissions of greenhouse gases from 2.01 to 2.34 kg. It was evaluated that savings of Rs. 3.19, Rs. 3.34, Rs. 3.52 and Rs. 3.29 per kg of torrefied sawdust, elephant grass, and CTL and palm wastes could also be made.

Keywords Torrefaction · Lignocellulosic · Greenhouse gases

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_40,

Short Introduction

Mauritius (a small developing island) has no natural fossil fuel reserves, but has however important potentials to increase its renewable energy share through increased biomass use. This study was therefore initiated to assess the potential of torrefaction of biomass in Mauritius. The benefit of torrefaction is that a fuel produced (commonly known as biocoal) has a uniform composition compared to unprocessed biomass. The amount of coal that can possibly be displaced and the greenhouse gases avoided by the use of torrefied biomass in Mauritius was subsequently evaluated.

Introduction

The world is living with growing anxieties of an imminent energy crisis (Chang et al. 2011; Riley 2000). Escalating energy demands in developed and developing countries whilst an almost stagnant energy supply is only aggravating the scenario. The globe's leaders are already insecure about the price and continued supply of fossil fuels in the forthcoming years. In January 2012, it was reported that the price of oil was around $103 per barrel (Kahn 2012). An analysis of the Central Statistics Office (CSO) report leads to the conclusion that Mauritius is heavily dependent on imports to be able to meet its energy demands (CSO 2010). 82.5 % of the primary energy requirement in the island is fulfilled by fossil fuel imports with a 55 % share of petroleum products (CSO 2010). Hence, the country is highly susceptible to energy shocks such as rise in oil price in the world.

Moreover, growing fossil fuel use worldwide is also increasing the amount of greenhouse gas emissions in the world leading to a threatening climate change. Developing countries are considered to be more vulnerable to the climate change problem since they possess little resources to adjust and adapt to climate change in terms of social, technological and financial aspects (UNFCCC 2007). Mauritius, though having little contribution to climate change compared to developed countries is already experiencing its negative effects. Rise in air temperature from 0.74 to 1.2 °C in comparison to the 1990s, rise in sea level by 1.5 mm per year and an 8 % decrease in rainfall as well as warmer summers and milder winters (Mauritius Meteorological Services 2012) are some of the experienced consequences of climate change in the country. To combat the problems related to fossil fuels, alternative energy sources need to be sought. Biomass is a promising alternative to replace fossil fuels given its wide distribution globally compared to other sources of fuel (US DOE 2011). Additionally, biomass is also a clean source of energy and will help in the reduction of emissions of greenhouse gases (Zhang et al. 2010).

However, the contribution of biomass in energy generation in Mauritius is very minimal accounting for only 20.5 % of the electricity generation in the country which is sustained by the biomass bagasse, a by-product of the sugarcane milling process (CSO 2010). It can be clearly deduced that expansion of the biomass sector involves various challenges. Along with political, economic barriers and a lack of strategies and frameworks for promoting the biomass industry, the properties of the biomass itself as a fuel act as a significant hindrance for its own development (Bridgeman et al. 2008).

A comparison of coal with biomass reveals that the latter is still regarded as a relatively inferior fuel not able to meet the same benchmarked characteristics as coal (Bridgeman et al. 2008). One of the main challenges encountered by biomass is that their low calorific value and low ash sintering temperature causes technical problems during its use in combustion and gasification (Baxter et al. 1998). Biomass also have high moisture content and low bulk density which further hinder its use due to high transportation costs associated for handling it (Kumar et al. 2009). A high level of moisture also poses storage difficulties and dangers of degradation or self-heating of the biomass along with reduction in the efficiency of biomass and it limits the gasifier construction design (Bridgeman et al. 2008). Moreover, the heterogeneous nature of biomass hinders its competitiveness in the energy market (Chew and Doshi 2011). Efficient biomass conversion technologies can aid to improve of the problems related to biomass (Rousset et al. 2011).

Torrefaction is a thermal pre-treatment process, which can be described as a mild pyrolysis, during which the biomass is subjected to a temperature range of 200–300 °C under atmospheric conditions with little or no oxygen (Rousset et al. 2011). The process helps to. Torrefaction is advantageous in many ways: biomass degradation is reduced since the water absorption capacity of the torrefied biomass is reduced and alongside, its energy value is also improved on a mass basis; the torrefied biomass can be easily ground to a powder and it can also be co-fired with coal (Arias et al. 2008; Bergman et al. 2005; Rousset et al. 2011). The properties of the torrefied biomass are somewhat similar to low rank coal.

Various studies have been conducted on torrefaction (Arias et al. 2008; Bridgeman et al. 2008; Patel et al. 2011; Rousset et al. 2011; Uemura et al. 2010) but none of them have focused on agricultural wastes: cane tops and leaves and palm trunks as well as the energy crop elephant grass. This paper investigates the relationship between the calorific value and the residence time and torrefaction temperature of four different biomass species available in Mauritius (2012) (sawdust, elephant grass, cane tops and leaves and palm trunks) and attempts to find the optimum temperature for each biomass.

Methodology

Moisture Content and Dry Mass Determination

To find the moisture content of the biomass, 100 g of each of the 5 different samples were weighed in different plates. The samples were then placed in the oven at a temperature of 105 °C and allowed to dry until constant weight was obtained.

Energy Content of Biomass

The energy content of the biomass samples was evaluated on a dry basis using a bomb calorimeter model 3188 series. The sample was first dried in an oven (Labcon) at a temperature of 105 °C for a period of 3 h. It was then pelletised. The pellet should weigh less than 1 g. The sample was placed in a metal capsule which is then positioned on a ring which acted as an electrode to which a bent fuse wire is attached such that it touches the sample. The ring was placed on the bomb cylinder which is afterwards filled with oxygen at a pressure of 25 atm. The bomb cylinder was then connected to ignition wires and lowered in the bomb calorimeter bucket filled with 2 l of water. After mounting the stirrer on the calorimeter bucket, mixing was allowed in the vessel. The initial temperature of the water was next recorded before switching on power to fire the fuse wire. The final temperature reached was noted and the higher heating value of the biomass was calculated taking into consideration the temperature difference and mass of the sample.

Torrefaction Experiment

A batch cylindrical reactor with a length of 10 cm and a diameter of 10 was used. The reactor was enclosed in a heater whose temperature can be varied from 0 to 300 °C is used. The reactor had a gas inlet for supplying nitrogen to the reactor and a gas outlet to allow flue gas to leave the reactor. Nitrogen was supplied to the reactor at a rate of 2 litres per minute. For each run, 5 g of sample was placed in the reactor for a period of 1 h at the required temperature. The heater was then switched off. The sample was allowed to cool in the reactor to room temperature before being removed after which the torrefied sample was weighed. Four different temperatures were chosen for the study: 230, 250, 270, 290 °C. The torrefied samples were then analysed for their composition and heat value using a bomb calorimeter.

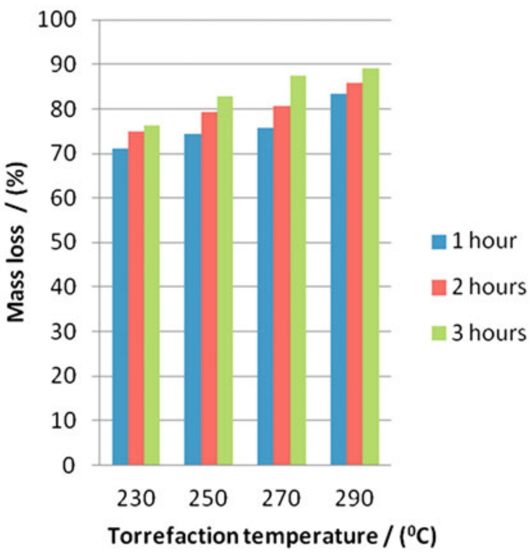
Results and Discussion

Mass Loss at Different Torrefaction Temperatures and Residence Time

One of the main benefits of the torrefaction process is that it eventually leads to the complete drying of the biomass and torrefied biomass is also known to be less prone to moisture absorption (Patel et al. 2011). Hydrophobicity is conferred to the biomass due to the breaking of its OH bonds during the torrefaction process and its inability for hydrogen bonding (Bergman et al. 2005). Following torrefaction, char and volatiles are obtained as end-products. It has been reported that mass loss gives an indication of the impact of torrefaction on a particular biomass (Almeida et al. 2010). The mass loss occurring can be mainly attributed to the degradation of the hemicellulose structure producing volatiles (Almeida et al. 2010; Patel et al. 2011). Chen and Kuo (2011) observed that at a temperature of 260 °C 37.98 wt% of hemicellulose were degraded while at 290 °C 58.33 wt% of hemicellulose were decomposed. Temperature and residence time significantly affects the torrefaction process (Bergman et al. 2005).

Figures 40.1, 40.2, 40.3 and 40.4 demonstrate the relationship between mass loss, torrefaction temperatures and residence times of CTL, Elephant grass, Palm wastes and sawdust respectively. As the temperature and residence time was increased, a rise in mass loss was experienced. From Fig. 40.1, it was observed that for a residence time of 1 h, as the temperature increased from 230 °C to 290 °C, the mass loss in CTL also increased from 71.1 to 83.4 %; at 2 h residence time, the mass loss varied from 74.9 to 86.0 % while at 3 h residence time, variations in mass loss from 76.2 to 89.1 % were observed. Similarly, in Fig. 40.2, as the temperature rose from 230 to 290 °C for a residence time of 1 h, noticeable mass losses were observed in the elephant grass species ranging from 85.3 to 92.0 %. The rise in residence time from 1 to 3 h at temperatures of 200 °C, 230 °C, 250 °C and 290 °C brought about increases in the mass loss from 85.3 to 85.9 %, 86.6 to 89.6 %, 91.2 to 92.3 % and 92.0 to 93.1 % respectively. Likewise, in Fig. 40.3, a variation in temperature from 230 to 290 °C for 1 h caused an increase in the mass loss of the palm wastes from 53.0 to 81.2 %. At 230 °C, an elevation in residence time from 1 to 3 h caused mass losses to increase from 53.6 to 54.8 %. From Fig. 40.4, it was observed that at a residence time of 1 h, as the temperature augmented from 230 to 290 °C, the mass loss in the sawdust increased

Fig. 40.1 Mass loss of CTL at different torrefaction temperature and residence time



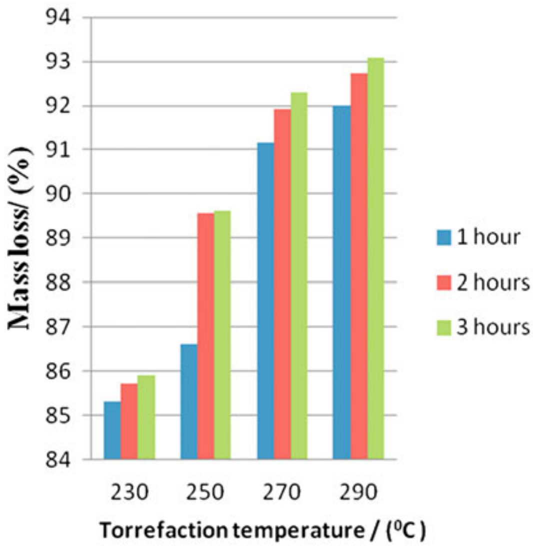


Fig. 40.2 Mass loss of elephant grass at different torrefaction temperature and residence time

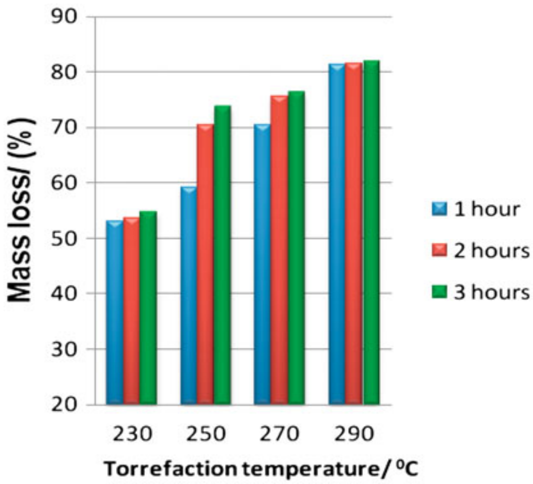


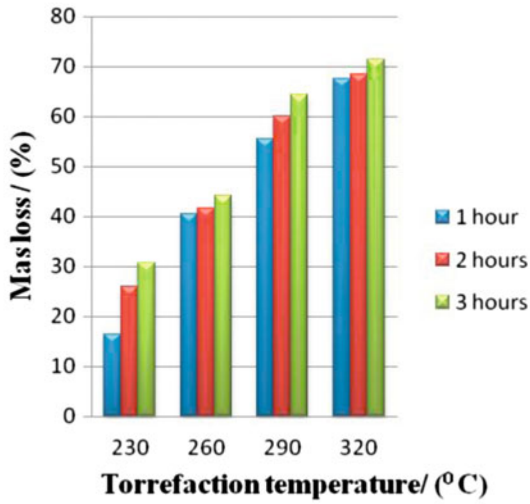
Fig. 40.3 Mass loss of palm wastes at different torrefaction temperature and residence time

from 16.5 to 37.6 %. For residence times of 1, 2 and 3 h, the mass loss are as follows: at 230 °C, 16.5, 25.9, 30.7 %; at 250 °C, 40.4, 41.7 and 44.2 %; at 270 °C, 55, 60 and 64.3 %; at 290 °C, 67.6, 68.5 and 71.4 %.

A rise in temperature and residence time brings about a decrease in the solid bio-coal yielddue to decomposition of the lignocellulosic structures in the biomass producing more volatiles (Medic et al. 2012). Similar trends for mass loss at different torrefaction conditions for oven dried E. grandis, E. saligna, C. citrioda samples were observed (Almeida et al. 2010).

During the torrefaction process, drying of biomass occurs at temperatures of 100–150 °C (Patel et al. 2011). From experiments, it was determined that when the

Fig. 40.4 Mass loss of sawdust at different torrefaction temperature and residence time



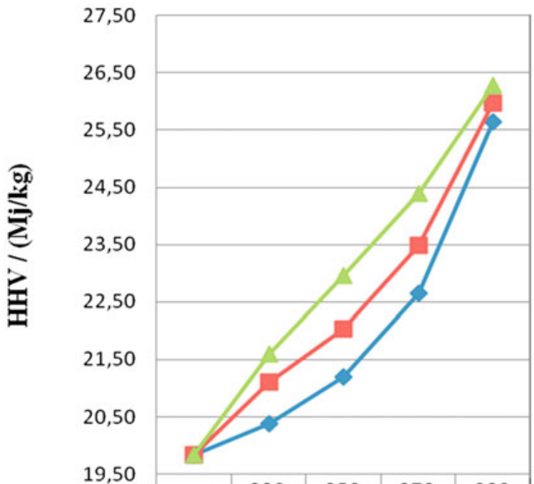
different biomass CTL, palm wastes, elephant grass and sawdust were dried at a temperature of 105 °C, the mass loss due to moisture was 63.53, 52.89, 84.44 and 14.80 % respectively. Further increase in temperature from 150 to 200 °C caused depolymerisation and degradration of the shortened polymer structure within the solid structure of the biomass (Patel et al. 2011). At temperatures greater than 200 °C, the biomass started to decompose liberating volatiles and leaving behind a solid product known as char (Bergman et al. 2005). Thermal decomposition of the chemical compounds present in biomass such as hemicelluloses and celluloses cause mass losses and since hemicelluloses is less thermally, it is more easily degraded (Almeida et al. 2010). Rising temperatures lead to a decrease in solid bio-char yield (Zhang et al. 2010). The loss in mass was greater at temperatures higher than 250 °C. This may be attributed to the higher reactivity of hemicellulose at temperatures greater than 250 °C (Medic et al. 2012).

From Figs. 40.1, 40.2, 40.3 and 40.4 it can be deduced that the mass losses for the different biomass are dissimilar. The mass loss was caused mainly by the moisture loss and devolatisation in the biomass. A rise in temperature gives rise to a decrease in the mass yield, oxygen content and volatiles but an increase in the carbon content (Yan et al. 2009). At a temperature of 230 °C and residence time of 1 h, elephant grass has the highest mass loss of 85.3 % followed by CTL with a mass loss of 71.03 % and palm wastes with a mass loss of 53.0 %. From Table 40.1, it can be deduced that elephant grass has higher moisture content than CTL whose moisture content is higher than that of palm wastes (52.89 %). Since the raw material used for the torrefaction experiments were on a wet basis, this explains that the moisture content of the samples influence the percentage mass. Another factor responsible for the difference in the mass of the 4 different biomass is the lignocellulosic content which varies for the different biomass.

Calorific Value at Different Torrefaction Temperature and Residence Time

The calorific value relates to the energy released during the burning of fuel in the presence of air. The gross calorific value represents the maximum amount of energy recoverable from the biomass. A rise in the calorific value indicates an improvement in the energy content of the torrefied biomass compared to the raw biomass (Almeida et al. 2010). One of the major challenges faced by biomass for its potential use as a fuel is its low calorific value. The torrefaction process helps to enhance the energy content of the fuel.

The relationship between the calorific value, torrefaction temperature and residence time for CTL, palm wastes, elephant grass and sawdust is depicted in Figs. 40.5, 40.6, 40.7, 40.8 respectively. Improvements in the energy content of: CTL from 21.89 MJ/kg to 25.51 MJ/kg; Palm wastes from 20.38 to 25.64 MJ/kg; elephant grass from 20.66 to 21.91 MJ/kg; sawdust from 20.79 to 26.82 MJ/kg have been observed as torrefaction temperature was increased from 230 °C to 290 °C for a residence time of 1 h. The heating value of the biomass was observed to increase with the torrefaction temperature. This can be explained by the decrease in the oxygen to carbon ratio which is caused by the degradation of the lignocellulosic material in the palm wastes (Li et al. 2012). Additionally, an increase in residence time also improved the calorific values of CTL, palm wastes,



	raw	230	250	270	290
1 hour	19,84	20,38	21,19	22,64	25,64
2 hours	19,84	21,11	22,04	23,48	25,97
3 hours	19,84	21,59	22,96	24,39	26,27

Fig. 40.5 GCV change in CTL at torrefaction temperature and residence time

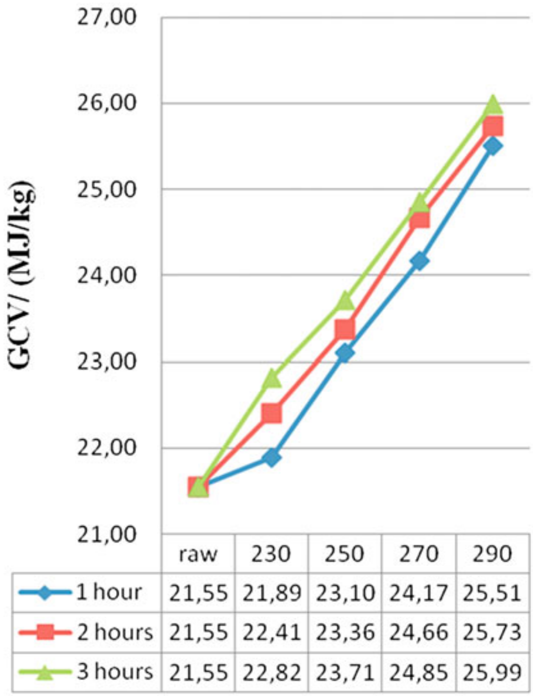


Fig. 40.6 GCV variation in palm waste sat torrefaction temperature and residence time

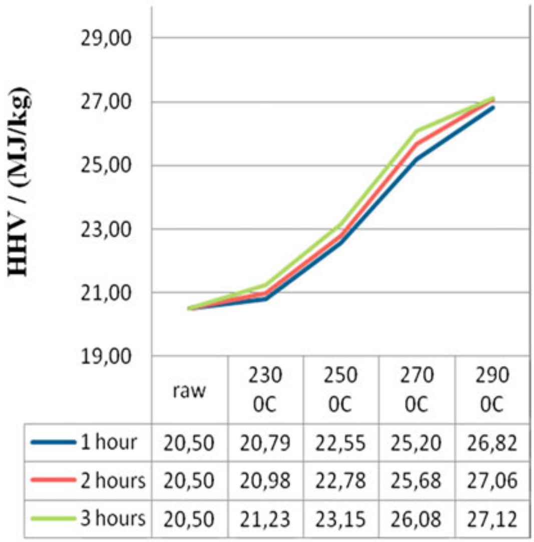
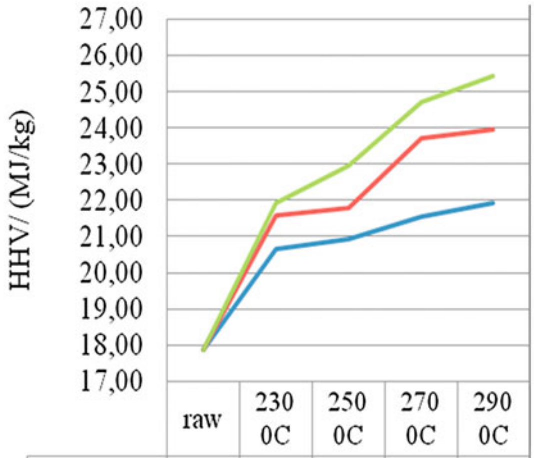


Fig. 40.7 Energy changes in elephant grass at different torrefaction temperature and residence time

elephant grass and sawdust. Changes in the calorific value at a temperature of 270 °C and for an increase in residence time from 1 to 3 h were noted as follows: CTL, 24.17 to 24.85 MJ/kg; palm wastes, 22.64 to 24.39 MJ/kg; Elephant grass, 21.56 to 24.72 MJ/kg; sawdust, 25.20 to 26.08 MJ/kg.

Fig. 40.8 Energy changes in sawdust at different torrefaction temperature and residence time



	raw	230 0C	250 0C	270 0C	290 0C
1 hour	17,87	20,66	20,92	21,56	21,91
2 hours	17,87	21,57	21,80	23,70	23,96
3 hours	17,87	21,94	22,96	24,72	25,43

Similar trends have been obtained with different biomass such as *E.Saligna* and *E.grandis* and *C.citriodora* (Almeida et al. 2010). The increase in calorific value with rise in temperature at specific residence time can be explained by the fact that during torrefaction, carbon monoxide and carbon dioxide are formed due to carboxylation reactions and splitting of the acetyl group present in the xylan chain in the biomass (Ponder and Richards 1991; Shen et al. 2010). The carbon dioxide formed reacts with the char formed during the thermal degradation of the sawdusts producing more carbon monoxide (Li et al. 2012). The carbon dioxide and carbon monoxide thus liberated causes removal of oxygen from the solid char thus decreasing the oxygen to carbon ratio in the torrefied sawdust and leaving behind a higher calorific value solid char (Li et al. 2012). As the torrefaction temperature and residence time is increased, an increase in fixed carbon and a decrease in volatiles and oxygen contentwerenoted for different varieties of biomass thus increasing its suitability for energy production (Almeida et al. 2010; Kongkeaw and Patumsawad 2011). During fuel combustion, the carbon in the fuel is mainly responsible for the exothermic reaction occurring while the oxygen present has an endothermic role and a higher torrefaction temperature leadsto a higher Carbon and lower Oxygen content (Chen et al. 2011).

Experimentation performed on Wheat straw revealed that at torrefaction temperatures of 230, 250, 270 and 290 °C and residence time of 30 min, the heating value of the torrefied biomass were 19400, 19800 and 22600 kJ/kg (Bridgeman et al. 2008). Likewise, the calorific values of willow at 230, 250, 270 and 290 °C at a residence time of 30 min were determined to be 20,200, 20,600, 21,400 and 21,900 kJ/kg respectively (Bridgeman et al., 2008). Torrefying Reed canary grass at 250, 270 and 290 °C for a period of 30 min resulted in heating values of 20,000 kJ/kg, 20,800 kJ/kg and 21,800 kJ/kg respectively (Bridgeman et al. 2008).

Chen et al. (2011) reported values of: 23.62 MJ to 28.08 MJ/kg for bamboo torrefaction; 23.71 MJ/kg to 29.64 MJ/kg for willow torrefaction at a 1 h residence time. Untreated pine and pine torrefied at 230, 260 and 280 °C had the following energy values: 20.2, 20.37, 20.45 and 21.70 MJ/kg respectively (Pierre et al. 2011). However in another study, heating values of 18.46, 22.87, 25.77 and 28.00 MJ/kg for untreated Banyan and Banyan samples torrefied for 1 h at temperatures of 230, 260 and 290 °C were reported (Chen et al. 2011). The difference in HHV can be explained by the difference in lignocellulosic content of the different biomass.

At temperatures of 220, 250 and 300 °C, calorific values of torrefied Mesocarp fibres were reported as 19.03, 19.24 and 22.17 MJ/kg respectively (Uemura et al. 2010) which are than lower those reported in Fig. 40.6. This can be attributed to the difference in biomass species, physical properties of the biomass and its harvesting season. The palm species used in the current study is utilised for the production of palm hearts in Mauritius which is used for culinary purposes and exportation while that used in Uemera et al. (2010) is a species grown in Malaysia specifically for oil production. Furthermore, the palm wastes consisted of only trunks and fronds which had a higher woody content than the mesocarp fibre and kernel shell. Moreover, the heating value of the raw palm biomass had been determined on a dry basis and was found to be 19.84 MJ/kg. In contrast, in a study performed on palm wastes, heating values of 18.8 MJ/kg and 20.1 MJ/kg for mesocarp fibre and kernel shell were reported respectively (Uemura et al. 2010).

The enhancement in calorific value was calculated by taking the ratio of the gross calorific value at the specified temperature and time to that of the of the raw biomass sample. From the Table 40.1, enhancement ratios in the energy content of the torrefied biomass were found to vary from 1.02 to 1.34 depending on the

Table 40.1 Enhancement in HHV of the different biomass at different conditions

Enhancement in HHV		Torrefaction residence time		
Biomass	Torrefaction temperature (°C)	1 h	2 h	3 h
CTL	230	1.02	1.04	1.06
	250	1.07	1.08	1.10
	270	1.12	1.14	1.15
	290	1.18	1.19	1.21
Elephant grass	230	1.16	1.21	1.23
	250	1.17	1.22	1.29
	270	1.21	1.33	1.38
	290	1.23	1.34	1.42
Palm wastes	230	1.03	1.06	1.09
	250	1.07	1.11	1.16
	270	1.14	1.18	1.23
	290	1.29	1.31	1.32
Sawdust	230	1.01	1.02	1.04
	250	1.10	1.11	1.13
	270	1.23	1.25	1.27
	290	1.31	1.32	1.32

torrefaction temperature and the residence time of the biomass. It was observed that as the torrefaction temperature was increased, the enhancement ratio increased accordingly due to an increase in the energy in the pre-treated biomass. Likewise, with increases in residence time, the energy enhancements were also observed. At a temperature of 290 °C and following 1 h of torrefaction, the enhancement of HHV for CTL was determined to be 1.18. In the case of palm wastes, at a temperature of 230 °C, for residence times of 1, 2 and 3 h, the GCV enhancement increased from 1.03 to 1.06 to 1.09 respectively. When the torrefaction temperature is increased from 230 °C to 290 °C for a residence time of 1 h, the enhancement is however more significant. This is because at lower temperatures the hemicellulose content is degraded but temperatures higher than 250 °C initiates degradation of the cellulose and lignin content as well (Chen et al. 2011). Enhancement ratios in the energy content of the torrefied elephant grass were found to vary from 1.16 to 1.42 depending on the torrefaction temperature and the residence time of the biomass. At a temperature 290 °C and following 1 h of torrefaction, the enhancement of HHV was determined to be 1.23. However, Chen et al. (2011) reported values of 1.40, 1.32 and 1.46 respectively for the same conditions with the biomass bamboo, banyan and willow. The lower value recorded can be attributed to the lignocellulosic content of the biomass owing to the fact that the elephant grass was harvested after 10 months and was not a fully mature plant.

Energy to Mass Loss Characteristics

The Energy gain/mass loss for the four different biomass under study (Sawdust, Elephant grass, CTL and palm wastes) were evaluated at different torrefaction temperatures and residence time. From Table 40.2, it was observed that the highest energy gain to mass loss ratio for sawdust was obtained at torrefaction conditions of: 230 °C, 3 h followed by 230 °C, 2 h; 250 °C, 2 h; 250 °C, 3 h and 270 °C, 3 h. In the case of Elephant grass, the utmost energy gain/mass loss can be specified at the following condition: 290 °C, 1 h; 270 °C, 1 h and 290 °C 2 h. For CTL, the greatest energy gain to mass loss are at 250 °C, 1 h; 230 °C 1 h; and 230 °C, 2 h. As for palm wastes, the highest mass loss to energy loss are obtained at the following conditions: 250 °C, 1 h, 230 °C, 3 h; 250 °C 2 h; 230 °C, 1 h.

In this study, the energy gain to mass loss ratio was used as an indicator for the determination of the optimum torrefaction conditions for the different biomass with the highest ratio representing the best condition. A high energy gain to mass loss ratio would mean that energy recovered in the char is higher than the mass loss in the volatiles which also contain energy. The optimal condition conditions are summarised in Table 40.3. In the case of palm wastes, both a temperature of 250 °C 2 h and 230 °C 3 h gave the same mass to energy ratio. However the torrefaction condition with a lower residence time was chosen since a higher residence time would increase the energy requirement of the process. It is observed that optimum conditions obtained for each biomass is different.

Table 40.2 Energy gain versus mass loss of different biomass at different torrefaction conditions

Energy gain/mass loss					
Residence time	Torrefaction temperature (°C)	Sawdust	Elephant grass	CTL	Palm wastes
1 h	230	6.39	−26.40	27.73	22.72
	250	15.72	−0.49	32.35	26.88
	270	15.37	13.05	14.63	16.44
	290	17.42	13.60	17.91	18.24
2 h	230	20.50	−21.94	19.97	21.55
	250	19.86	9.92	18.35	19.16
	270	18.68	11.58	17.35	18.04
	290	17.74	12.56	18.92	18.94
3 h	230	20.50	−20.04	17.73	19.17
	250	19.59	7.73	19.37	19.63
	270	18.86	11.20	19.99	19.81
	290	17.88	11.86	19.93	19.65

GHG Avoided

The torrefied biomass can be potentially co-fired with coal in existing power plants thus displacing a significant quantity of coal. The amount of coal displaced and greenhouse gas avoided by the different biomass torrefied at their optimum torrefaction conditions are shown in Table 40.4.

From Table 40.4, it can be observed that burning 1 kg of sawdust torrefied at 2 h at a temperature of 230 °C will avoid 19.56.4 g CO_2 by displacing 0.776 kg of coal. Amongst the different biomass, the GHG emissions avoided by torrefied CTL is highest due to its higher energy content and hence ability to displace a relatively larger amount of carbon. It can be inferred that burning torrefied biomass will help offset the use of coal and will considerably reduce greenhouse gas emissions.

Table 40.3 Optimum conditions for torrefaction of each of the different biomass

Biomass	Torrefaction temperature (°C)	Residence time/(h)	GCV/(MJ/kg)
Saw dust	230	2	20.98
Elephant grass	290	1	21.91
CTL	250	1	23.10
Palm wastes	250	1	21.19

Table 40.4 Amount of coal displaced per kg of torrefied biomass

Biomass	Torrefaction temperature (°C)	Residence time/(h)	Amount of coal displaced per kg biomass/kg	Electrical energy from coal displaced/kWh_e	GHG avoided/(g CO_2)
Saw dust	230	2	0.776	1.34	1956.4
Elephant grass	290	1	0.811	1.47	2146.2
CTL	250	1	0.855	1.63	2379.8
Palm wastes	250	1	0.785	1.37	2000.2

Conclusion

Pre-treatment technologies can however help valorise biomass as a source of fuel. Torrefaction of four diverse biomass available in Mauritius (2012) involving elephant grass, cane tops and leaves, palm trunk wastes and sawdust have been considered in this study. The biomass were subjected to different temperatures (ranging from 230 to 290 °C) and residence times (1–3 h). During the process, major changes in mass loss were reported as the torrefaction temperature and residence time was increased. The mass loss was however varied for the different biomass depending on their composition. Likewise, a rise in temperature and residence time also brought about improvements in the energy content of the fuel. However, mass loss can also be associated with a loss in energy since the volatiles given off contain significant amount of energy. Thus, in certain cases, energy changes due to mass loss overpowered the energy gain due to torrefaction. Hence a ratio of energy gain to mass loss was calculated and the conditions giving the highest ratio were considered as the optimum torrefaction conditions for the different biomass studied and were as follows: CTL, 250 °C, 1 h; elephant grass, 290 °C, 1 h; sawdust, 230 °C, 2 h and palm wastes, 250 °C, 1 h. An evaluation of the amount of coal displaced and subsequently the amount of greenhouse gas avoided by the use of torrefied biomass was conducted.

The result and discussion from this study will be helpful for those willing to use torrefied CTL, palm wastes, wood wastes and elephant grass as a source of solid fuel. The potential use of biocoal produced from biomass through the torrefaction process is very solicited in Europe and the technology is under research and development in various countries. Torrefaction products can be projected as being a clean source of energy capable of offsetting large amounts of coal and promoting the use of biomass as a fuel. Moreover, due to its reduced carbon dioxide emission, torrefaction projects can be considered for emission reductions via the Clean Development Mechanism.

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Chapter 41
Investigating the Potential of Using Coconut Oil–Diesel Blends in a Diesel Engine in Rodriques Islands

Dinesh Surroop and Krishna Sooprayen

Abstract The transportation sector of Rodrigues Island is fully dependent on petroleum products, mainly diesel and to a lesser extent gasoline. As an alternative solution to reduce the consumption of petroleum product over the island, this study was thus conducted to assess the performances of coconut oil–diesel blends in a diesel engine in Rodrigues Island. The fuel properties of coconut oil blends in this study were comparable to those of diesel. The engine performance showed that the mechanical efficiency of diesel was 71 % and that of the blends were around 71–77 %. The brake specific fuel consumption (BSFC) for both diesel and blends were around 0.5 kg/kWh with engine revolution below 1,500 rpm; but above 1,500 rpm the BSFC of the blends were twice as much as that of diesel. A reduction in carbon dioxide and carbon monoxide emissions were achieved up to 16.46 and 22.81 % respectively. The land requirement for the production of coconut oil to substitute 5 and 25 % of actual diesel consumption was 0.95 and 4.73 % respectively of the total area of Rodrigues Island. The economic analysis showed that a coconut oil production plant was profitable with payback periods ranging from 4.16 years for 5 %—COCO to 1.82 years for 25 %—COCO. Potential savings on diesel importation could range from Rs. 8,630,400 to Rs. 43,152,000.

Keywords Transportation · Coconut oil · Diesel oil blends · Engine performance · Rodrigues Island · CO_2 emissions avoided · Economic analysis

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*, Climate Change Management, DOI: 10.1007/978-3-642-37753-2_41,

Short Introduction

The transportation sector of most countries has evolved from wheel carts to petroleum fuelled vehicles. The petroleum fuel cars are usually run by gasoline and diesel. It has been observed that the transportation sector is the leading energy consuming sector of almost all countries. The economies of these countries are heavily bonded to their respective transportation sector. A particular fluctuation of the price of the petroleum products can create a chaos in the economy of a country. The first countries of the world to suffer from a future oil crisis will be the developing and underdeveloped countries such as Mauritius and consequently Rodrigues Island as well.

Introduction

The transportation sector of most countries has evolved from wheel carts to petroleum fuelled vehicles. The petroleum fuel cars are usually run by gasoline and diesel. It has been observed that the transportation sector is the leading energy consuming sector of almost all countries. The economies of these countries are heavily bonded to their respective transportation sector. A particular fluctuation of the price of the petroleum products can create a chaos in the economy of a country. The exponential increase and abrupt fluctuation of the price of petroleum products has aroused the awareness of the leaders of the world. Furthermore, the use of petroleum products enhances environmental problems such as the global warming effect on the world.

The first countries of the world to suffer from a future oil crisis will be the developing and underdeveloped countries such as Mauritius and consequently Rodrigues Island as well. Rodrigues Island is the second largest island of the Republic of Mauritius. The transportation sector of Rodrigues Island is fully dependent on petroleum products, mainly diesel and to a lesser extent gasoline. The number of vehicles is increasing considerably each year resulting in an increase in the fuel consumption.

The actual petroleum dependency and consumption trend will certainly lead the island to a disaster point of not having a single drop of fuel oil in their engine. The alternatives proposed to avoid this chaos are to either substitute the actual transportation fleet with hybrid vehicles or to substitute the petroleum fuels with vegetable oils, biofuel, synthetic fuels or biogas. The price of hybrid vehicle is quite expensive and unaffordable for the Rodriguans. Since most of the actual electricity production of the island is from heavy fuel oil, hybrid vehicles will not be a sustainable option. The only solution left is to opt for clean alternative fuels which can be produced locally such as coconut oil. The production of coconut oil fuel locally will effectively have a positive impact on the island economy and unemployment rate.

Coconut Oil as a Fuel

Coconut oil can be used in four ways in a diesel engine, namely:

- As a blend to diesel
- As a direct substitute to diesel
- As the base ingredient of the bio-diesel
- As a blend to bio-diesel

The different ways in which the coconut oil is used in a diesel engine is illustrated in Fig. 41.1. The study is focused on Route 1 only, i.e., Coconut oil blended with diesel. There is no or minor alteration on the diesel engine with coconut oil concentration below 20 % (Cloin et al. 2005).

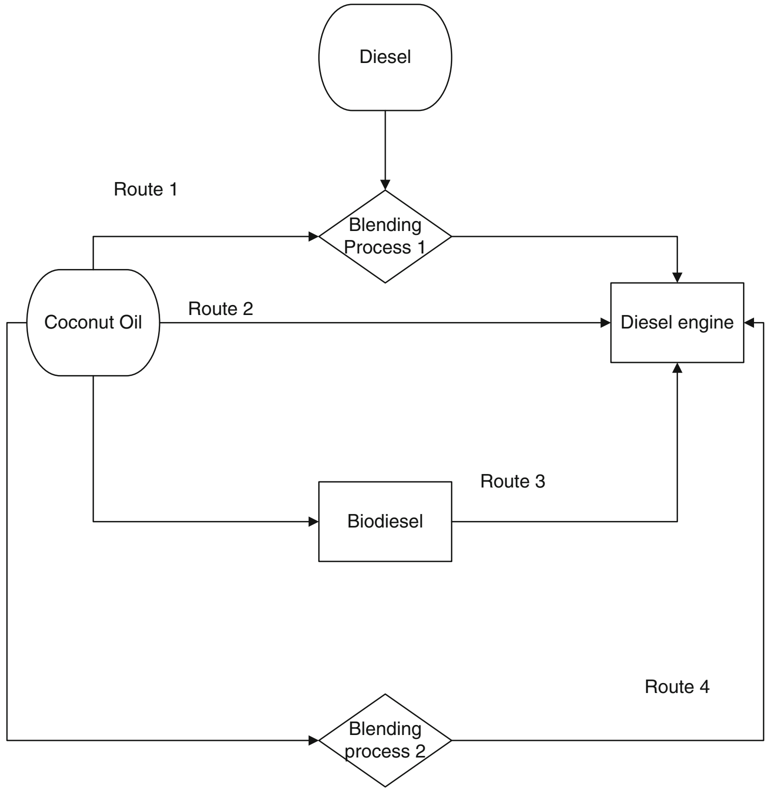


Fig. 41.1 Illustration of coconut oil as fuel

Comparison of Chemical and Physical Properties of Diesel and Coconut Oil

The percentage composition of carbon and hydrogen is almost the same for both fuels. Oxygen is present in coconut oil which is not the case for diesel and there is a higher concentration of sulphur in diesel than in the oil (Table 41.1).

The specific gravity and density of diesel are 5–10 % superior to coconut oil while there is a slight difference in the surface tension of the fuels. On the other hand, the viscosity of coconut oil can be 10 times greater than that of diesel at 40 °C. However, the viscosity of coconut oil can be decrease by either blending or heating.

Cetane number (CN) is a measurement of the combustion quality under diesel engine conditions. Coconut oil has a comparable CN to diesel. The difference in the boiling, freezing, flash and auto-ignition points are mainly due to the molecular bonding of each fuel. The higher calorific value of diesel is greater than that of coconut oil and can reach up to 10 MJ/kg difference.

Experimental Set-Up and Procedures

A Petter diesel engine coupled with a hydraulic dynamometer was used to determine the performance and exhaust emissions of the engine and fuel blends respectively. The characteristics of the engine are shown in Table 41.2. The Petter engine was connected to a Froude hydraulic dynamometer of type D.P.X non

Table 41.1 Chemical and physical properties of diesel and coconut oil

Property	Diesel	Coconut oil
Composition C/H/O ratio	0.357/0.643	0.317/0.631/0.0517
Sulphur (%wt)	0.100	<0.009
Iodine value	–	6.3–10.6
Specific gravity	0.82–0.88	0.9–0.915
Density (kg/m^3)	820–880	900–915
Viscosity @ 40 °C (cSt)	2–4	31.59
Cetane number	40–55	37–66
Surface tension (N/m)	0.0318	0.0348
Boiling point (°C)	160–366	>450
Freezing point (°C)	−40 to−34	23–26
Flash Point (°C)	>52	315
Auto-ignition Temperature (°C)	257	190–232
Heating Value (MJ/kg)	45.5	37.3
•High Calorific Value •Low Calorific Value	42.8	–66

Table 41.2 Engine Description

Description	Specification
Combustion chamber	Direct injection
No. of cylinders	2
No. of stroke per cycle	4
Cooling system	Water-cooled
Compression ratio	16.5:1
Bore x Stroke	80 mm × 110 mm
Cubic capacity	1106 cc
Maximum Rated Power at 1800 rpm	8.95 kW
Compression pressure	37.6 kg cm^{-2}
Maximum firing Pressure	73.8 kg cm^{-2}
Fuel injection release	176 kg cm^{-2}

reversible. A hydraulic dynamometer used the resistance offered by water within the system in order to measure the corresponding force, torque or power. The main shaft of the dynamometer was fixed by the bearing found in the casing.

The engine was directly coupled to the main shaft transmitting power to a rotor revolving inside the casing, through which water was distributed. The heat developed was carried away by the water. The hydraulic resistance applied a force upon the casing which turned on its anti-frictional support. This action was counteracted by a lever arm connected to a weighing balance. The resistance of the hydraulic dynamometer was varied by rotating a hand wheel as shown in Table 41.2.

The fuels used in this study were conventional diesel, coconut oil and coconut oil–diesel fuel blends. The conventional diesel and coconut oil were the parent fuel of the blends. The fuel blends were categorised as shown in Table 41.3. There was 5 % coconut oil by volume in the first blend and the percentage concentration was gradually increased to 25 %.

The test procedures were classified as follows:

1. Fuel Properties
2. Engine Performance
3. Exhaust Emissions

Table 41.3 Fuel composition

Fuel	Composition
Diesel (D)	100 % Diesel
5 %—COCO	5 % Coconut Oil + 95 % Diesel
10 %—COCO	10 % Coconut Oil + 90 % Diesel
15 %—COCO	15 % Coconut Oil + 85 % Diesel
20 %—COCO	20 % Coconut Oil + 80 % Diesel
25 %—COCO	25 % Coconut Oil + 75 % Diesel
COCO	100 % Coconut Oil

The Land requirement for coconut plantation in Rodrigues Island and an economic evaluation of locally produced coconut oil were also assessed.

Experiments were carried out to determine the Fuel properties such as density, viscosity and free fatty acid concentration of the different fuel blends. The calorific value and Cetane number of the coconut oil were derived from literature experiments data. The density, viscosity and free fatty acid concentration were measured by weighing a fixed volume of blend on an electronic balance, Brook-Field Synchro-Lectric RVT Model viscometer, titration with potassium hydroxide respectively. The Cetane number of the coconut oil was obtained from the Krisnangkura Equation (Krisnangkura 1986). The engine performance and exhaust gas emission of the different blends were evaluated using by the Froude hydraulic dynamometer and infra-red Kane automotive gas analyzer. The flue gas of the fuel blends were compared to that of conventional diesel.

The land requirement for the coconut cultivation was estimated from literature review data as shown in Eq. 41.1. The amount of coconut oil needed was obtained by using the importation data of diesel in Rodrigues Island for 2010 as a point of reference. The energetic factor is a ratio of the calorific value of diesel to that of coconut oil. It catered for the difference in calorific value of the two fuels.

$$\begin{gathered} Required\,Volume\,of\,coconut\,oil\,peryear = \\ \%\,Concentration\,of\,coconut\,oil\,x\,annual\,Diesel\,consumption \times EnergeticFactor. \end{gathered} \tag{41.1}$$

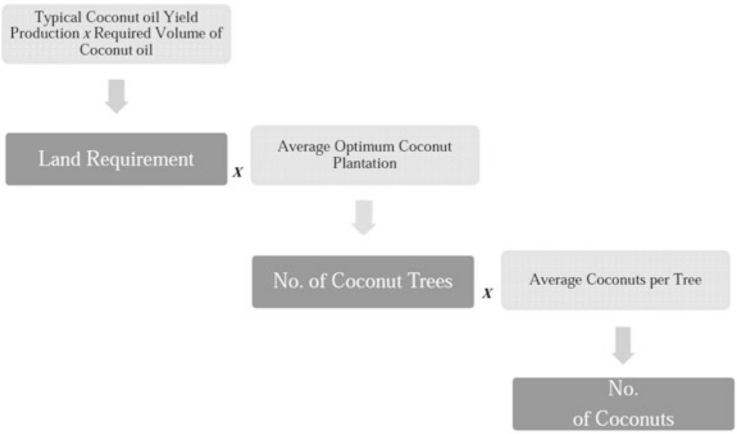
The number of coconuts trees and coconuts were also estimated by using the relations shown in Fig. 41.2.

An economic analysis was performed for a local coconut oil production. The raw material was dried copra and the sales of the by-products of the coconut were not taken into account. The estimation of the cost of the raw materials and coconut oil produced were based on literature review data, quotations as well as taking local constraints into consideration. The size and throughput of the equipment were determined for the respective blends based on the amount of dry copra and coconut oil processed. The total capital investment, profit, payback period and internal rate of return were evaluated for the different coconut oil production percentage.

General Findings

Fuel Properties

There was a slight increase in the density of the fuel blends as the coconut oil concentration was increased. A graph of density against coconut oil concentration was plotted and a straight line was generated with a gradient of 1 kg m^{-3}. The kinematic viscosity had a likewise change as the density with an increase of



	Typical Value	Source
Coconut oil yield production per hectare	2,470 Litres	ASTAE, 2009
Average optimum coconut trees per hectare	175	Fernando & Bandaranayake, 1996
Average coconuts per coconut tree	67	Kumar, 2006

Fig. 41.2 Land requirement calculations

coconut oil concentration. The kinematic viscosity was significantly higher than that of diesel. Although coconut oil was 3 times more viscous than diesel, the viscosity of 25 %—COCO was only 30 %-greater than that of diesel. The viscosity of coconut oil was reduced when blended to diesel. The calorific value of the blends acted differently from the density and viscosity scenarios. The calorific value of the COCO blend decreased by 0.096 MJ/kg for each percentage increases in the concentration of coconut oil. The coconut oil was of moderate quality as it had an acid value of 3.77. The Cetane number of the coconut oil was close to that of diesel (Table 41.4).

Table 41.4 Fuel properties

	Diesel	5 %—COCO	10 %—COCO	15 %—COCO	20 %—COCO	25 %—COCO	COCO
Density (kg/m^3)	804	809	814	819	823	826	904
Viscosity (cSt)	2.24	2.35	2.46	2.63	2.73	2.91	8.41
Calorific value (MJ/kg)	45.5	45.0	44.5	44.0	43.6	43.1	35.8
Acid value/oil quality	–	–	–	–	–	–	3.77
Cetane number	–	–	–	–	–	–	59

Engine Performance

The variation of brake power at different speed of the engine of all the fuels is shown in Fig. 41.3. Almost all the fuel lines generated the same trend line except for 20 %—COCO fuel blend. It was observed that as engine speed tended to infinity, the brake power reached zero. The highest brake power of 4.5 kW was recorded with 25 %—COCO blend which was greater than that of diesel. However, diesel had a constant brake power over a larger range of engine speed tested than any other fuel. 10 %—COCO blend yielded a greater brake power over a wider range of engine speed than 5 %—COCO, 15 %—COCO and 20 %—COCO blends. The brake power of all the fuel blends at around 1,530 rpm was about 0.254 kW while the brake power of diesel at the same range of engine speed was twice as much, 0.506 kW. These values were obtained with the minimum amount of brake load applied ranging from 1 to 2 pounds.

The brake specific fuel consumption (BSFC) of the fuels at different engine speed and brake power is shown in Figs. 41.4, 41.5 respectively. In Fig. 41.4, all the fuel lines had BSFC of less than 0.75 kg/kWh up to 1,500 rpm. However, as the engine speed was increased up to 1,530 rpm, the BSFC of the fuels consequently increased abruptly with a steep gradient. The BSFC of diesel was lower than that of the fuel blends. Since, coconut oil had a lower calorific value than diesel; the engine consumed more fuel to obtain the desirable power to operate at high engine speed.

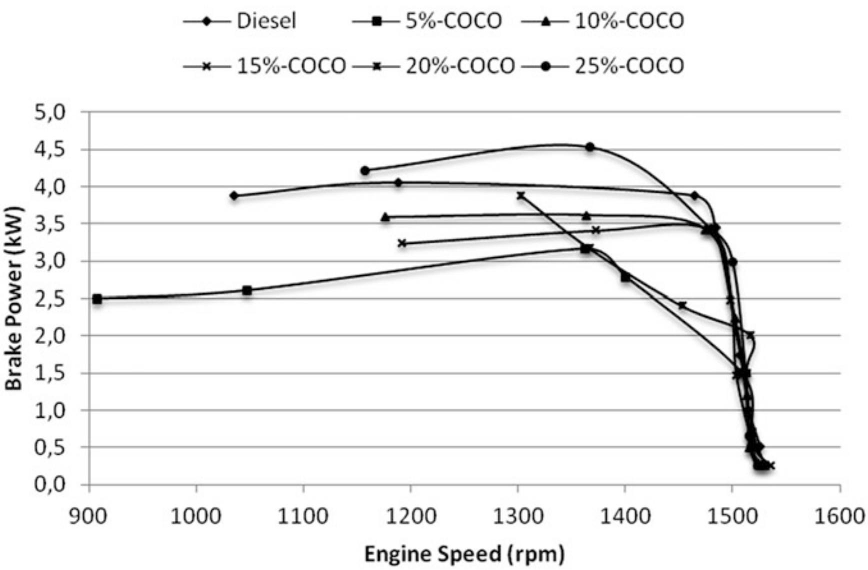


Fig. 41.3 Brake power versus engine speed

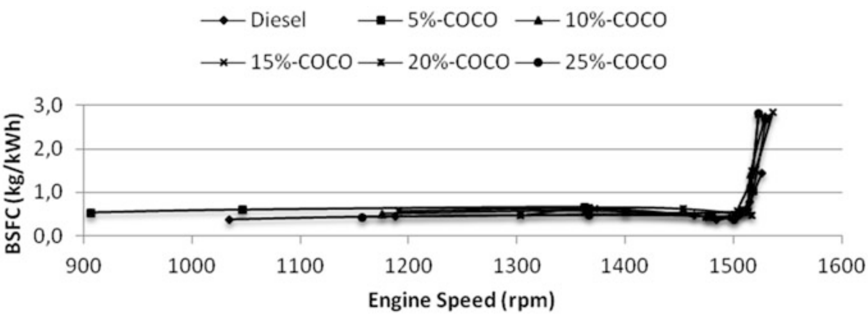


Fig. 41.4 BSFC versus engine speed

All the fuels had greater BSFC at their respective minimum brake power or load in Fig. 41.5. The BSFC of the fuel blends at minimum load ranged from 2.7 to 2.8 kg/kWh while the BSFC of diesel at corresponding load was 1.4 kg/kWh. The maximum BSFC was obtained with 15 %—COCO blend which was 2.836 kg/kWh followed by 25 %—COCO blend with 2.808 kg/kWh. The BSFC of all fuels decreases below 1 kg/kWh when brake power was greater than 1 kW. The BSFC of the fuels decreased slightly even though after reaching the maximum brake power point. The maximum brake power of diesel was 4.06 kW with a BSFC of 0.444 kg/kWh while that of 25 %—COCO blend was 4.532 kW with a BSFC of 0.478 kg/kWh. The engine consumed almost the same amount of diesel and 25 %—COCO blend to generate 1 kWh at maximum brake power.

The linear relationship of average fuel consumption and brake power is called William's Line. An extrapolation of the William's Line to zero on the horizontal axis yields to the frictional losses within the engine. The William's Lines of the fuels are shown in Fig. 41.6 and their corresponding gradient and y-intercept are tabulated in Table 41.5.

The fuel consumption-brake power data did not generate a perfect straight line as it turned up slightly at low loads and considerably at full loads. The frictional power of the fuels ranged from 0.96 kW to 1.66 kW. The fuel consumption required by

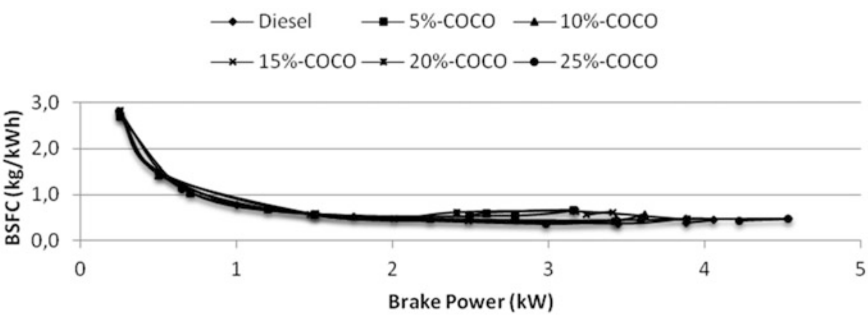


Fig. 41.5 BSFC versus brake power

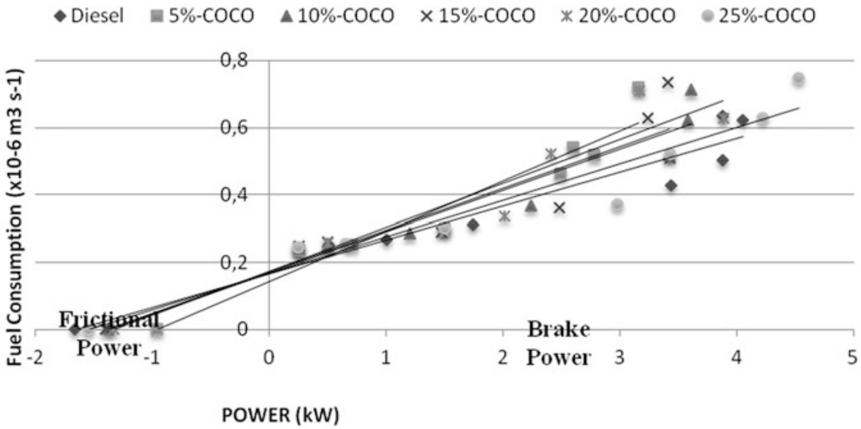


Fig. 41.6 William's line diagram of the fuels

Table 41.5 William's line results

	Fuel consumption per kW ($m^3\ s^{-1}\ kW^{-1}$)	Fuel consumption for frictional power ($\times\ 10^{-6}\ m^3\ s^{-1}$)
Diesel	0.100	0.166
5 %—COCO	0.149	0.143
10 %—COCO	0.122	0.168
15 %—COCO	0.123	0.172
20 %—COCO	0.130	0.173
25 %—COCO	0.108	0.167

the engine to overcome frictional power was around $1.7 \times 10^{-7}\ m^3\ s^{-1}$ with most of the blends. The exception was obtained with 5 %—COCO. The slope of the William's line of diesel was 0.1 $m^3\ s^{-1}$/kW which meant that 0.1 $m^3\ s^{-1}$ of diesel was required to produce 1 kW of power. 25 %—COCO was the more energy effective blend while 5 %—COCO was the least energy effective blend. The engine blends had similar consumption pattern 10 %—COCO and 15 %—COCO.

The experimental fuel consumption-brake power data obtained for the different fuels followed the profile stated in the literature review. Hence, the requirements which were set in order to generate the William's Line were achieved. The trend of the fuel consumption with increasing coconut oil concentration in order to generate 1 kW of power was not constant, but was still greater than that of diesel. The reason for that irregular trend could be explained by the different frictional power obtained for the fuels.

The mechanical efficiencies of the fuels at varying brake power are shown in Fig. 41.7. All the fuel blends had greater mechanical efficiency than diesel. 5 %—COCO blend had the greatest mechanical efficiency of all fuels. The mechanical efficiency curves of 10, 15 and 20 %—COCO blends were relatively

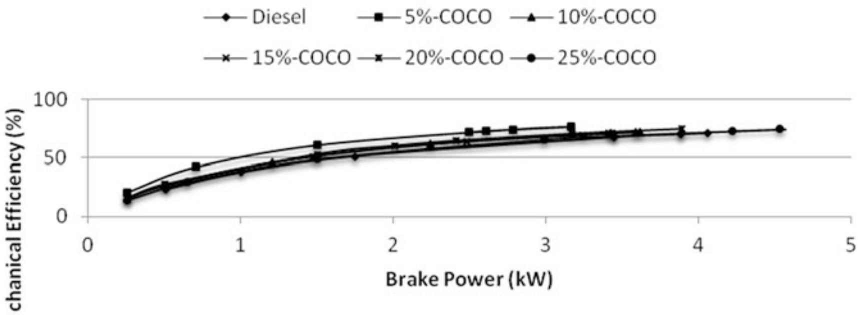


Fig. 41.7 Mechanical efficiency

similar. The mechanical efficiency curve nearer to diesel was obtained with the 25 %—COCO blend.

The total power produced increased with the addition of coconut oil in the mixture. The maximum power generated was obtained with 25 %—COCO blend with 6.08 kW. The brake power of diesel was 0.36 kW lesser than that of 25 %—COCO. 5 %—COCO blend had the least maximum brake power and frictional power of all fuels. The power generated by 10 %—COCO was higher than 15 %—COCO but lower than 20 %—COCO blend. The maximum mechanical efficiency that was obtained with the different fuels was tabulated below (Table 41.6).

The maximum mechanical efficiency was recorded with 5 %—COCO although it had the lowest brake power of all the fuels. On the other hand, 5 %—COCO had the lowest frictional power of the fuels by a greater margin which compensated its small brake power. The higher mechanical efficiency recorded was explained by the positive effect of the COCO blends on the frictional power.

Flue Gas Emission

The relative flue gas emission was based on the exhaust emission obtained with diesel fuel. The percentage volume composition recorded by the flue gas analyser with diesel as fuel is shown in Table 41.7. The percentage volume of carbon

Table 41.6 Mechanical efficiency results

	Frictional power (kW)	Maximum brake power (kW)	Maximum η_{mech} (%)
Diesel	1.66	4.06	71.0
5 %—COCO	0.96	3.16	76.7
10 %—COCO	1.38	3.62	72.4
15 %—COCO	1.40	3.43	71.1
20 %—COCO	1.33	3.89	74.5
25 %—COCO	1.55	4.53	74.6

Table 41.7 Diesel flue gas emission

Flue gas	No load		With load		Average
Carbon monoxide (% vol)	0.17	0.18	0.09	0.13	0.14
Carbon dioxide (% vol)	3.30	3.30	8.30	8.80	5.93
Oxygen (% vol)	16.77	16.84	9.89	9.29	13.20
Nitrogen oxides (ppm)	152	148	674	726	425

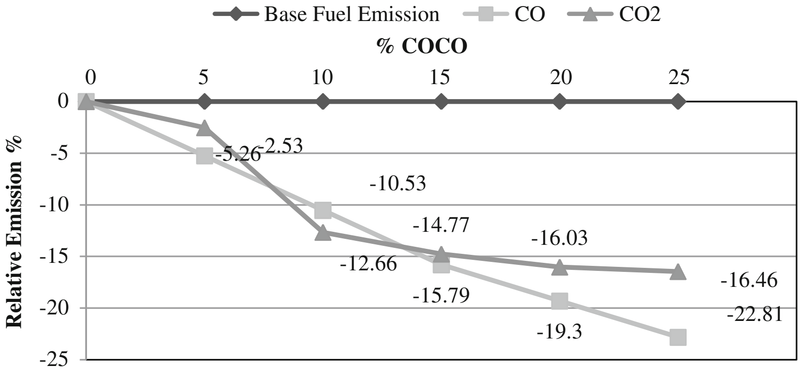


Fig. 41.8 Relative flue gas emissions

monoxide and oxygen decreased with an increase in the brake load. Conversely, the percentage volume of carbon dioxide and nitrogen oxide increased with additional load. The average percentage composition of nitrogen gas in the exhaust was 80.7 %.

The relative emissions of carbon monoxide and carbon dioxide for the different blends are shown in Fig. 41.8. The carbon monoxide and carbon dioxide decreased up 22.81 and 16.46 % respectively with a 25 %—COCO blend. The line generated by the carbon monoxide line had a steeper gradient than that of carbon dioxide. The relative emission of carbon dioxide almost stabilised at 16–17 % while that of carbon dioxide continued to diminish. The presence of oxygen molecule in the coconut oil favoured complete combustion thus decreasing the carbon monoxide emission.

The relative emission of nitrogen oxides were not accounted for since no data were recorded for nitrogen oxides emission by the flue gas analyser. There could have been a technical problem with the apparatus or the nitrogen oxides emission was below the standard limit of the flue gas analyser. The smoke intensity of the exhaust was visually assessed and there was a noticeable decrease with increasing coconut oil concentration. A pleasant coconut oil smell was detected with 15, 20 and 25 %—COCO blend.

The exhaust emissions were reduced with increasing COCO in blends except for carbon dioxide (Kalam et al. 2003). However, a reduction in all the exhaust gases including carbon dioxide was observed with increase COCO in blends during the experiments. It could be explained by the higher carbon percentage composition present in Diesel.

Land Requirement for Coconut Plantation

The land required for coconut plantation was calculated for production of coconut oil for different scenarios. The land requirement eventually increased as the production of coconut oil was increased. The minimum land requirement for the production of coconut oil would be about 102 ha, which is less than 1 % of the total surface area of Rodrigues. It was estimated that 102 ha was required for each 5 % increase in the production of coconut oil. The number of coconuts needed per year for the production of 252,156–1,260,782 litres would range from 1,196,975 to 5,984,886. A total of 357,307 coconut trees would be required to meet the actual demand of diesel on the island with a corresponding percentage land requirement was about 19 %.

However, unoccupied agricultural land of Rodrigues island should be determined in order to find out the actual potential of the coconut plantation. It is worth noting that Table 41.8 data represented land requirement for the cultivation of coconut trees only. The area needed for coconut oil processing and extraction were not included in the study. The land requirement for these processes was dependent on the type of equipment used. Figure 41.9 gives a broad overview of the actual land requirement for the different case scenarios.

Economic Analysis

The economic analysis was performed for a plant producing coconut oil with dry copra as raw material. The sales of the valuable by-products of the coconut and the relevant cost incurred previous to the dry copra production were not taken into

Table 41.8 Land requirement data

% COCO	Required volume of COCO (litres/year)	No. of coconuts/year	No. of coconut trees	Land required(ha)	%Land requirement(%)
5	252,156	1,196,975	17,865	102	0.95
10	504,313	2,393,955	35,731	204	1.89
15	756,469	3,590,931	53,596	306	2.84
20	1,008,626	4,787,911	71,461	408	3.78
25	1,260,782	5,984,886	89,327	510	4.73
100	5,043,128	23,939,547	357,307	2,042	18.91

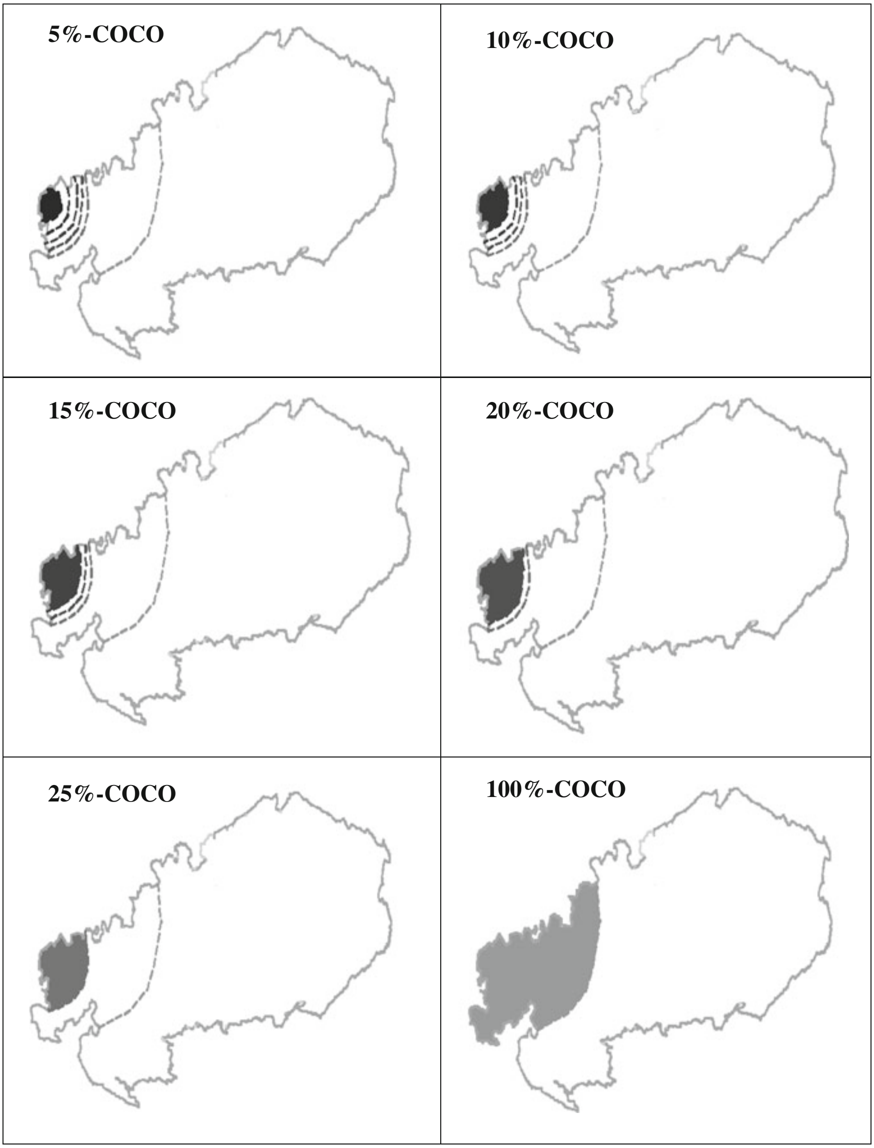


Fig. 41.9 Land requirement

account. The estimation of the cost of the dry copra was based on the price of coconut on the local market as well as taking in consideration that there would be additional revenue from the sales of the by-products. On the other hand, the selling price of the coconut oil coconut oil produced was based on literature review data and quotations.

Table 41.9 Economic evaluation Results

	5 %—COCO	10 %—COCO	15 %—COCO	20 %—COCO	25 %—COCO
Revenue (Rs/year)	9,329,772	18,659,575	27,989,353	37,319,162	46,648,934
Total product cost (TPC) (Rs/year)	9,052,735	18,050,592	27,038,000	36,024,771	44,997,292
Profit (Rs/year)	277,037	608,983	951,353	1,294,391	1,651,642
Total capital investment (TCI) (Rs/year)	1,151,822	1,738,223	2,216,971	2,634,655	3,012,101
Pay back period (PBP) (year)	4.16	2.85	2.33	2.08	1.82
IRR (%)	23 %	35 %	43 %	49 %	55 %
Savings on diesel (Rs/year)	8,630,400	17,260,800	25,891,200	34,521,600	43,152,000

A positive economic response was obtained for all the blends. However, the minimum TCI required for starting a COCO plant was Rs. 1,151,822. The average cost of raw material and labour cost per litre of oil production were Rs. 18 and Rs. 4 respectively while the average profit was estimated to be around Rs. 1.38 per litre. The payback period of 5 %—COCO and 25 %—COCO was 4.16 and 1.82 years respectively. There was a subsequent increase in the IRR with an increase in coconut oil production. The savings on the importation of diesel ranged from Rs. 8,630,400 to Rs. 43,152,000. A summary of the economic evaluation of the fuels is shown in Table 41.9.

Conclusion

The conclusions that were drawn from this study are:

1. The properties of coconut oil were comparable to that of conventional diesel.
2. The engine ran smoothly with coconut oil–diesel blends tested and no engine modification was required.
3. BSFC for both diesel and blends were around 0.5 kg/kWh with engine revolution below 1,500 rpm; but above 1,500 rpm the BSFC of the blends were twice as much as that of diesel.
4. The mechanical efficiency of the engine obtained with the blends was greater than diesel since coconut oil had a positive effect on the frictional power of the engine.
5. The presence of coconut oil in the blends considerably reduced the emission of carbon dioxide and carbon monoxide as well as the smoke intensity. The percentage carbon composition and the presence of oxygen in the coconut oil contributed to a reduction of carbon dioxide and carbon monoxide up to 16.46 and 22.81 % respectively.

6. The land requirement for the production of coconut oil to substitute 5–25 % of actual diesel consumption was 0.95 and 4.73 % respectively of the total area of Rodrigues Island.
7. The production of coconut oil would be economically feasible in the island with all case scenarios.

A general conclusion is that all the tested coconut oil–diesel blends can be used safely in the diesel engine. The only limitation is that at high loads, the fuel consumption of the engine with the blends is much higher than with diesel. Since all the economic case scenarios of coconut oil production are feasible, the island can start replacing the actual diesel consumption by 5 % and gradually increase to 25 % diesel consumption displacement. There will be numerous job creations from craftsmen to engineer which will help to decrease the actual high unemployment rate on the island. Moreover, the plantation of coconut trees not only reduce the carbon emissions but also act as a barrier to sand and soil erosion which is actually a major problem in Rodrigues island. The evaluation of the economical, environmental and social aspects of the project showed that the project is a sustainable and will greatly improve the well-being of the Rodriguans.

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Chapter 42
Investigation of Vegetable Oil Conversion by Thermal Deoxygenation and Cracking for Alternative Biofuel Generation

Christian Augustin and Thomas Willner

Abstract The shortage of worldwide resources, the discussion about the global warming as well as energy independence policies are driving forces for developing new alternative fuel technologies based on renewable sources. One possibility is the conversion of vegetable oil into cracked vegetable oil (CVO) by cracking and deoxygenating in small decentralized plants. This paper describes a study in the context of which the conversion has been investigated on laboratory scale under atmospheric pressure in the absence of catalysts at temperatures from 350 to 400 °C. Under these conditions different feedstocks have been tested such as refined rapeseed oil, crude rapeseed oil, palm oil and used frying oil. Resulting yield of CVO is about 70–80 wt.−%. The measured physical properties of CVO are well complying with the specifications of the diesel standard DIN EN 590. Due to chain length reduction by cracking viscosity is decreased and cold stability is improved in CVO. Even in case of palm oil the resulting CVO stays liquid at room temperature. The kinetics of the deoxygenation of the raw material can be described by the decrease of the oxygen content in the oil during reaction time. The oxygen content can be calculated by the net calorific value which has been confirmed by elemental analysis. In case of rapeseed oil, the oxygen content can be reduced from 11 wt.−% to a level of 3–5 wt.−% while the net calorific value is increased from 37 MJ/kg to a level above 40 MJ/kg. The results indicate a chance to produce alternative fuels from vegetable oils with improved properties compared to biodiesel.

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_42,

Keywords Deoxygenation · Cracking · Triacylglycerol · Palm oil · Rapeseed oil · Used frying oil · Cracked vegetable oil · CVO · Kinetics · Physical properties · Biofuel

Short introduction

This paper describes the conversion of vegetable oil into an alternative diesel fuel. The conversion takes place in a stainless steel reactor under ambient pressure without any catalyst. The investigated raw materials are rapeseed oil, bio rapeseed oil and palm oil. These oils are used as model substances for the conversion of used frying oil. The results are shown in the paper in comparison to the European diesel standard. A special focus lies on the increase of the energy density due to the removal of oxygen. In this paper is also a kinetic study about the oxygen removal.

Introduction

The known deposits of fossil fuels are going to decrease. This gap must be replenished with new resources which are getting more and more expensive due to increasingly difficult development (World Energy Outlook 2010). There is no question about "if", but rather "when" alternatives are needed to replace existing energy sources. The rising energy demand of the world as well as energy independence policies intensifies this problem. A further demand next to the exploration of alternative energy sources, CO_2-neutral energy sources are inevitable to reduce the effects of global warming. One way to address this problem is the use of renewable energy sources such as biomass. But the change to alternative energy sources alone will not solve the world's energy problem. In addition, energy savings are indispensable.

A special demand is expected to arise from the transportation and aviation sector. These sectors need fuels with high energy density especially for traveling long distances and for carrying heavy loads. A comparison of presently discussed alternative fuel options shows that maximum energy density is provided by liquid hydrocarbons (Fig. 42.1). Thus liquid hydrocarbons are favorite fuels for aviation and long distance driving.

Most of the currently used liquid hydrocarbons have a net energy density of approx. 35 GJ/m^3. That is about two times higher than the next best alternatives, such as alcohols, liquefied methane or hydrogen in form of light metal hydrides, the latter being still in development (World Energy Outlook 2010). One major question is how to produce liquid hydrocarbons based on renewable feedstock sources. Triacylglcerols of fats and oils is the group of renewable substances, which is closest to the fossil fuels due to low oxygen content. According to

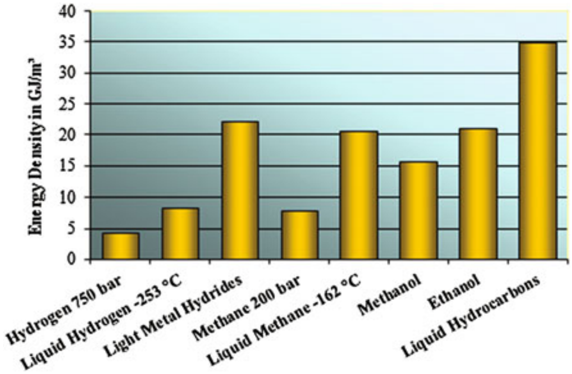

Fig. 42.1 Energy density comparison for alternative fuels

11 wt.−% oxygen content they reach an average net energy density of about 34 GJ/m^3. But the direct combustion of vegetable oils in I.C. (internal combustion) engines leads to other problems, such as high viscosity affecting injection systems or poor cold stability leading to solidification at ambient conditions as in the case of palm oil e.g. as well as shorter oil change intervals due to triacylglycerol enrichment in the lubricating oil accompanied by polymerization reactions (Ramadhas et al. 2004).

The viscosity of vegetable oil fuels can be decreased by transesterification of vegetable oils into FAME (fatty acid methyl ester), commonly known as biodiesel. This process has been applied and studied extensively in the last years. Both cold stability and net calorific value is not significantly improved by transesterification, the latter due to the fact that no oxygen is removed. In diesel engines FAME cause some problems due to narrow boiling range caused by narrow chain length distribution, for example again the necessity of shorter oil change intervals (Ma and Hanna 1999). According to these significant differences between biodiesel and conventional diesel fuel the biodiesel content in diesel fuel is limited to 7 vol.−% (B7) in Germany.

Thus further upgrading of vegetable oils is needed for property improvement such as oxygen reduction and adjustment of chain length distribution. This can be achieved by a combination of cracking and deoxygenation or hydrogenation. In case of hydrogenation both pressurized hydrogen and catalysts is needed involving increased production costs. Therefore, thermal cracking and deoxygenation at ambient pressure without catalysts could be an alternative for improving cost effectiveness. The aim of this work is to investigate the thermal conversion process at atmospheric pressure. Particularly, global kinetics for cracking of vegetable oils, and oxygen reduction will be examined. The resulting products of thermal cracking and deoxygenation are called CVO (cracked vegetable oils).

Materials, Methods and Experimental Results

Raw Materials

The main focus for a technical application of the deoxygenation of triacylglycerols may be the processing of used frying fat due to the fact that the reuse of vegetable oil does not compete with the food market. Refined rapeseed oil, crude rapeseed oil and palm oil have been used as model substances since they are the main components of frying fat. The examined feedstocks are shown in Fig. 42.2. The refined rapeseed oil and the crude rapeseed oil are liquid at ambient temperature, the palm oil is solid and the used frying fat separates in a solid part at the bottom due to the palm oil content and a liquid phase above.

The physical data of the feedstocks is shown in Table 42.1. In all cases the densities are in the same range. The viscosity of the palm oil is slightly higher compared to the viscosities of the two rapeseed oils. This is caused by the lower cold temperature stability of palm oil. The higher acid number of the used frying oil indicates an increased content of free fatty acids resulting in higher water content and accordingly lower net calorific value. The ageing of the used frying oil due to the thermal load is also shown in terms of higher viscosity.

Oxygen Content Calculation Method

An adequate instrument to determine the oxygen reduction of thermal cracking experiments is the net calorific value (H_U). With decreasing oxygen content the

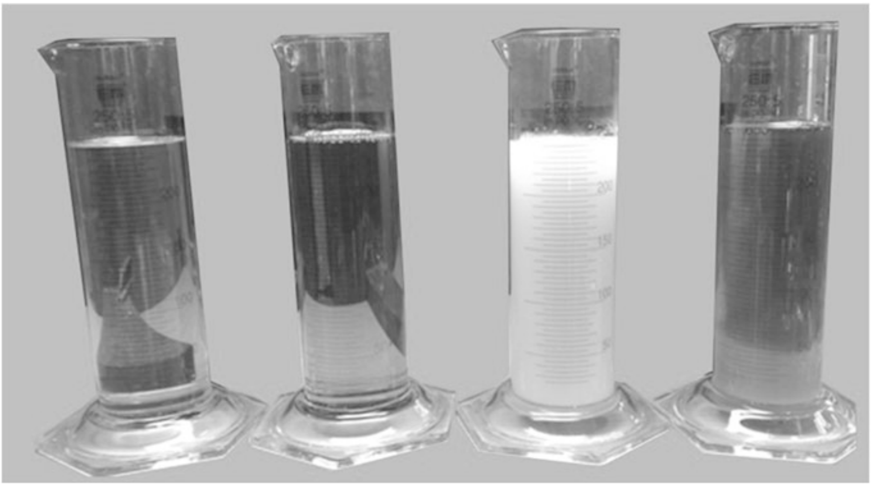

Fig. 42.2 Feedstocks: rapeseed oil, crude rapeseed oil, palm oil and used frying oil

Table 42.1 Feedstock data for rapeseed oil, bio rapeseed oil, palm oil and used frying oil

	Rapeseed oil	Bio rapeseed oil	Palm oil	Used frying oil
Density 15 °C [kg/m^3]	924	924	928*	931
Density 40 °C [kg/m^3]	890	890	885	896
Viscosity 40 °C [mm^2/s]	35.3	34.4	42.5	44.5
Acid number [mg KOH/g oil]	1.4	2.9	1.0	6.2
Iodine number [g I_2/100 g oil]	112	111	52	107
Gross calorific value [kJ/kg]	39,900	40,100	39,800	38,500
Net calorific value [kJ/kg]	37,500	37,800	37,400	36,100
Water content [wt %]	0.03**	0.05**	0.02**	0.14**
Melting point [°C]	-***	-***	35.5	-***

* measured with the gas pycnometer, ** near the detection limit 0.01 wt.−%, *** not measured

calorific value increases. The net calorific value is measured with a bomb calorimeter which is cheaper in terms of investment than an elemental analysis. The influence of the oxygen content on the net calorific value is shown in well-known formulas. One possible approach for the calculation of net calorific value out of the elemental analysis is the formula of Dulong (42.1). Vice versa the oxygen content can be calculated, if the H/C ratio and the net calorific value are known (Grote and Feldhusen 2007).

$$H_U = 33.9 \cdot C + 121.4 \cdot (H - 0/8) + 10.5 \cdot S - 2.44 \cdot w \ \ [\mathrm{MJ/kg}] \tag{42.1}$$

(Mass fraction of C (carbon), H (hydrogen), O (oxygen), S (sulfur) and w (water content)).

For younger fuels Boie's formula (42.2) is more accurate than the formula of Dulong(Boie 1957).

$$H_U = 35 \cdot C + 94.3 \cdot H + 10.4 \cdot S + 6.3 \cdot N - 10.8 \cdot O - 2.44 \cdot w \ \ [\mathrm{MJ/kg}] \tag{42.2}$$

(Mass fraction of C (carbon), H (hydrogen), S (sulfur), N (nitrogen), O (oxygen), and w (water content))

Table 42.2 Comparison between the net calorific values of different substances from literature and the respective values calculated by the formulas of Dulong (42.1) and Boie (42.2)

Name	Molecular formula	Net calorific value from literature [MJ/kg]	Net calorific value according to Dulong [MJ/kg]	Net calorific value according to Boie [MJ/kg]
Methane	CH_4	50.0 [4]	55.9	49.9
Ethanol	C_2H_6O	27.0 [4]	28.3	26.9
Maleic acid	$C_4H_4O_4$	11.9 [6]	9.9	11.8
Saccharose	$C_{12}H_{22}O_{11}$	15.1 [6]	14.3	15.3

Examples of such calculations are shown in Table 42.2. It turns out that in all cases shown here, the calculation formula of Boie is more precise than the formula of Dulong. Therefore, the formula of Boie has been used in this work.

Refined rapeseed oil has been used as a model substance for the kinetic investigations during the thermal decomposition of vegetable oils. The net calorific value is calculated from the composition of fatty acids of the rapeseed oil with the formula of Boie. According to Henry Lamotte Oils GmbH (2009) the used rapeseed oil has a fatty acid composition with 61 wt.−% oleic acid ($C_{18}H_{34}O_2$), 22 wt.−% linoleic acid ($C_{18}H_{32}O_2$), 10 wt.−% linolenic acid ($C_{18}H_{30}O_2$), 5 wt.−% palmitic acid ($C_{16}H_{32}O_2$) and 2 wt.−% stearic acid ($C_{18}H_{36}O_2$). The calculation of the total molecular formula (42.3) of the rapeseed oil is compiled, assuming three fatty acid molecules per glycerol molecule. According to the fatty acid composition the calculated elemental composition of rapeseed oil is:

$$77.5\,\text{wt.} - \%\,\text{C},\ 11.6\,\text{wt.} - \%\,\text{H},\ 10.9\,\text{wt.} - \%\,\text{O}\quad \text{H/C ratio } 1.8$$

$$\text{Molecular formula}_{\text{triacylglcerol}} = 3 \cdot [\text{fatty acid}] + \text{glycerol} - 3\ \text{H}_2\text{O} \tag{42.3}$$

The composition of rapeseed oil is verified with the elemental analysis (Elemantar Microcube Vario EL). The measured elemental composition of the used rapeseed oil is:

$$77.5\,\text{wt.} - \%\,\text{C},\ 11.8\,\text{wt.} - \%\,\text{H},\ 10.7\,\text{wt.} - \%\,\text{O}\quad \text{H/C ratio } 1.8$$

This agrees well with the calculated composition above. Three options are now available for the determination of the net calorific value:

- Measurement of the net calorific value by bomb calorimeter (IKA C 2000).
- Calculation of the net calorific value out of the calculated elemental composition.
- Calculation of the net calorific value out of the measured elemental composition.

The results of all methods are shown in Table 42.3.

The determined net calorific values show good agreement. Thus it is feasible to carry out further calculations of the elemental composition based on measured calorific values.

Table 42.3 Comparison of the net calorific values: measured with the bomb calorimeter, calculated out of the calculated elemental composition with Boie and calculated out of the elemental analysis with Boie

37.0	MJ/kg	Measured with bomb calorimeter
36.9	MJ/kg	Calculated out of the calculated elemental composition with formula 42.2
37.0	MJ/kg	Calculated out of the measured elemental analysis with formula 42.2

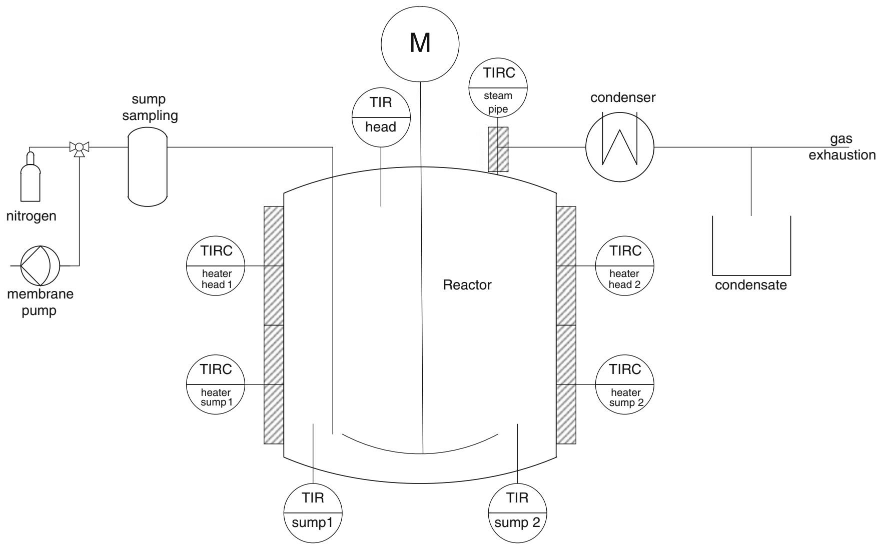

Fig. 42.3 The experimental setup for oil cracking, stainless steel reactor

Experimental Setup

Figure 42.3 shows the flowchart of the experimental setup for the thermal deoxygenation and cracking of vegetable oils. The 4 liter batch reactor is equipped with stirrer and electric heating, two heating sleeves, one at the top (head) and one at the bottom (sump) of the reactor. The data acquisition and process control system is a Siemens Simatic PCS 7 with Win CC visualization. The process is observed with several thermocouple elements. The reaction temperature of the liquid phase (sump phase) is controlled by PID controller and the sump heating sleeve. The vegetable oil is filled in through an inlet screw on the top of the reactor. At the bottom an oil outlet screw is installed to release the sump phase at the end of the experiment.

During the experiments the gaseous and volatile cracking products leave the reactor through the top steam pipe. The condensable products such as cracked vegetable oil (CVO) and water phase are collected in liquid state after cooling and condensation. Sump phase sampling during reaction time enables the determination of the oxygen reduction kinetics. It is equipped with nitrogen purge, membrane pump and sampling glasses.

Experimental Procedure of Kinetics Investigations

For the investigation of the reaction kinetics the reactor is filled with approx. 1.8 kg of rapeseed oil. During the heating period the reactor is purged with

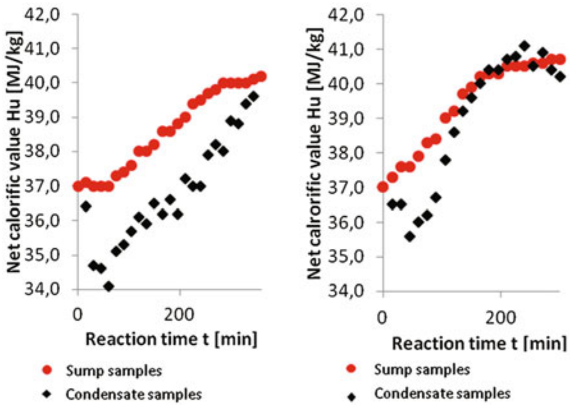

Fig. 42.4 Net calorific value developing of sump phase and the CVO condensates at different temperatures 360, 370 and 380 °C

nitrogen. When the reaction temperature is reached the first sump phase and condensate samples are taken. The experiments are carried out at three temperature levels 360, 370 and 380 °C. The sampling interval is 15 min.

Experimental Results of Kinetics Investigations

For both sump phase and CVO condensates Fig. 42.4 shows the measured net calorific values of the experiments over the reaction time. The experiment at 380 °C shows a shortened reaction time. The expeditious decrease of the level in the reactor is due to the high reaction rates at the temperature of 380 °C. That is the reason for reduced sample number for the 380 °C test run.

During the early reaction stage the net calorific values of sump phase and CVO condensates show different trends. The sump value is continuously increasing while the CVO value is initially decreasing followed by continuously increasing. Apart from that the calorific values of both sump phase and CVO condensates start at the same level of 37 MJ/kg and they finally reach the same level of appr. 40 MJ/kg. Formation of capric acid, a decomposition product of oleic acid, might be the reason for the initially decreasing calorific values of the CVO condensates due to higher oxygen content of the capric acid compared to rapeseed oil.

Modeling of Deoxygenation Kinetics

As a first approach of thermal deoxygenation kinetics modeling the sump phase has been considered only. A mathematical model for the condensate fraction is

Table 42.4 Elementary analysis and molar H/C ratio of sump phase samples of the 370 °C run

Experiment at 370 °C	Carbon [wt −%]	Hydrogen [wt −%]	Oxygen [wt −%]	H/C ratio
Sump sample after 15 min reaction time	78.03	11.88	10.09	1.81
Sump sample after 105 min reaction time	82.04	11.93	6.03	1.73
Sump sample after 300 min reaction time	85.73	11.96	2.31	1.66

going to be created in a following project, when the chemical procedures concerning the oxygen degradation in the sump phase are better understood. The calculation of the oxygen content from the net calorific value of the sump phase samples according to Boie requires the definition of a H/C ratio. Otherwise there are too many degrees of freedom in the formula of Boie. The elemental analysis of some representative sump phase samples of the experiment at 370 °C is shown in Table 42.4. The H/C ratio is slightly decreasing with increasing reaction time. For the following calculations the H/C ratio of the sump phase is set on an average value of 1.7.

The calculated oxygen content of the sump phase samples over reaction time based on the H/C ratio of 1.7 is shown in Fig. 42.5. The oxygen reduction kinetics is calculated according to a first order reaction. A first order reaction is mathematically described by formula (42.4).

$$r = -\frac{dw_0}{dt} = k \cdot w_O (r = \text{rate of reaction}, w_O = \text{oxygen mass per cent}, k = \text{rate constant}) \tag{42.4}$$

After integration assuming isothermal reaction conditions the reaction rate constant k can be determined according to the linear relationship of formula (42.5) (Schwister 2010).

$$\ln w_O = -k \cdot t + \ln w_{0,O} \left(t = \text{reaction time}, w_{O,0} = \text{oxygen mass per cent at } t = 0 \text{ min}\right) \tag{42.5}$$

The oxygen reduction modeling according to first order reaction compared to experimental data is shown in Fig. 42.5. Apart from the early reaction period the first order modeling of the experimental results seems to be suitable. However, the early stage indicates some reaction delay followed by acceleration. Further improvement of modeling such as the application of an auto-catalytic model is in preparation.

The determined reaction rate constants as a function of temperature can be described by the Arrhenius equation. The Arrhenius equation is shown in formula (42.6). The corresponding Arrhenius plot is depicted in Fig. 42.6. The resulting activation energy E_A is 184 kJ/mol.

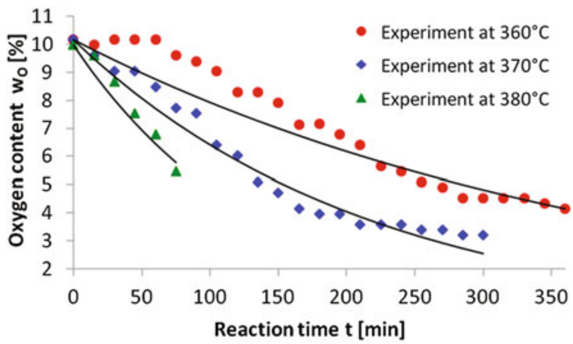

Fig. 42.5 Modeling of the sump phase deoxygenation kinetics according to first order reaction compared to experimental data calculated from measured calorific values for the experiments at 360, 370 and 380 °C

$$k = k_0 \cdot e^{\frac{E_A}{R \cdot T}} \quad \begin{matrix} (k_0 = \text{preexponential factor}, E_A = \text{activation energy},) \\ (R = \text{universal gas constant}, T = \text{temperature in kelvin}) \end{matrix} \tag{42.6}$$

Results of the Continuous Thermal Deoxygenation and Cracking Experiments

Based on the above determined kinetic data continuous thermal cracking experiments were conducted. The continuously achieved CVO yields of different feedstocks are shown in Table 42.5. Rapeseed oils provide highest yields above 80 wt.−% followed by used frying oil. Palm oil reaches a lower level of about 73 wt.−%. The intermediate position of frying is well corresponding with the assumption that frying fat is a mixture of palm oil and rapeseed oil. The oil yield of the fat is close to 80 wt.−%. The value for the reaction water is slightly higher compared to the vegetable oils and the yield of gases and losses is about 15.5 wt.−%.

The analytical data of the produced oils are shown in Table 42.6. The densities of the cracked oils are lower compared to those of the vegetable oil feedstocks. This indicates a reduction of chain length. The water content of the cracking products from rapeseed oil and palm oil is slightly higher compared to the water

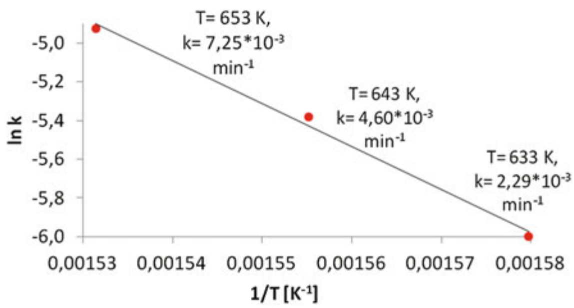

Fig. 42.6 Arrhenius plot for the experiments at 360, 370 and 380 °C

Table 42.5 Reaction product yields of the used raw materials, rapeseed oil, crude rapeseed oil, palm oil and used frying oil, calculated from the mass balance of continuous experiments

	Rapeseed oil	Crude rapeseed oil	Palm oil	Used frying oil
Feedstock [wt.−%]	100	100	100	100
CVO [wt.−%]	84.3	83.3	72.9	78.9
Reaction water [wt.−%]	3.5	3.3	4.6	5.7
Gas und losses [wt.−%]	12.2	13.4	22.6	15.5

Table 42.6 Physical data of the CVO products of the continuous thermal cracking of vegetable oils using rapeseed oil, crude rapeseed oil, palm oil and used frying oil as feedstocks

	Rapeseed oil	Crude rapeseed oil	Palm oil	Used frying oil	Unit
Density 15 °C	846	843.2	799.6	837	kg/m^3
Water content	0.12*	0.1*	0.05*	0.08*	wt.−%
Viscosity 40 °C	4.1	3.82	2.23	2.6	mm^2/s
Net calorific value	40.8	41.0	42.7	41.1	MJ/kg
Acid number	75	68	33	80	mg KOH/g
Iodine number	64	57	50	65	g Iodine/100 g

* near the detection limit

content of the feedstock materials. A possible cause is the formation of fatty acids which is supported by the increase of the acid number. The oxygen content of all cracked products is reduced which results in an increased net calorific value between 40 and 43 MJ/kg compared to the feedstock value range of 36–38 MJ/kg. Assuming an H/C ratio of 2 for the CVO product (e.g. alkanes, alkenes with one double bond, and free fatty acids) an oxygen content of 3–5 wt.−% is calculated.

In order to evaluate the CVO products with regard to the application as an alternative fuel, the properties need be compared to the values of the diesel standard. Such a comparison regarding crude rapeseed oil and palm oil as feedstocks is shown in Table 42.7. The measured values of the cetan number, cetan index, copper strip corrosion, oxidation stability, lubricity and viscosity at 40 °C are well complying with the limits of the standard. The density of the CVO from palm oil is slightly to low which could be caused by shorter chain length molecules. This assumption is supported by the lower level boiling curve of the palm oil product compared to the rapeseed oil product in Fig. 42.7. Such higher contents of volatile substances in the palm oil product could result in a lower flashpoint which is also below the limits of the standard. The low-volatile substances from the crude rapeseed oil product are expected to cause the high conradson carbon value.

Even though the water contents of both samples are fairly low according to Table 42.2 it is not possible to determine them more accurately by volumetric Karl Fischer titration. A higher precision in this value range can be achieved by coulometric Karl Fischer titration.

Particularly the low viscosities of the CVO products in Table 42.2 indicate, that the thermal cracking of vegetable oils could be an interesting pathway for

Table 42.7 Comparison of the properties of the condensates of the continuous experiments with crude rapeseed oil and palm oil with the diesel standard DIN EN 590

		Diesel-standard DIN EN 590	Product of crude rapeseed oil	Product of palm oil	Unit
Cetane number	min	51	ca. 62	57-59	
Cetane index	min	46	51	65.6	
Density 15 °C		820–845	843.2	799.6	kg/m^3
Flash point	min	55	22/23.5	22	°C
Conradson carbon	max	0.3	1.29/1.25	0.16	wt.−%
Ash content	max	0.01	<0.001	<0.001	wt.−%
Water content	max	200 mg/kg	0.1 %*	0.05 %*	mg/kg
Copper strip corrosion		1	1	1	grad class
Oxidation stability	max	25	3	1	g/m^3
Lubricity	max	460	295	249	μm
Viscosity 40 °C		2.00–4.50	3.82	2.23	mm^2/s
Distillation					
Collected at 250 °C	max	<65	24.6	37.2	vol.−%
Collected at 350 °C	min	85	84.2	95.5	vol.−%
95 % collected at	max	360	373.2	346.2	°C
Acid number		–	68	33	mg KOH/g
Iodine number		–	57	50	g Iodine/100 g
Net calorific value		–	41	42.7	MJ/kg

* Measured with the volumetric KF-Titration, for mg/kg is a coulometric KF-Titration necessary

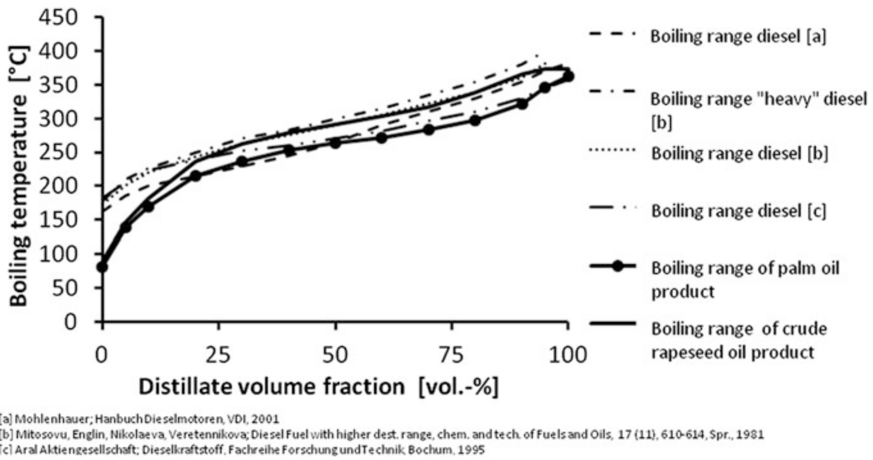

Fig. 42.7 Comparison of the boiling ranges of the continuously achieved product oils from crude rapeseed oil and palm oil with the boiling ranges of diesel from literature

alternative fuels. Many requirements of the diesel standard are met. Apart from that the acid number needs to be adjusted, which could be achieved by additional hydrotreating of the CVO products. Possible problems caused by higher contents of volatile fractions could be addressed by separating these substances by means of a distillation upgrading process.

Discussion/Perspective

The development of a kinetic model for thermal deoxygenation and cracking of vegetable oils provides a better understanding of the conversion processes taking place. The results show that a significant reduction of oxygen by pure thermal cracking is possible. The calculation method using the Boie's formula is a good tool to determine the oxygen content from the measured net calorific value. The first order kinetic seems suitable to describe the main trend of the oxygen reduction in the sump phase. Further investigations should be focused on expanding the first order kinetics with an auto-catalytic model approach supported by further experimental data. A further improvement option could be the implementation of a varying H/C ratio of the sump phase. Further experiments need to be conducted to set a higher data density and therefore higher accuracy of the model. By means of detailed model calculations also regarding the quality of the condensates the prediction of long-term running behavior might be possible.

The results from the continuous experiments can be improved by better process control and by upgrading of the condensates. The boiling range can be adjusted by fractional distillation of volatile and low-volatile substances in the CVOs. An improvement of the acid number can be achieved by hydrogenation. Further research is needed in this field.

Acknowledgments The authors are very grateful to the Johann Heinrich von Thünen Institute for the analytical support and to A. Lüken, M.Sc., H. Gause, M.Sc., Dipl.-Ing. D. Kröhnert, Dipl.-Ing. A. Sievers and the employees of the HAW Hamburg for the assistance at the execution of the experiments.

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Chapter 43
Bio-ethanol Production from Readily Available Lignocellulosic Biomass in Mauritius Through Enzymatic Hydrolysis

Pratima Khadoo- Jeetah and Romeela Mohee

Abstract Bio-ethanol production from biomass is attracting attention all over the world in view of its use as an alternative source to petrol in the transportation sector. With the aim of having a clean environment, the Government of Mauritius has set out the goal of using ethanol blends, in all vehicles in Mauritius by end of 2012. Thus, the purpose of this study was to find out the potential of obtaining bio-ethanol under the most favorable processing conditions from other types of locally available lignocellulosic biomass to meet the demand for 2012. For that reason, five most readily available feedstock in Mauritius, namely peels of cane stalk (PCS), cane tops and leaves (CTL), elephant grass (EG), coconut husk (CH) and Acacia leaves were used to produce bio-ethanol via the enzymatic hydrolysis technology using the ACCELERASE TM 1,000 enzyme. The hydrolysis was carried out at a temperature of 50 °C and a pH of 5.0. Maximum fermentable sugars were obtained respectively when an enzyme loading of 0.10 ml/gram dry peels of cane stalk were hydrolyzed for 48 h; an enzyme loading of 0.20 ml/gram dry cane tops and leaves, an enzyme loading of 0.20 ml/gram dry elephant grass both hydrolyzed for 72 h, enzyme loading of 0.25 ml/gram dry coconut residues hydrolysed for 96 h and enzyme loading of 0.15 ml/gram dry acacia leaves were hydrolysed for 72 h. A maximum bio-ethanol yield of 361 L/t peels of cane stalk, 259 L/t cane tops and leaves, 228 L/t elephant grass, 208 L/t Acacia leaves and 196 L/t coconut husk were obtained when enzymatic hydrolysate were fermented at 35 °C and a pH of 6.5.

Keywords Hydrolysis · Enzyme · ACCELERASE · Lignocellulosic · Bio-ethanol

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_43,

Introduction

The energy consumption has been increasing progressively over the last century due to population growth and industrialization. The use of fossil fuel oil is projected to reach its zenith around the year 2007 and the supply is then projected to be extremely scarce in the coming 40–50 years. It has also been predicted that annual global oil production would decline from the current 25 billion barrels to approximately 5 billion barrels in 2050. As a result, significant efforts have been made towards the conservation of fossil-based fuels and the exploration and exploitation of new renewable resources (Graham et al. 1998). The focus primarily has been on the outlook for alternatives to the petroleum products. In this spectrum, alcohol manufacture from biomass has attracted a large attention all over the world which could be used as an alternative source to petrol or in blends with petrol. The commercial feasibility of ethanol production from locally available renewable lignocellulosic resources depends both on its ease of availability and its low cost. Hence, locally produced renewable fuel; ethanol, has the potential to broaden the energy portfolios, lower dependence on foreign oil and to improve trade balances in oil-importing nations.

Lignocellulosic biomass such as agricultural, forest products (hardwood and softwood) and their residues are renewable resources of energy. Approximately 90 % of the dry weight of most plant material is stored in the form of cellulose, hemi-cellulose, pectin, and lignin. Conversion of cellulose and hemi-cellulose from waste materials to sugars provides a feedstock for the production of fuel ethanol and substantially reduces the amount of wastes that would otherwise exert pressure on municipal landfills. Furthermore, the production of ethanol from lignocellulosic biomass results in a no net contribution to global warming, since the carbon dioxide produced by the combustion of ethanol is consumed by the growing raw material (Sivers and Zacchi 1995).

Lignocellulosic Biomass Composition

Lignocellulosic biomass represents the major fraction of most plant matter. Common examples of lignocellulosic biomass include agricultural and forestry residues, organic fraction of municipal solid waste (MSW), industrial processing residues such as wastes in the paper and pulp industry, and herbaceous and woody plants grown as fodder for animals or as feedstocks for the production of fuels. Lignocellulosic biomass basically consists of three major fractions: cellulose, hemicellulose and lignin. In general in most types of lignocellulosic biomass, cellulose, the largest fraction of biomass and the primary component of most plants consisting mainly of glucose, appears to be of the order of 35–50 % (Updegraff 1969), hemicellulose, consisting predominantly of the five carbon

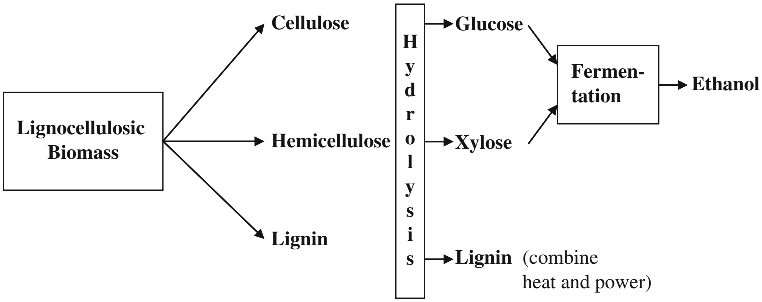


Fig. 43.1 Lignocellulosic biomass to ethanol flowchart

sugar xylose, appears in the order of 20-35 %, while lignin, a polymer of complex composition that cannot be broken down to form sugar molecules appears to be of the order of 15 to about 25 %.

Lignin provides the structural support of a plant and contains no sugar. It encloses the cellulose and hemicellulose thus minimizing their accessibility to microbial enzymes (Martone et al. 2009). Normally, trees have higher lignin content than grasses (Boerjan et al. 2003). A number of other compounds such as plant oils, proteins, and ash make up the remaining fraction of the lignocellulosic biomass structure. However, the composition and percentages of the cellulose, hemicellulose and lignin vary from one plant species to another. Moreover, the composition within a single plant varies with age, stage of growth and other conditions (Fig. 43.1).

Ethanol from Lignocellulosic Biomass

Lignocellulosic biomass represents a vast resource that could be used for production of ethanol. This can be represented in a generalized flowchart as shown in Fig. 43.1.

Hydrolysis Principle

The hydrolysis principle can be thought of as a two-step namely pretreatment and hydrolysis process with production of monomeric sugars. The hydrolysis process can be performed via acid, alkali or enzyme as depicted in the (Fig. 43.2).

To attain higher efficiency, both physical and chemical pretreatment are required. Physical pretreatment consists of size reduction while chemical pretreatment consists of removing chemical barriers so that the enzymes can access

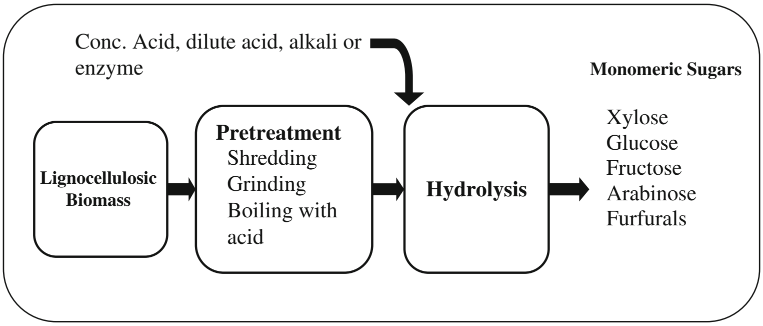


Fig. 43.2 Steps of hydrolysis

the cellulose easily for microbial destruction. In the pretreatment phase the lignocellulosic material are made amenable to the subsequent hydrolysis step. During hydrolysis, the cellulose and hemicellulose in lignocellulosic biomass are broken down to form individual sugar molecules which can be fermented into ethanol. These sugars are thereafter separated from the residual materials which are the lignin part. The latter can then be burnt as boiler fuel to provide energy to power the process, converted into octane boosters, or used as feedstocks for production of chemicals.

Enzymatic Hydrolysis Technology

This study has explored the enzymatic hydrolysis potential for bioethanol production. Enzymes that catalyze the breakdown of cellulose into glucose are known as cellulose. Enzymatic hydrolysis provides a method to convert cellulose to glucose at high yields without sugar product degradation. Enzymatic hydrolysis of cellulose proceeds in several steps to break glycosidic bonds by the use of cellulase enzymes. Factors effecting hydrolysis of cellulose include type of substrate, cellulase loading, and reaction conditions such as temperature and pH, and end-product inhibitors. Because enzymes are highly specific in the reactions that they catalyze, formation of by-products as found in dilute acid hydrolysis is avoided, and waste treatment costs are reduced. Furthermore, enzymatic reactions take place at mild conditions and achieve high yields with relatively low amounts of catalysts. Enzymes have the further advantage in that they are naturally occurring compounds which are biodegradable and environmentally benign. Advances in enzyme-based technology for ethanol production have been substantial over the years, and as a result, ethanol production costs have been reduced considerably.

Methodology

For this study, five most easily available feedstocks were used. These were cane tops and leaves, Acacia branches and leaves, elephant grass, coconut husk and cane stalk. Sugar cane tops and leaves are generally left in the field after harvest where only a minor amount is collected for fodder for ruminants or treated to be used for thatch roofs and handicrafts. Acacia and elephant grasses are also used as fodder and are highly abundant as they are found everywhere throughout the island. As regards coconut husk, they are found in large quantities near seaside and in markets which are thrown as only the water and the white-cream part are consumed. Only a small amount is being used for artisanal work while the rests consequently add on the pressures of disposal in the landfill. It must be noted that, cane stalk have also been used as one of the feedstock though it is not available that straightforwardly. But since peels of cane stalk have some readily available sugars, it was a potential feedstock.

Enzymatic Hydrolysis

The feedstock were first pretreated for 15 min at 121 °C in the autoclave with the optimum diluted acid concentration determined in the dilute acid hydrolysis part to expose the cellulose and catalyze the hemicellulose removal for enzymatic hydrolysis. The resulting mixture was filtered and brought to a pH of 5.0 by addition of NaOH. The enzyme ACCELERASE 1,000 was then utilized for the hydrolysis.

As per the Product Information sheet the optimal conditions were found to be: a pH of 4.0–5.0 and a temperature in the range of 50–65 °C and an enzyme loading of 0.05–0.25 ml per g of dry feedstock and a hydrolysis period of 24 h or more.

Fermentation

The hydrolysates were fermented for 24, 48 and 72 h at a temperature of 32 °C and pH of 4.0, 5.0 and 6.0 and the best possible fermentation pH and period were determined for each feedstock used via statistical analysis. It must be noted that for Alcodis Limited, normally 1 gram distiller's yeast is used per litre of diluted molasse. For this study, 1.5 g distiller's yeast was used instead so as to ensure maximum ethanol yield as there might be presence of toxic chemicals that can inhibit the fermentation process since hydrolysis was necessary to obtain the fermentable sugars. Before fermentation, the distiller's yeast has to be cultured in the medium to be fermented. For that purpose, hydrolysates for each feedstock from the various hydrolysis technology was prepared using the optimal conditions.

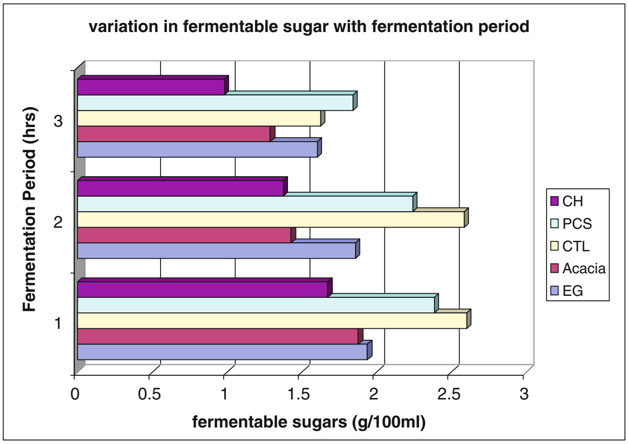
Ethanol Percentage Determination

Ethanol was determined through a precise equipment called the Ebulliometer that bears the standard EC (European Community) marking.

Results and Discussions

Optimum reaction Time for Enzymatic hydrolysis

The 5 types of lignocellulosic biomass reached their best yield when hydrolysed for 72 h. The topmost yield was a sugar content of 2.684 g/100 ml released from the cellulosic and hemicellulosic structure of PCS when hydrolysed for 72 h. For the first 24 h of enzymatic hydrolysis, the fermentable sugar content reached an amount of 1.842 g/100 ml. Subsequently, an increase of 14.87 and 16.5 % in the yield was noted for 48 and 72 h of enzymatic hydrolysis respectively. As regards elephant grass biomass an increase in 11.93 and 13.14 of fermentable sugar yield was obtained when fermented for more than 24 h and 48 h respectively. CTL showed an augmentation of 23.31 and 9.08 % in yield for 48 and 72 h of fermentation while for coconut husk, for the same fermentation periods, the yield increase was 23.46 and 17.77 % (Figs. 43.3 and 43.4).



EG – Elephant Grass

CTL – cane Tops & Leaves

PCS – Peels of Cane stalk

CH – Coconut Husk

Fig. 43.3 Variation in fermentable sugar with fermentation period

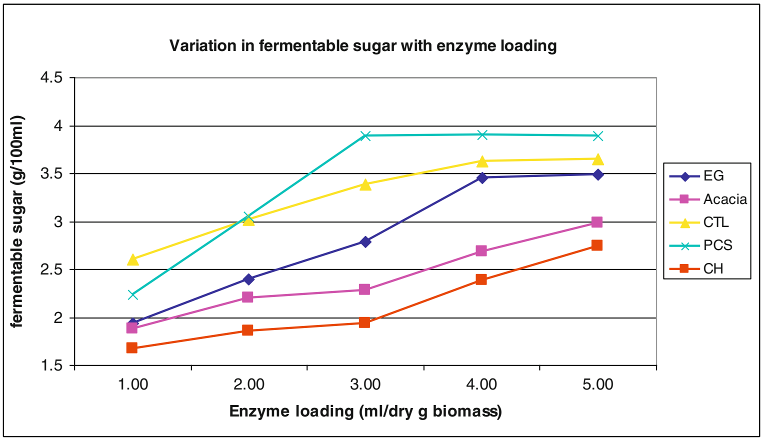


Fig. 43.4 Variation in fermentable sugar with enzyme loading

Optimum Enzyme Loading for Enzymatic Hydrolysis

The fermentable sugar yield for EG feedstock increased with increasing enzyme loading, at higher rate of around 13.36 with loadings of 0.05–0.20 and a lower rate of 0.7 with loading of 0.25 ml/dry g biomass. A loading of 0.25 ml enzyme mash/dry g biomass resulted in the highest yield. As regards acacia feedstock, highest yield was obtained with 0.25 enzyme loading. Enzyme loading from 0.20 to 0.25 resulted in an increase in 0.16 times implying an increase in yield by 10.11 % with a further loading of 0.05 ml/g dry biomass. CTL feedstock reached its maximum fermentable sugar yield at a loading of 0.20 ml/g dry biomass itself. Concerning the feedstock PCS, 0.15 ml/g dry biomass was taken to be the best enzyme load. Even though, the highest yield was obtained with an enzyme loading of 0.20, it was observed that the net increase in yield that resulted from a further 0.05 loading was <1 % (0.31 %) and thus was considered to be uneconomical. For the CH, 0.25 enzymes loading resulted in the maximum sugar yield of 2.746 g/100 ml solution. From ANOVA single factor, the p value was <0.05, hence variations in enzyme loading to fermentable sugars yields are significant.

Fermentation of Hydrolysates

After hydrolysis stage, the hydrolysates of all the five lignocellulosic biomass obtained from enzymatic hydrolysis, the optimal conditions determined were fermented with Distiller's yeast.

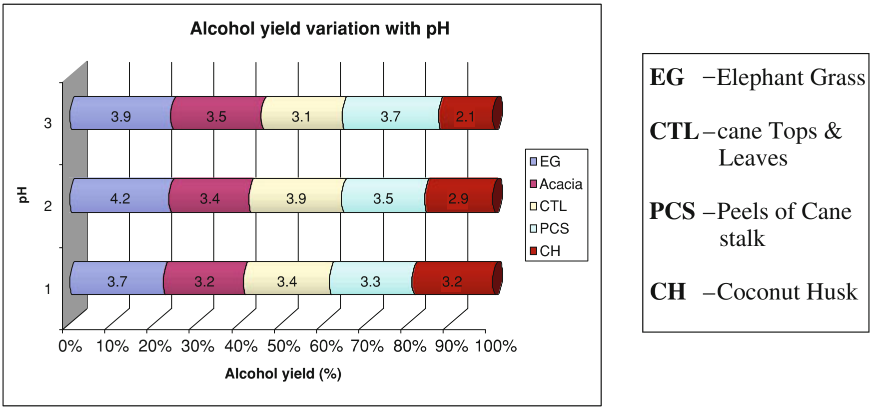


Fig. 43.5 Variation in ethanol yield with pH

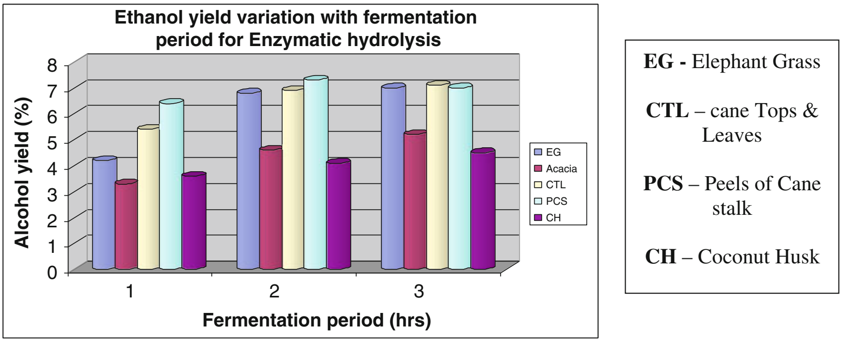


Fig. 43.6 Variations in ethanol % with fermentation period

Optimum pH for Fermentation

Highest alcohol yield was obtained at pH of 5 for EG (■)—4.2 % and CTL (□)—3.9 % after 48 h of fermentation, pH of 6 for Acacia (■)—3.5 % and PCS (□)—3.7 % after 72 and 48 h of fermentation respectively and pH of 4 for CH (■)—3.2 % after 48 h of fermentation. These pH values were subsequently used for the rest of the fermentation process (Fig. 43.5).

Optimum Fermentation Period for Enzymatic Hydrolysates

From the Enzymatic hydrolysis, the feedstock that yielded the most ethanol % was PCS (7.3 %) followed by CTL (7.1 %), EG (7.0 %), Acacia (5.2 %) and CH (4.5 %).

Table 43.1 Amount of Ethanol at optimal operating conditions for pretreatment, hydrolysis and fermentation of enzymatic hydrolysates (EL—Enzyme loading)

Waste type	Amount of Ethanol (L/t dry biomass)	Optimal Conditions		
		Dilute Acid pretreatment	Enzymatic hydrolysis (h)	Fermentation (h)
Elephant grass	228	4 % Acid, 121 °C, 15 min	0.20 EL, 72	pH 5, 72
Acacia	208	2 % Acid, 100 °C, 15 min	0.25 EL, 72	pH 6, 72
Cane T & L	259	4 % Acid, 121 °C, 15 min	0.20 EL, 72	pH 5, 72
Cane stalk's Peel	361	2 % Acid, 100 °C, 15 min	0.15 EL, 48	pH 6, 24
Coconut husk	196	6 % Acid, 121 °C, 15 min	0.25 EL, 72	pH 4, 72

These topmost yields have been achieved within 72 h of fermentation except for PCS where maximum yield was already reached after 48 h of fermentation (Fig. 43.6).

Conclusion

This study investigated the optimal enzymatic hydrolysis conditions as well as optimal fermentation conditions of five different lignocellulosic feedstocks which are summarized in the Table 43.1.

The highest ethanol yield after undergoing a dilute acid pretreatment was 361 L/t dry PCS biomass followed by 259 L/t dry biomass for CTL, 228 L/t dry biomass for EG, 208 L/t dry biomass for Acacia and 196 L/t dry biomass for CH. The experiment carried out on corn stover by using genetically engineered yeast gave an ethanol yield of 165 L/t corn stover after 24 h of fermentation. Study carried out with pretreated sugar cane bagasse by Danisco Division at a pH of 5 using ACCELERASE 1,000 gave an ethanol yield of 311 L/t dry biomass when fermented for 72 h at an enzyme loading of 0.24. This value can be compared to CTL of the present study. The result obtained from Danisco Division was a little higher to that obtained in present study which can be accounted by the difference in enzyme loading and the biomass structure. However, higher ethanol results were obtained with ACCELERASE 1,000 as compared to that of corn stover using genetically engineered yeast.

Hence, all the five biomass are potential feedstock that can be used for effective ethanol production to yield more than 150 L/t dry biomass from enzymatic hydrolysis. Moreover, PCS and CTL have been found to be the most favorable feedstock for enzymatic hydrolysis.

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Chapter 44
A Smart Technology of Carbon Sequestration by the Use of Biochar

Ulrich Suer, Friedrich Naehring and Gopathi Balachandra

Abstract Climate change and decreasing reserves of oil, gas, coal and uranium are a current reality. Therefore, to feed an ever growing world population and to deliver raw materials and energy, biomass needs to be used more wisely. As far as possible, biomass should be used for the production of food rather than for energy and raw materials, which currently tends to be prioritised. Moreover, the remaining biomass, which is not suitable for food production, should be used more efficiently than before. For example, raw materials could also be produced from biowaste, whereby the emerging waste heat could be used further to generate electricity and space heating. Biomass binds the greenhouse gas carbon dioxide until it is digested, rotten or burnt, but may also be transformed into biochar through pyrolysis. Biochar is a material comprising a carbon sink to mitigate global warming. Once applied to the soil it will steadily contribute to the growth of plants for thousand of years. The raw material biochar is produced from biological waste by pyrolysis. Liquid and gaseous mixtures develop as by-products, which, once refined, may be used for a wider range of applications. The development of our pyrolysis technology comprises the following steps: (1) using waste heat to pre-dry the input biomass and to preheat the inlet air, (2) feeding wet biomass, (3) minimizing heat loss by an upright reactor scheme with only a few pipe flanges, (4) testing reactors with upstream as well as with downfall mass flow, (5) flow path through heat zones from 200 up to 800 °C due to the progression of

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_44,

the pyrolysis process, (6) hence biochar extracted from the hot zone showing high quality, (7) directly injecting pre-dried biowaste into the warm zone to suppress unwanted tar by-products and to produce a low-oil synthesis gas, (8) bypass to partly burn syngas for direct heating the hot zone, (9) accurate control of the combustion air flow to optimize the output quantity of the biochar, (10) avoiding movable parts at the reactor to guarantee an operation with low rate of failure, (11) using the evolving syngas to generate electricity, process and thermal heat, (12) restricted converter size to limit the transport distance and use in companies at the waste source and (13) maintenance requiring only minor technical skills in virtue of a simple plant design. At this stage of development, the main objectives of these pyrolysis reactors are production and sale of the produced biochar and the use of the generated electricity within the company. The biomass converters are designed for German and Sri Lankan (communal) enterprise, using mutually beneficial skills and potentials of both countries. Logging slash, lop, greenery from silvicultural measures, saw dust, municipal and food-industrial waste will be processed into high quality biochar.

Keywords Biochar · Biomass · Bio-sequestration · Carbon · Energy · Fertilizer · Food · Pyrolysis · Sustainability

Short Introduction

Population growth, land use change and land degradation increase the pressure on food production, biodiversity and mitigation of climate change. The use of biochar together with compost and organic waste is an option to stabilise and enhance the fertility of poor soil and simultaneously sequester carbon dioxide from the atmosphere for centuries. During pyrolysis in the herein described bio-converters, the biowaste is transformed into biochar. At the same time, gaseous and liquid fractions emerge, which may be converted into additional energy and raw material and could help to reduce some of the oil-and-gas gap in the post-fossil world.

Biochar Removes Carbon from the Atmosphere and Manures Soil

Can biochar contribute to mitigate climate change and to stabilize the agricultural production of food and raw materials for a growing population after fossil fuel ceases to be used?

It is estimated that agriculture binds about 500 g carbon on 1 m^2 in one year on land with low fertility. On this square meter 2 kg biomass will grow, containing

1 kg water and 1 kg dry biomass. From soil of very high fertility, 3 kg dry biomass can be harvested (Strobl 2009). During the growth season of a year, the biomass carbon is extracted from the carbon dioxide of the atmosphere by photosynthesis. Through digestion, rotting and direct combustion, the containing carbon is released back into the atmosphere as CO_2. This can take as little as few minutes up to a few years, depending on the process. Let us assume that 20 % of the biomass, that is 0.4 kg /m^2 from low fertility soil, will be converted into biochar carbon by pyrolysis. Such an amount would probably not harm sustainable agriculture. The carbon content of this input biomass, taken from the field area of 1 m^2, is 100 g. During the pyrolysis process, the biomass is split into water, biochar and syngas, the char containing 30 % of the carbon and the syngas 70 %. The syngas together with the excess heat could be used to produce several forms of energy and raw materials (Brown 2011). This, however, was not explored further in this research.

In order to double the fertility of poor soil, a mixture of 5 kg biochar and 10 kg compost has to be applied once to 1 m^2 (Fischer and Glaser 2012). With this method, inspired by the research of Terra Preta and subsistence agriculture, most soil fertility factors could be enhanced and stabilised without artificial manure, though further research is needed (Jeffery et al. 2011). Based on the figures above, 20 % of the harvest of nearly 200 m^2 has to be applied as biochar onto 1 m^2. In other words, the sustainable carbon harvest (i.e. 20 %) would have to be re-introduced to the area in form of biochar for nearly 200 years, in order to double fertility. It is generally accepted that good biochar will remain in the soil for more than 1,000 years. Therefore, within less than 200 years, an equilibrium of manured soil on all initially low fertile land could be established globally.

Therefore, it is expected that the import and use of mineral fertilizers and energy to maintain food and industrial production could be reduced. The pessimistic estimate sketched above could be improved by adding other sustainable sources of biochar feedstock, such as municipal waste, saw dust, wood chips, greenery from silvicultural measures and biowaste from industry. Optimizing this process may bind up to 6 % (Woolf et al. 2010) of the current anthropogenic greenhouse gas emissions of 30 Pg/a (OECD 2011) in a sustainable way (1Pg = 1 billion metric tons). From a global perspective, biochar has a larger climate-change mitigation potential than combustion of the same feedstock biomass for bioenergy (Woolf et.al. 2010). In reality, global emissions have risen, rather than shrunk in recent years. However, for the period 2000–2050, they have to be limited to ~20 Pg/a in order to limit the increase of global warming to 2 °C (Meinshausen et al. 2009). Taking into account that a change in human behaviour and the development of low emission technologies are slowly running and adaptive processes, the reduction from now 30 to 10 Pg by 2050 may be a realistic target to meet the 20 Pg mean value for the first half century. 20 Pg corresponds to a mean value of the specific greenhouse gas emission of approximately 2 Mg per capita and year (1 Mg = 1metric ton). In order to achieve a reduction from 30 to 10 Pg/a, emissions have to be reduced gradually by 67 % by the middle of the century. Biochar with a reduction potential of approx. 6 % will be one of multiple measures to cut greenhouse gas emissions to the 2 °C target.

In conclusion, besides its global 'cooling' effect, biochar can, when added as a mixture with compost, make poor soil sustainably fertile. In order to realise this potential around the world, pyrolyse-technology has to be improved, proliferated and applied for several human generations.

Improvements in Biochar Technology

Figure 44.1a outlines the usual process of biochar production. The biomass is inserted at one end of the horizontal vessel via an air lock, then preheated and dried at temperatures of around 200 centigrade, using external or internal heat sources. Once the pyrolysis has started at a temperature of around 400 centigrade, pyrolysis becomes self-sustaining as an exothermal reaction. No oxygen or air is introduced. Syngas develops and can be used to feed external processes. It is composed of water vapour, nitrogen, carbon dioxide, carbon monoxide, methane and small amounts of heavier organic compounds, which can be gathered as pyrolysis oil. The heat contained within the syngas stream could also be used for drying or other thermal processes.

The slow pyrolysis process (Meier 2001) occurs in steel containers of various configurations. The transformation of biomass into biochar takes about 20 min and the process velocity can be controlled easily. Permanent operation is preferred but batch processing may be useful in some cases. For instance a limited amount of a special feedstock may have to be transformed.

Below is a description of the permanent pyrolysis setups we have developed as alternatives to the usual configuration. These are sketched in Fig. 44.1b–d. All reactors are of vertical type. The material moves vertically upstream in version (b) and downstream in (c) and (d), respectively. In version (b) the preheating is done by external waste heat. Hot gas streams through a heat exchange mantle surrounding the reactor. In version (c) and (d) the fresh biomass is preheated by flooding with the syngas itself. Figure 44.1b) shows the coupling with an external process, in our case co-generation of electricity and heat by a standard diesel generator. This is typical for pyrolysis processing and has to be adapted to local conditions for optimum use of the evolving resources i.e. syngas and heat. This would also apply to versions Fig. 44.1c and d but was not installed during the course of the investigation. Instead, the syngas was completely burned.

The syngas content of water and organic compounds of higher-molecular weight can be deposited as 'pyrolysis oil' in a drum. For long-term stable operation, the temperature in all syngas piping up to the drum trap should be maintained at high level to avoid condensation. In the model we have developed we installed a centrifugal separator directly at the outlet of the syngas in the setup due to Fig. 44.1b in order to eliminate the condensation problem.

The experimental plant of the type sketched in Fig. 44.1b is shown in Fig. 44.2. The biomass is pressed into the lower end of the vessel. The material is moved up by a centred screw made of blades that work as a circular stirrer in the lower part,

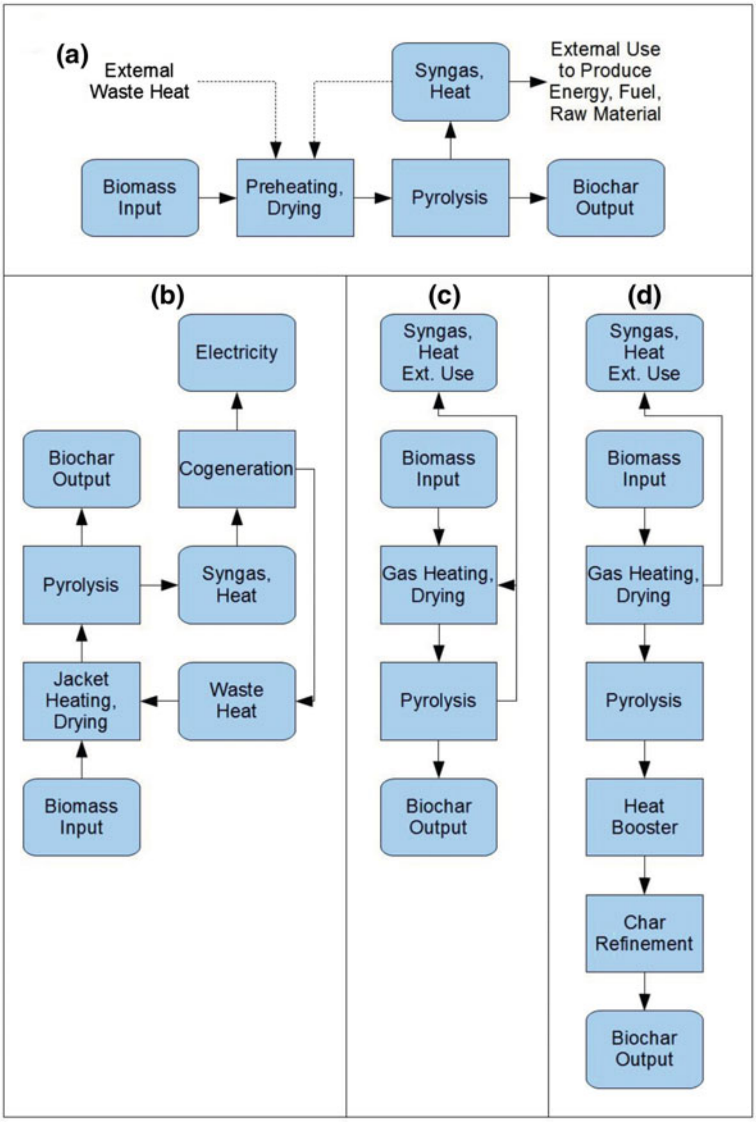

Fig. 44.1 Biochar technology modes. **a** Often adapted vertical process flow, **b** upstream, **c** downstream, **d** downstream with additional high temperature zone

and as a conveyor in the upper. The moving parts run on elevated temperature to ensure continuous and stable operation.

Figure 44.3 shows the Converter of the type Fig. 44.1c. In contrast to Fig. 44.1b movable components have been omitted in the heat zone of the converter column for low-maintenance operation. Gravity and shrinking during

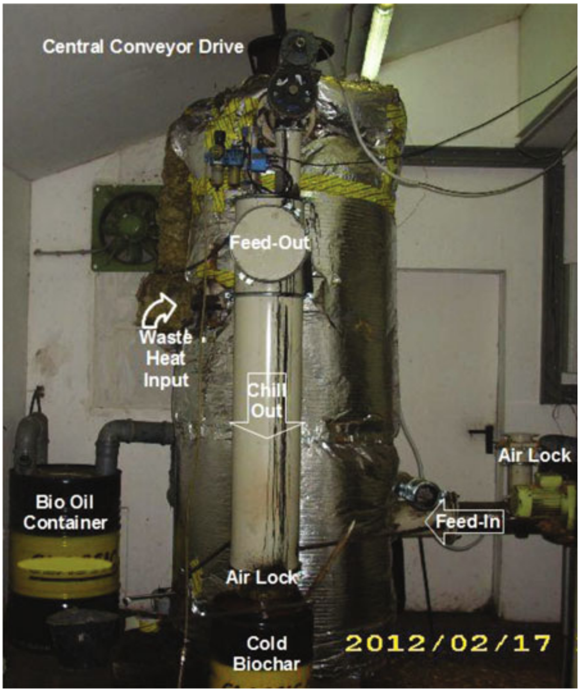

Fig. 44.2 Experimental biomass converter with central conveyor

carbonisation enables the feedstock to move through the different heat zones. Within the zones the material is equally tempered by the flow of syngas acting as the heat carrier. Thermal insulation of the converter column is essential in order to maintain uniform temperature profiles across the pyrolysis tube. Figure 44.3 presents the converter column after removal of the thermal insulation and the measuring installation. The produced biochar is mainly in form of volume-reduced chips but to a lesser extend also char dust.

The Biomass Converter of the type Fig. 44.1c has been completed with an additional biochar refinement as sketched in Fig. 44.1d. The booster in the lower part of the column will heat the char up to 800 centigrade and refine it from high-molecular organic compounds, i.e. polycyclic aromatic hydrocarbons (PAHs) and others. Inside the booster, a portion of syngas, taken from the central part of the column, gets burned. The air-to-syngas ratio of this burner is controlled by a lambda sensor to omit oxidation of the char. To adopt the pyrolysis process for different kinds of biowaste requiring individual heat profiles, the gas fluxes have to be controlled within the converter. Figure 44.4 shows the test unit at work. Lodging slash biomass is delivered in big packs or by a trailer, as shown in the picture, and is continuously fed into the converter through a sector gate air lock and a screw elevator.

During this permanent process, 1,000 kg of wood chips from silvicultural measures containing 20 weight percent water are carbonised within 9 h to yield at least 100 kg of biochar. Hence the productivity of the test equipment is at least

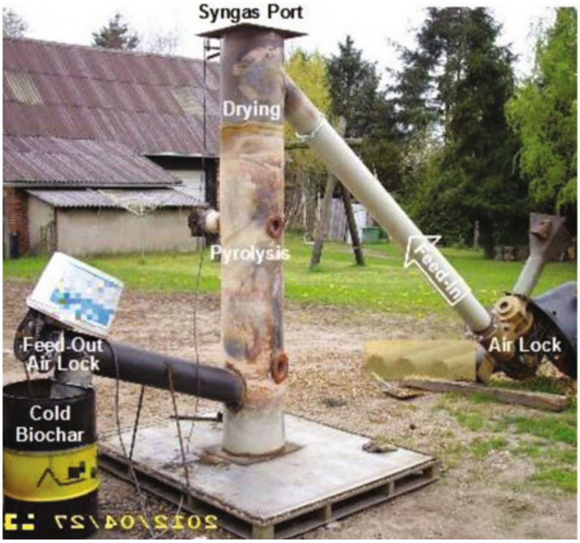

Fig. 44.3 Simple converter, gravity-driving biomass feed

Fig. 44.4 Converter with heat booster, photo is courtesy of Peter Dörr

11 kg biochar per hour. The other part of the feedstock is converted into syngas, which in turn is burned and thereby turned into process heat for external use.

Testing the performance of the equipment of Fig. 44.4 shows continuous failure-proof operation. The converter is constructed in such a way that it is inherently explosion-proof. As long as the column is filled with biomass and/or biochar, no explosion can occur. The minimum volume that is capable for explosion is 10 L, more than any gas-filled space in the converters Figs. 44.2, 44.3 and 44.4.

Analysis of unwanted remains in the biochar is ongoing in several laboratories.

The biochar is sold mainly for agricultural tests and gardening. It could also be used for filtering, absorption (for instance in paddy fields), blacksmith fire, cooking and barbecue, food additive and barn bedding, but biochar application in those areas has been outside the scope of this study. Especially the use of lower-quality biochar may be useful in some cases.

The full range of biomass resources available for biochar production have yet to be identified properly. In temperate-climate Germany, for example, almost all biomass grown on agricultural land and forestry is used for food, bio-energy and raw materials (Destatis de Statistisches Bundesamt 2011). The harvest from 25.5 the million hectares of agricultural and timber land comprises 265 million tons, i.e. 1 kg per m^2 and year (Destatis de Statistisches Bundesamt 2012). Much of this amount could be used a second time as biowaste to produce biochar instead of co-burning it with coal, oil and gas in garbage incineration plants, cf. Fig. 44.6. For each type of biowaste a specific process scheme has to be designed to take into account its water content, structure and risks from certain chemical elements, for instance sulphur and chlorine. The amount of 'unused' biomass such as leafs, straw etc. is not known to the authors, but may yield another 1 kg per m^2 and year or even more. From an ecological point of view, however, this kind of biomass should ideally not be transformed into biochar. To reduce pressure on land-use and biodiversity the market for and usage of biomass have to be better adapted to ecological principles and full-cycle view. In tropical Sri Lanka with a population density similar to Germany, food production has been based predominantly on organic principles until now. However, the pressure to produce food and raw materials on industrial scale is now increasing. There is plenty of biowaste from food and wood industry like coconut shells, rice and coconut fibre husk and saw mill remains. The mature foliage from non-indigenous cultures (Pines, Eucalyptus, Acacias, Rubber, Sugar Cane) may also be included. It has to be gathered from the ground because it cannot be absorbed effectively by the tropical ecosystem due to

Fig. 44.5 Biochar from wood chips, photo is courtesy of Peter Dörr

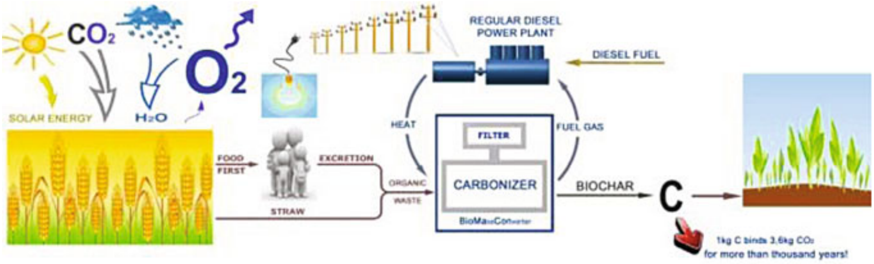

Fig. 44.6 Scheme for a proposed second use of crop biomass

anaerobe processes. Instead, it harms and kills indigenous trees, enhances fire risk and lowers water retention.

Figure 44.5 compares the fed-in wood chips with the produced biochar. The form of the chips is retained during the carbonisation process though the linear extend of the chip is shrunken to half of its original value, that is, the volume is reduced to 1/8. The loss of water and hydro-carbonaceous compounds during the physico-chemical destruction of the biomass molecular structure results in the biochar mass (cooled and loaded with air) of one tens of the intake (20 % water content).

The unit of Fig. 44.4 has been re-designed as seen in Fig. 44.7, for the use in semi-automatic operations as, for example, in German biowaste community centers It has to be revised for the working conditions in a Sri Lankan cooperative.

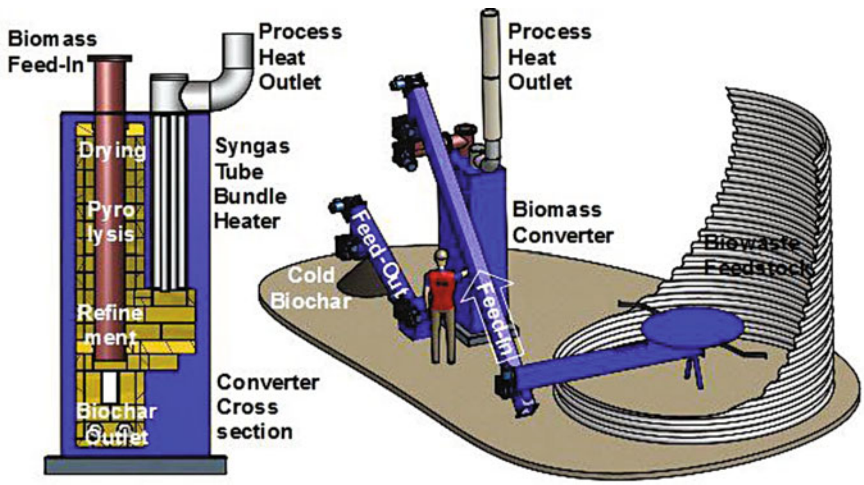

Fig. 44.7 Biochar unit for municipal waste in Germany

Conclusion

The biomass carbonisation technology presented here is designed for permanent low-maintenance operation by semi-skilled workers. The converters produce high-quality biochar, to be used as a long-lasting soil conditioner. It stabilises local cycles of matter and simultaneously sequesters carbon from the atmosphere. A number of sustainable biomass resources have been identified in Germany and Sri Lanka for biochar production. These are regional contributions to globally regain the agricultural performance of soil by natural fertilization in a post-fossil era.

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Chapter 45
The Impact of Smart Metering on Energy Efficiency in Low-Income Housing in Mediterranean

Ales Podgornik, Boris Sucic, Peter Bevk and Damir Stanicic

Abstract Comparison between the EU's 2020 energy efficiency targets and the forecasted energy saving indicates a gap for expected energy savings in 2020. One of the reasons lies in the lack of specific policies for low-income households, which represents about 40 % of Mediterranean households and are considered as *far to reach* through traditional public policies and requires innovative technical and financial approaches in order to help them reduce their energy consumption. Smart Metering has been identified as one of technologies where end-use energy efficiency can particularly be encouraged in low-income households through its impact on tenants' behaviour. Analysis of current multi-energies Smart Metering projects in Mediterranean area indicates the potential for consumer benefits through demand response and consumption feedback services, which were recognised as most appropriate for low-income households. Implementation of dynamic pricing in combination with home automation and individualized consumption feedback using different efficiency indicators enables households to respond to energy prices and become more energy efficient. Activities presented in this paper have been evaluated within the EU project called ELIH-Med. Objective of the ELIH-Med project is to identify and conduct a large scale experimentation of cost effective solutions and innovative public and private financing mechanisms backed with Structural Funds to foster energy efficiency investment in low income households. Energy and costs savings prediction and verification flowchart is also

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_45,

presented, where different functionalities of Smart Meters in combination with energy efficiency measures and other influential factors are considered.

Keywords Energy efficiency · Smart metering · Demand-response · Consumption feedback · Change of behavior · Low-income housing · Mediterranean · ELIH-Med

Short Introduction

Special attention must be given to residential sector if EU 2020 energy savings goals are to be achieved. And especially the population living in low-income households (LIH) must be targeted as they represent about 40 % of the total building stock in the Mediterranean area. Currently the LIH are considered as *far to reach* through traditional public policies on energy efficiency. Innovative technical and financial approaches are required and Smart Metering has been identified as one of technologies where end-use energy efficiency can particularly be encouraged through its impact on tenants' behaviour. Analysis of current Smart Metering projects in Mediterranean area indicates high potential for LIH consumer benefits through implementation of various consumption feedback services supported by Smart Meters.

Introduction

The European Union (EU) has a primary energy savings target of 20 % below the 2007 projections for 2020. This is one of the EU's three energy and climate headline targets, together with the 20 % reduction in greenhouse gases (GHG) emissions and the 20 % of gross final energy consumption to come from renewable energy sources by 2020 (European Commission, An Energy Policy for Europe 2011a). Additionally, the EU's energy policy is steered by three objectives. The first objective is economic competitiveness, the second is security of energy supply and the third is sustainability with a concern towards environmentally friendly forms of energy. Improved energy end-use efficiency will make it possible to exploit potential cost-effective energy savings in an economically effective way.

Energy efficiency in low-income housing in Mediterranean (ELIH-Med) project, which started in 2011 (strategic project within the MED Programme), focuses on energy efficiency in the context of these EU 2020 objectives. As indicated by the ELIH-Med project (ELIH-Med 2010), the population living in low-income households (LIH) targeted by the project, including households suffering energy poverty, represents about 40 % of the total building stock in the Mediterranean area. The LIH are considered as *far to reach* through traditional public policies—

innovative technical and financial approaches are required in order to help them reduce their energy consumption. The project focuses on identifying and demonstrating the feasibility of cost efficient innovative solutions, financial mechanisms backed with European Regional Development Funds (ERDF) and Smart Metering solutions which could then be extended to all Mediterranean territories. Smart Metering is included as a technology where end-use energy efficiency can be particularly encouraged in LIH through its impact on tenants' behaviour. It must be emphasized that the achievements of ambitious energy savings targets highly rely on the people's choices and behaviour. Smart Meters can give consumers (at an affordable cost) clear and comprehensive information about their energy consumption and, with providing better information, can help consumers to become more energy efficient.

This paper addresses the reasons why targeting LIH is important for achieving EU 2020 objectives. Also, the contribution of Smart Metering systems through economically justified functions and services with the highest impact on the final consumer in LIH are explained.

Reaching EU 2020 Objectives in Mediterranean Area

According to the requirements of Directive 2006/32/EC, each EU Member State must adopt and achieve an indicative energy saving target of 9 % by 2016 in the framework of first National Energy Efficiency Action Plan (NEEAP). Despite the commitment and huge policy efforts to boost energy efficiency improvements by EU Member States, the EU is far from reaching its 2020 energy savings target as shown in the Fig. 45.1 (European Commission 2009).

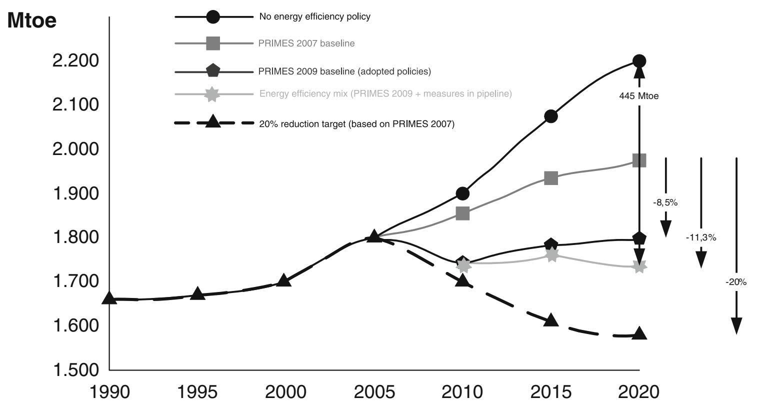

Fig. 45.1 Energy savings policy gap in the EU countries: development and projection of gross inland energy consumption for EU by 2020 (European Commission 2009)

Forecasted energy savings may be rather optimistic if the measures (according to the first and second NEEAPs) will not be implemented successfully. In that case, the expected gap by 2020 will be even larger. In 2008 the share of energy consumption in households was 25.3 % of the total EU final energy consumption (EEA 2011). While space heating and cooling remains the most significant component of household energy demand in EU, it is the demand for electricity from appliances that has increased most rapidly in percentage terms in recent years—increase of more than 21 % per dwelling since 1990 (EEA 2011). Concerning the projected gap and high percentage of LIH in residential sector each Mediterranean country will have to revise its energy efficiency policy and new innovative and efficient measures must be considered in the future. There are many causes for the projected gap in the residential sector by 2020 and most of them are associated with symptomatic unbalance between efforts for preparing polices, and preparations for policy implementation. The vast majority of policy makers are focused on incorporating requirements of international policies and requirements into national strategic and legislative frameworks, without systematic evaluation of the energy efficiency market maturity in a country. Additionally, considering the high percentage of LIH in Mediterranean area, lack of available and accessible funding mechanisms designed for end users and especially for LIH is hindering the expected energy savings goals. In most cases, the private–public financing synergies are not enough for all the LIH end-users and the scheme of tax incentives for energy efficiency investment is not followed by the most of users. This is also due to lack of information and awareness by the end-users in terms of environmental and economic benefits of the energy savings in households. Energy efficient end-user behaviour is a critical parameter to the success of each national energy policy and programs.

New innovative and efficient measures need to be considered in the residential sector with LIH and public sector specially targeted in order to achieve the overall 20 % energy saving. Most of these measures deal with renovation and retrofitting of old buildings including innovative business models, financial support and incentives. As demand for electricity from appliances is increasing, one of the measures includes installation of Smart Metering. Unfortunately, most of the people, not just those living in the LIH, tend not to see or feel direct link between their actions and energy/environmental performance. It is obvious that new approach in overall energy efficiency policy is needed, and the Smart Metering with its dynamics is one part of it. Introduction of Smart Metering, beside the benefits for the utilities, in its essence has the goal to help consumers to understand their energy consumption. Only after understanding its energy consumption it can be expected that the consumer will be capable to systematically decrease its energy demand. It has to be emphasized that wider installation of Smart Meters also requires development of additional procedures for entire energy efficiency policy monitoring and evaluation that will reveal what works and what does not work in the practice and provide inputs for policy improved redesign.

Legislative Framework and Implementation of Smart Metering in EU

Under current EU legislation, final consumers should already be frequently informed about their energy consumption at the time of use. EU member states are also obliged to roll out smart electricity meters for at least 80 % of their final consumers by 2020 and to achieve full coverage by 2022 (European Commission, Energy Efficiency Plan 2011b). According to (European Commission, Smart Grids 2011c) *Smart Grid* is supposed to help deal simultaneously with a range of issues: grid management optimisation, peak-hours electricity consumption reduction, wider usage of renewable energy sources for the electricity production and consequently GHG emissions reduction. However, smart grid concept cannot be taken for granted as the universal solution for all problems. It is a powerful framework which can assure that the full potential of concrete energy efficiency measures is systematically utilised and verified.

Due to differing national regulations, the Smart Metering landscape in EU is highly dynamic with many Member States adjusting their energy legislation to comply with the third EU energy market package and the Energy Services Directive. There are various layers of action in and between EU Member States and different EU institutions that are currently working on standardisation, regulatory recommendations, technical functionalities, and other issues of importance. While some Member States await the results of these various working groups and task forces, some actively move towards smart metering and start with a rollout independent of existing barriers to the deployment of Smart Grids (Renner 2011). Another drawback is a lack of coherent definition of Smart Meter or Smart Metering in existing EU legislation. Neither the Directive on Energy End-use Efficiency and Services (2006/32/EC) nor the Electricity and Gas Directives in the 3rd Energy Package (2009/72/EC and 2009/73/EC) define these terms when imposing obligations on the Member States to deploy Smart Metering technologies (ESMIG 2012). Therefore a clear definition of Smart Meter or Smart Metering was proposed to be included in the future Energy Efficiency Directive. Namely, a key feature of a Smart Meter is the ability to provide bi-directional communication between the consumer and supplier/utility. By including a clear and concise definition of Smart Metering in the Energy Efficiency Directive, the EU will fill a legislative gap in previous directives and, at the same time, provide guidance to the Member States when planning Smart Metering roll-outs, and give a degree of regulatory certainty to the energy companies in Europe who must make the necessary investments (ESMIG 2012). For this reason the European Commission has recently published a Recommendation to prepare the roll-out of Smart Metering systems. It provides the guidelines for Member States on how to conduct cost-benefit analysis and sets common minimum functionalities of Smart Metering systems and addresses data protection and security issues. Member States are also encouraged to assess Smart Metering roll-out scenarios with Smart Meters that go beyond the minimum set of requirements (European Commission 2012).

Additionally, the new Energy Efficiency Directive is introducing two new Smart Metering obligations, namely billing must be based on actual energy consumption with monthly or at least bi- monthly frequency, provision of a consumer interface for better control and management of energy consumption and minimum requirements for informative billing.

Each member state is also facing the problem of funding the Smart Metering implementation. Roll-out of Smart Meters should be set in the development plans of individual Distribution Network Operator(s) in each Member State. It is assumed that the necessary funds for implementation would be allocated from the grid fee and Distribution Network Operator(s) would be the equipment owners. Current practice is that costs of implementing additional services and additional Smart Metering equipment (i.e. In-house display or individual appliances consumption metering) are charged separately and directly to the end user. In the case of LIH it is crucial that electricity suppliers offer innovative ways of funding for additional services and the equipment. Due to the specific structure of this customer group, one of the options is to stimulate the implementation of additional energy services for energy efficiency by awarding the achieved energy savings in LIH with higher multiplication factor when suppliers are reporting the achieved energy savings at the final consumers. In this way, suppliers will be more interested in the preparation of suitable programs for the LIH.

Smart Metering in LIH

In the light of EU energy savings efforts, the ELIH-Med project tries to identify the most effective Smart Metering functionalities and services to increase energy efficiency in LIH and achieve measurable energy savings. Analysis of current multi-energies Smart Metering projects in the Mediterranean area was performed in the scope of LIH objective with the emphasis on local and regional conditions (Smart Metering Projects 2011). Performed analysis shows the leading role of electricity in Smart Metering. Such outcome is expected as electrical smart-grids are the backbone of the future energy grids where electricity Smart Meters are expected to carry out the "data concentrator" role for other sources (Heat, Cold, Gas and Water). Evaluated projects were segmented by 9 topics representing different benefits of Smart Metering for final consumers on one side and suppliers and utilities on the other. As shown in Table 45.1, projects are preferably exploring benefits for the supply side, which indicates the need to put bigger emphasis on exploring consumer benefits in upcoming Smart Metering. Without deliberate focus on final consumers, LIH tenants will be pushed even further from expected benefits of Smart Metering.

Table 45.1 Topics segmentation of evaluated smart metering projects

	Topic	No. of Projects	Benefits
1	Customer feedback / change of behaviour	8	Consumer
2	Advanced tariff systems	3	
3	Other / new Customer services (ESCO)	4	
4	Demand response / DSM	5	
5	Utilization of RES	6	
6	Standardization	1	Suppliers
7	Interoperability	7	Utilities
8	Equipment testing	11	
9	System services (distribution, supplier)	8	

Benefits Related to End-User Energy Savings in LIH

Smart Metering is a technology encouraging end-use energy efficiency. Smart Meters can give consumers clear and comprehensive information about their energy consumption and, giving them better information, can help consumers to become more energy efficient. However, installing Smart Meter without consumer participation and additional services will, by itself, do nothing to save energy since the meter is simply an "enabler". Energy savings will be achieved only if the installation of meters is connected with the comprehensive informational campaign which will help consumers to actually understand their energy consumption and incite them toward sustainable behavioural changes (ESMA 2010). In order for energy savings to be realized, financial incentives also have to be introduced to make energy saving measures more attractive to LIH in economic terms (ESMA 2010).

Demand Response

The target of Demand Response is to enable active participation of final consumers in the market through the provision of consumption flexibility services to different players in the power system. Particularly challenging is the integration of households which are generally unable to make precise predictions on their available load flexibilities and it is difficult for them to offer services in the classical sense.

Therefore the typical demand response of household consumers is a voluntary reaction to a price signal (JRC—IE 2011). Typical response is load shifting where electricity demand is delayed and can easily be employed to LIH. Although the deployment of Smart Meters can enable active participation of final consumers in the market (i.e. purchase of home energy resources), it is the energy savings and energy costs reduction which are of interest to LIH consumers and can potentially range up to 15 % (JRC—IE 2011).

Dynamic Pricing

Dynamic pricing encourages consumers to shift consumption away from peak consumption periods to lower consumption periods, lowering distribution and supply costs. This is achieved through dynamic pricing mechanisms which better reflect the cost of supplying electricity and is most appropriate for LIH as it reflects immediately on consumption costs. This mechanism can also utilise the characteristics of Mediterranean environment with high potential for solar electricity generation within certain time of day. There are several methods and degrees of dynamic pricing and Time-Of-Use (TOU) pricing scheme was recognised as most appropriate for LIH consumers as it is simplest to implement. TOU tariffs induce people into using electricity during times when consumption is lower. The peak hours are known in advance by the customers and the prices may also vary according to the season. Potential for consumer financial savings using TOU tariffs is 5 % (Stromback et al. 2011). Energy savings through dynamic pricing are not achieved at final consumer as he only shifts the time of usage but are instead achieved on supply side because of levering the losses during peak hours.

Tariff Use Planning and Home Automation

The consequence of poorly designed tariff dynamics is that only a few households see the sense in order to perform housework during the cheaper energy tariff in return for a few euros lower expense. Advanced tariffs are pointless if consumers don’t have a thorough understanding of its timeframes and possible money savings. For this reason the consumption feedback introduced in ELIH-Med project (through informative billing and interactive web page) includes additional explanation of implemented tariff systems and proposed use of home appliances with high intensity of consumption (space heating and cooling systems, electrical boilers for domestic hot water preparation, appliances with adjustable time of operation) according to implemented tariff system. This can then be used for simple home automation as advanced home automation with remote load controllers is out of scope for LIH. The home automation in LIH concentrates on installation of electronic plug timers for demand shifting of intensive consumption appliances according to optimal tariffs and programing appliances with integrated time controllers for use in low or off-peak tariff.

The characteristics of Mediterranean area on one hand hinder some uses of demand response (e.g. space heating needs are not high due to mild winters) but on the other hand properly managed air conditioning (AC) systems, frequently found in Mediterranean households, can significantly reduce energy costs and energy consumption.

Consumption Feedback in LIH

The role of consumption feedback is to make the consumption of energy visible. Residential consumers can see how and how much energy circulates in the household, preferably including appliance specific consumption. Feedback can also provide a more direct, detailed, comparable and comprehensive information about household's energy consumption pattern. Direct or indirect consumption feedback can be provided to consumers utilising Smart Metering and its services.

Indirect Feedback

Through indirect feedback the end-consumer have no direct access to real-time consumption data and is therefore responding to previous consumption behaviour and have to rely on processed information. Examples of indirect feedback appropriate for use in LIH are through informative billing and interactive web-page. These types of feedback are based on Smart Meter readings with a combination of appropriate efficiency indicators, disaggregated consumption data, detailed energy reports and other forms of presenting the household consumption.

Indirect feedback may suit LIH in Mediterranean better, as there are indications that indirect feedback is more suitable than direct feedback for demonstrating effects on consumption of changes in space heating and cooling, household composition and the impact of investments in efficiency measures or high-consuming appliances. In other words, indirect feedback will show up longer term effects better, such as investment in insulation, use of new appliances, replacement of heating and cooling systems and appliances, home extensions and new members of the household (Darby 2006).

Informative Billing

One of the biggest advantages of Smart Metering implementation for household consumers is accurate and informative billing. As indicated in eSESH project (eSESH 2010), explaining energy savings options regarding the received monthly bill is a favourable feedback option for tenants in social housings. Additional information on correlation with influential factors (e.g. room temperature) is regarded as positive and benchmarking with past consumption on dwelling and building level had positive results.

From LIH perspective the informative billing should have the following features:

- Monthly billing based on actual consumption;
- Interpretation of monthly consumption in kWh and local currency (EUR);
- Graphic representation of monthly consumption (load profile) with appliance-specific consumption breakdown (where utility provides individual appliance metering). Additionally a graphic representation must include monthly consumption for at least past 3 months or more (up to 12 months);
- Comparative and Normative feedback (efficiency indicators)—e.g. graphic representation of billing consumption compared to consumption in comparable past periods, to average consumption in past year, correlated to inside and outside temperature difference etc.;
- Common bill for all utility meters on site (Electricity, Gas, Heat, Cold and Water).

Informative billing provides up-to date consumption data to domestic consumer, but the biggest challenge is making this data understandable to all consumers including tenants in LIH. More general information on energy efficiency and energy savings options of Smart Metering and final consumption should follow the billing data. The aim of this is educating the consumers to become the Smart Users who are using the Smart Meters. ELIH-Med project will include other stakeholders involved in different social and energy poverty programs. Especially municipalities should participate as owners of social housings, but also involvement of NGOs dealing with energy efficiency and energy poverty and local energy agencies are expected.

Interactive Web Page

Interactive web page with personal access as indirect consumption feedback must also be utilized in LIH. As indicated in eSESH project, web services can reach a wider group of tenants also in social housings. By eSESH projects survey 85 % of tenants own a PC and 77 % have access to the Internet. Similar to on-line banking, utilities should provide this service with an option of e-billing (same characteristics as for informative billing apply) and some degree of energy management (e.g. planning the use of home appliances with high intensity of consumption according to implemented tariff system).

Direct Feedback

The main characteristic for direct feedback is that consumers have an immediate and easily accessible display either directly on the meter or associated to the Smart Meter. The primary role of the meter is to provide a clearly-understood point of reference for improved feedback, preferably in combination with a separate In-house display (IHD) and individual appliances consumption metering. Using only Smart Meters display for direct consumption feedback has its advantages in LIH as it doesn't bring additional costs for separate IHD.

Direct feedback provided to LIH should include:

- Appropriate indication that allows consumers to easily distinguish between high and low levels of current consumption (current intensity of consumption);
- Appropriate indication that allows consumers to easily distinguish between peak and off-peak times (indication and price of active tariff) and clear overview of billing consumption (in kWh and currency), broken down by tariff (usually consumption from 1st in the month).

Event Notification

Besides meter display and potential use of IHD, tenants should be notified directly when different events concerning consumption occur. Such "alarms" may prove to be the most influential on behaviour changes. Due to already available mediums (SMS or Smart phone applications, E-mail) it is also simple to implement in LIH. Another option is ambient displays (semaphores), but this requires installation of additional equipment with additional costs. Triggering events of interest are:

- Steep deviation from average consumption and breached threshold in peak time;
- Tariff switch;
- Monthly threshold (average monthly consumption) has been breached.

ELIH-Med Smart Metering Experimentation Plan

Smart Metering experimentation plan of ELIH- Med project is divided into four time phases including period before Smart Metering Equipment Installation, Installation, Monitoring period and the closure of experiment with Evaluation of final data. Each phase will have its important role to help LIH consumers understand how they can use the information provided by Smart Metering to manage their energy consumption effectively and to save energy.

Pre-installation

Main purposes of pre-installation phase are assuring that selected dwellings comply with LIH criteria and households participating in experiment are getting accustomed to energy efficiency initiative. Awareness campaign includes information concerning all renovation (other ELIH-Med project initiatives) and installation works which will be carried out through the experiment. The second purpose of this phase is obtaining the baseline consumption data and behavioural patterns (survey) of participating LIH before experimentation takes place. Figure 45.2 shows the main characteristics of Pre-installation phase.

Smart Metering Equipment installation

During equipment installation phase it is essential to assure that all LIH participating in experiment are familiar with new Metering equipment installed. For this reason an educational input required by equipment supplier is mandatory in the call for tender. Figure 45.3 shows the main characteristics of Installation phase.

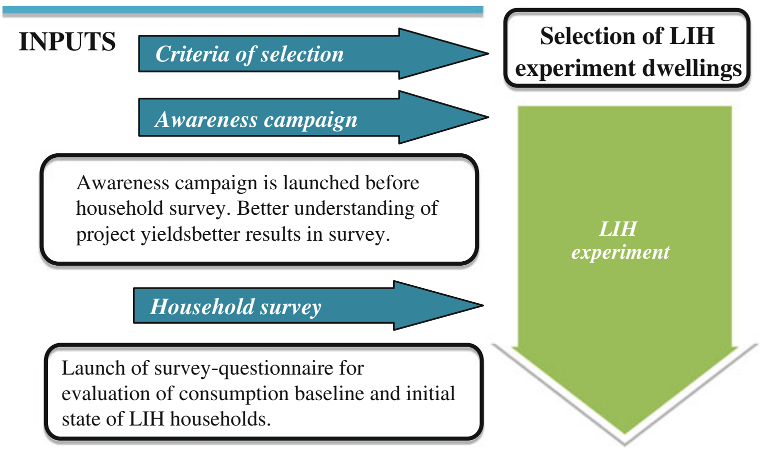

Fig. 45.2 Pre-installation phase

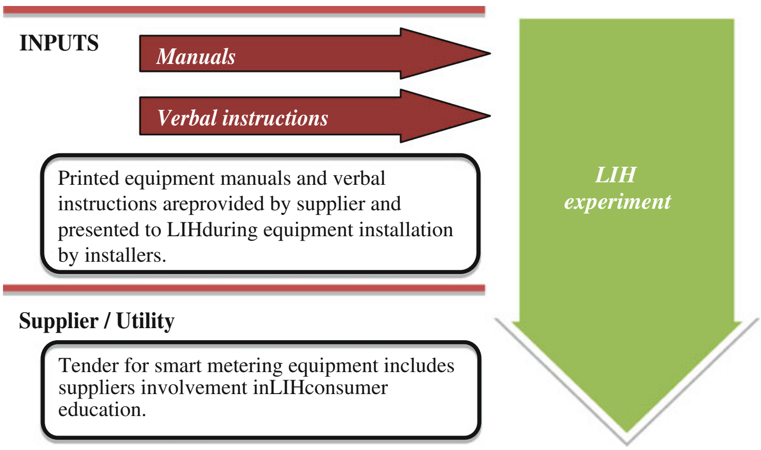

Fig. 45.3 Smart metering equipment installation phase

Monitoring

Main purpose of this phase is monitoring the effects of consumption feedback supported by Smart Metering on behavior of the LIH and adjustment of individual Smart Metering services according to the survey feedback from households, facilitating the living-lab approach to fine-tune different Smart Metering services to different households (impact of social, cultural and regional differences). Figure 45.4 shows the main characteristics of Monitoring phase.

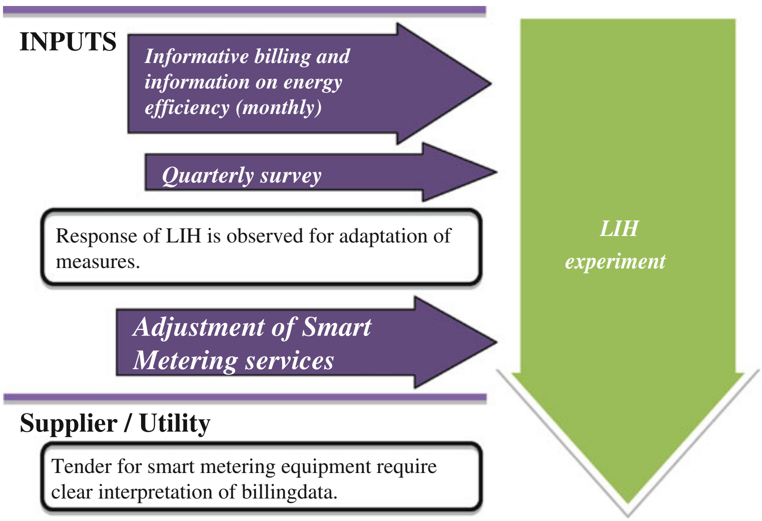

Fig. 45.4 Monitoring phase

Evaluation

Within this phase final household consumption as result of Smart Metering experiment and induced behavioral changes will be analyzed. Monitoring and review of the experimentation progress includes the consumer experience of the process, new Smart Metering functionalities and identified services.

Analysis of LIH Savings Potential

The preliminary analysis of LIH electricity consumption in ELIH-Med project has shown electricity savings potential with employment of described measures with minimum impact on the tenants comfort. Principles of demand response (load shifting) can provide up to 5 % of electricity consumption savings. When LIH consumers apply additional load optimisation (economical usage of household appliances) stimulated by consumption feedback, up to 7 % savings can be achieved.

The household motivation for load shifting to off-peak times is lower price of electricity supplied at that time. Highest price ratio between peak and off-peak tariff in Slovenia is 1.98 GEN-I (2010). This ratio was used in preliminary analysis of LIH electricity consumption costs in ELIH-Med project. In this case consumers can reach up to 6.9 % savings on electricity bill, when only load shifting is applied. In case of adding additional load optimisation, electricity costs can decrease for more than 8 %. For this reason two additional examples were analysed. In first case peak vs. off-peak tariff price ratio is increased to 2 and in second up to 2.2. In last case electricity costs savings can be above 10 % if all above measures are performed. Electricity costs savings for each case are presented in Table 45.2.

Table 45.2 Tariff rate ratio effect on electricity costs savings in households

Tariff rate ratio	Electricity costs savings (%)	
(Peak : off-peak)	Load shifting and demand optimization	Additional energy efficiency measures
1.98	6.9	8.1
2	7.1	8.9
2.2	9.0	10.1

Multi-Energy Metering

One of the Mediterranean area specifics is relatively low usage of natural gas and lack of district heating grids. Therefore electricity utilities must be involved in providing LIH new customized services as much as possible. When other energy utilities are present, the advantage of existing electricity grid infrastructure has to be explored. If Smart Meters are used for all utilities on site, communication with these meters can be done via a smart electricity meter as electricity meter can always provide the power supply for the communication. Sharing the remote communication channel can also greatly reduce the combined costs of communication, therefore reducing costs also for the final consumer. Metering of all energy forms is also needed to offer a complete view of the energy consumption to the final consumer through comprehensive feedback. Only a complete overview of household energy balance from all utilities can induce proper consumers behaviour changes as savings in one utility may be replaced by increased consumption in the others.

Energy Savings Verification

Monitoring and review of the experimentation progress of ELIH-Med Smart Metering will be used to build an algorithm using adaptive neural network model for predicting energy consumption and verifying energy savings considering different functionalities of Smart Meters in combination with energy efficiency measures and other influential factors. Those will include the social aspect of consumer experience of the process, dwelling typology and equipment, and new Smart Metering functionalities and services. Focus will be on predicting energy consumption cost savings as a result of change of behaviour on the basis of thorough consumption feedback. Additional external parameters will be monitored for statistical analysis and proper consideration of external circumstances. All LIH dwellings will be defined and classified based on the household survey before and after the Smart Metering experimentation. This survey includes two kinds of variables, ones that have direct influence on the energy savings (e.g. equipment and appliances used) and others, like residents education levels, which are strongly related to behaviour and indirectly affect the energy consumption. Database of performance results will also enable energy performance benchmarking, where a selected LIH can be benchmarked based on the input data gathered by household survey. Finally the prediction algorithm based on the results of Smart Metering experiment will enable the forecast of energy consumption costs savings and impact of individual new Smart Metering functionality or service as shown on Fig. 45.5.

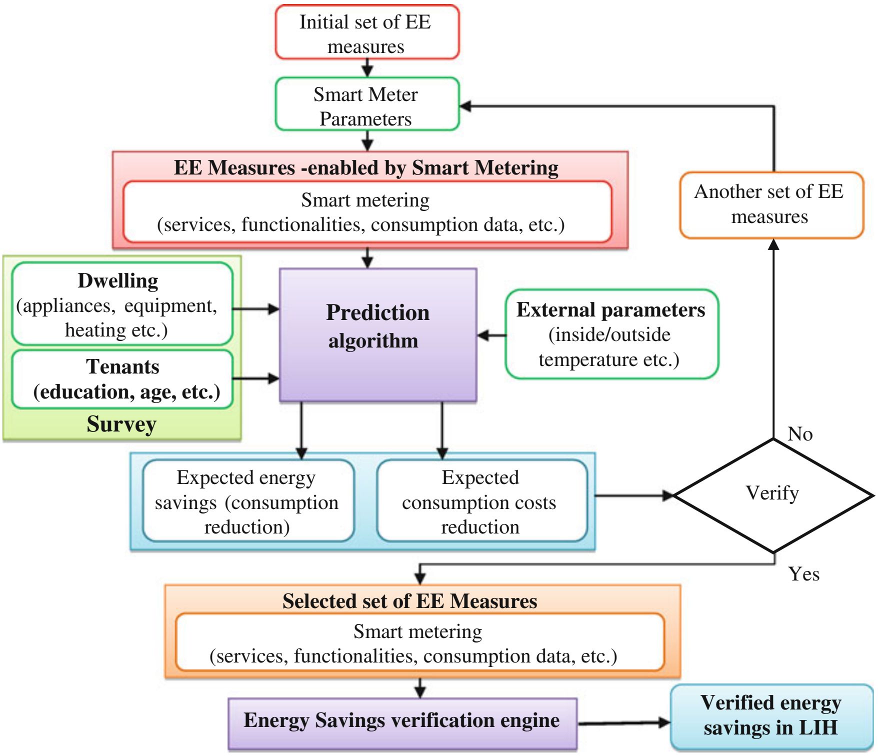

Fig. 45.5 Energy and costs savings prediction and verification flowchart

Conclusion

Successful energy efficiency policy must be adaptive and must rely on the empirical data. Smart Metering is a powerful tool for monitoring of achieved results and must be part of the comprehensive energy efficiency policy. Implementation of energy efficiency measures and utilization of the Smart Metering in LIH may prove to be quite challenging introduction of changes in a very complex environment. Suppliers should offer innovative ways of funding the costs of additional Smart Metering services and equipment in LIH which should not be directly borne by end users. Although individual consumption registration of high-energy usage household appliances may prove to have big influence on consumer behaviour, it is the notification about relevant and extraordinary events in energy consumption that may have the biggest impact to behavioural changes in LIH. Notification on tariff rate change when using advanced tariff systems may prove as most important for LIH as money savings on electricity consumption are most tangible. Lastly, final consumers must have several options of presentation and interpretation of billing consumption data. Internet access has proved to be available to most LIH and should be used for enriched consumption feedback. As consumption feedback will be specific to LIH, this is also an opportunity for different social programs to act through energy efficiency awareness campaigns in providing additional information and programs utilizing Smart Metering feedback medium. As behavioural patterns of LIH may differ from other domestic environments, therefore additional stakeholders (municipalities, local energy agencies, NGOs etc.) should be involved in interpretation and presentation of consumption data through consumption feedback. The low incomes also limit the possibilities of combining Smart Metering with sophisticated energy control systems for households due to high implementation costs. Due to characteristics (low natural gas consumption and lack of district heating systems) of the Mediterranean area Smart Metering in this region should primary focus on electricity metering. Consumption feedback provides an independent and customizable means to offer consumers a more direct, comparable and comprehensive information about their household's energy consumption pattern. Preliminary analysis confirmed positive impact on the electricity consumption of the consumption feedback in LIH in the Mediterranean region.

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Chapter 46
Optimization of a Stand-Alone Renewable Energy System for a Small Load Requirement

Shivneel Prasad, Ajal Kumar and Atul Raturi

Abstract Optimization of a stand-alone Renewable Energy (RE) system involves selecting the best RE resources and components, and sizing the system accordingly to get the most efficient and cost-effective solution. Design and optimization of an RE power system to serve the lighting in a University of the South Pacific car park was carried out using HOMER software and compared to manual calculations. Resource analysis showed that on average the site received 3.8 kWh m^{-2} day^{-1} of solar energy, with 1,387 full sun hours annually. Monthly average wind speed of 3.88 m s^{-1} at 10 m above ground level extrapolated to 15 m (the hub height of the wind turbine) resulted in an average wind speed of 4 m s^{-1}, with power density of 70 Wm^{-2}. With this wind resource, a Whisper 100 wind turbine would be in operation for approximately 50 % of the time in the year. The complementary nature of solar and wind resources showed good potential for a solar-wind hybrid system. In this study three possible systems—a PV system, a wind power system, and a hybrid power system (PV-wind)—were analyzed. It was found that a hybrid system is the best and most cost-effective option, as it is able to provide reliable power whilst minimizing the need for battery storage compared to a single RE power system. The optimum system comprised 0.270 kW_p PV combined with a 900 W Whisper wind turbine with total battery storage capacity of 440 Ah at 12 V. Manual calculations yielded results similar to the HOMER simulations.

Keywords HOMER · Hybrid systems · Optimization · Resource · Whisper 100

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W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_46,

Short Introduction

Pacific Island Countries (PIC) have huge renewable energy (RE) potentials, but to get the most efficient and cheapest solutions, one needs to select the best RE resource and size the system accordingly. The Sun is a good RE resource in PIC and can be used either directly (PV-photovoltaic) or indirectly (wind, biomass etc.), including combined solar/wind (so called hybrid) systems. The Paper analyses a stand-alone renewable energy system for lighting the car park at the University of the South Pacific. It was found that a hybrid system is the best option, because it can provide reliable power and does not require big battery storage.

Introduction

Dwindling fuel reserves and rising global awareness have caused many to look for alternative methods of energy generation to provide for the increasing energy demand (Zhenchao et al. 2002). These alternative sources are in the form of renewable energy, which is available in many forms, either derived directly (PV), or indirectly (wind, biomass, etc.) from the sun.

Pacific Island Countries (PICs) have huge renewable energy (RE) potentials which need to be tapped to meet their energy needs. Currently in the PICs, imported petroleum is the primary source of commercial energy, of which a large proportion is used in transportation (Prasad 2009). Fiji's annual energy consumption was estimated to be around 835 MWh in 2010, with approximately 292 MWh being generated from the use of diesel alone (Fiji Electricity Annual Report 2010). This energy however reaches approximately 70 % of the people only, and the rest are left to cater for their own needs since the grid of the local utility, Fiji Electricity Authority, does not cover the smaller islands and many of the rural settlements. Small diesel generator sets and kerosene lamps are usually used to meet the energy needs in these isolated areas, which are expensive given current fuel prices (Rehman et al. 2007). Renewable energy resources such as solar and wind are abundantly available in the PICs, and with proven technology one could easily set up a sensible system to harness either of the energies for electricity needs, or better still use a combination, hybridizing solar and wind to provide a more reliable source of power (Pecen et al. 2004). Many studies have been done to determine optimal hybrid system configurations for small load requirements. (Fortunato et al. 1997) reported that hybrid systems are now proven technologies to cater for electricity loads in remote locations.

Thus it is important that research be carried out in the PICs to study PV and wind resource distribution and inform the design of suitable systems to meet the load requirements of remote populations. The current study entails the study of PV and wind resource estimation at the University of the South Pacific (USP) Laucala to validate the affordability, reliability and appropriateness of using RE to harness cheap and clean energy.

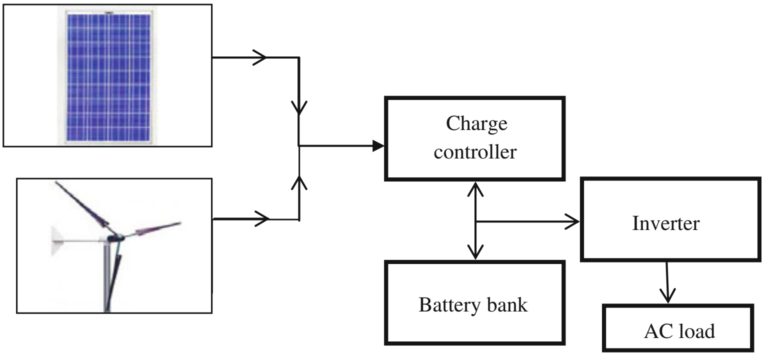

Fig. 46.1 Schematic showing PV-wind hybrid with storage

Methodology

The installed stand-alone Renewable Hybrid (RH) system (Fig. 46.1) consisted of a PV panel and wind turbine together with a battery backup and an inverter for AC conversion.

The current from the PV panel and the wind turbine was passed through the controller to charge the battery bank. The state of charge (SOC) of the battery was constantly monitored by the controller, which effectively stopped charging the battery once maximum SOC was reached. The current to the load was then supplied by the battery when needed. The essential components of the system (Table 46.1) comprised a wind turbine, PV panel, battery and inverter.

Renewable hybrid system sizing and optimization was divided into four parts: (1) system load was decided and categorized according to voltage requirements, (2) wind and solar resources were estimated at the site to explore the viability of such a system, (3) system design was carried out using manual and HOMER calculations, and (4) estimated output from the two methods was compared and analyzed.

Load Characterization and Calculation

The proposed RH system was designed to cater for street lights to be used in a car park at the USP Laucala campus. A total of 18 AC lights consisting of 12 × 9 W

Table 46.1 Essentials of a hybrid system

Equipment	Cost (FJ$)
Whisper 100 wind turbine	8,000
135 W Co energy panel	1,200
Haze 12 V 110 Ah battery	1,000
200 W inverter	500

CFL lamps and 6 × 3 W LED lamps were the required load. The design of the system was based on the usage of the lamps. All lamps were expected to be switched on between 6 p.m. and 6 a.m. daily. Hence, the load extracted current from the battery bank; however, the wind turbine was assumed to continuously replenish the charge in the battery bank during operation, and the PV module and wind turbine to charge the battery bank during the day. Thus the daily energy consumption (Eq. 46.1) was calculated by multiplying the total power rating of light (P_{light}) with the number of hours of use (H_L).

$$\text{Daily energy consumption (kWh)} = \frac{\mathrm{P_{light}} \times \mathrm{H_L}}{1000} \tag{46.1}$$

Because of the long distance transmission required and high losses expected from using DC supply, only an AC system was considered. The daily energy consumption was calculated by assuming the inverter efficiency was 90 % and further corrected by taking into account cabling and battery losses of 12.5 %. The corrected DC energy demand was then used to carry out the manual system sizing.

Wind and Solar Resources

The present study utilized wind/solar resource data obtained from a nearby monitoring site at the USP campus. A complete set of wind and PV resource data was available for 2007 to carry out the analysis and assessment. To separate short-term from long-term fluctuations, average monthly wind speeds were calculated. The wind and solar data were measured at 10 and 3 m above ground level respectively.

Manual System Sizing

The manual system sizing was carried out using monthly energy demand (E_{ML}), which was obtained by multiplying the corrected DC energy demand by the number of days in the month. The monthly energy demand was calculated to determine the energy contribution by the individual components of the wind and PV system. This was made possible by using the wind resource and wind power curve of the chosen wind turbine to determine the average monthly energy of the wind system (E_W). The wind speed was extrapolated to the hub height using the power law (Eq. 46.1). The data were analyzed to establish the fraction of the time the turbine would be producing power.

$$V = V_0 \left[\frac{H}{H_o} \right]^{\alpha} \tag{46.2}$$

where V is the speed at desired height, H and V_o are the known wind speed at H_o and α is the power law exponent. This and many other studies (Ilinka et al. 2003; Johonson 1985) have used a value of 1/7 for α. Vega (2005) stated that in order to estimate AEP, site-specific wind distribution is needed, and where wind distribution is not present it can be estimated using a Rayleigh distribution (Eq. 46.3).

$$F(v) = 1 - e^{\left[\frac{-\pi}{4}\left(\frac{V}{v_a}\right)^2\right]}, v \leq V \tag{46.3}$$

where $F(v)$ represents the time fraction or probability that the wind speed is smaller than or equal to a given wind speed, V, and v_a is the average wind speed.

Since wind power density is directly proportional to the cube of velocity, average power in wind was found by statistical analysis of wind, that is by finding the value of the average of wind speed cubed rather than averaging the wind speed then obtaining the cube (Master 2004). The average of wind speed cubed (v_i^3) (Eq. 46.4) can be obtained by multiplying the cube of wind speed with the fraction of hours that the wind speed will be experienced.

$$\left(v^3\right)_{avg} = \sum v_i^3 \times \text{probabilty } (v = v_i) \tag{46.4}$$

To determine the probability that $v = v_i$ a Rayleigh probability distribution (Eq. 46.5) was used. The probability of each wind speed was calculated using the sum of the product of power output (kW) from the power curve of the wind turbine, frequency of each bin and hours in the particular month.

$$p(v) = \frac{\pi}{2}\left[\frac{V}{v_a^2}\right] e^{\left[\frac{-\pi}{4}\left(\frac{V}{v_a}\right)^2\right]} \tag{46.5}$$

Thus, the energy demand to be met by the PV system (E_{PV}) was calculated by subtracting the monthly power generated (E_W) from E_{ML} (Eq. 46.6).

$$E_{PV}(\text{kWh}) = E_{ML} - E_W \tag{46.6}$$

The PV system size was then estimated using Eq. 46.6.

PV Array Sizing

Solar data for a horizontal surface were available from local measurements; however, in order to maximize the power production the panel must be tilted at an optimum angle. The optimum tilt for this study was 20° [2]. The number of modules in a series string (Eq. 46.7), the DC bus voltage (12 V), was added to the diode drop voltage (1 V) and divided by the module working voltage obtained from the I–V curve of the selected PV panel.

$$\text{Module in Series string} = \frac{\text{DC bus voltage} + \text{diode drop voltage}}{\text{module working voltage}} \tag{46.7}$$

To calculate the number of modules in parallel the gross mean daily output was determined by multiplying the working current (I_P) by the mean daily radiation of the design month at optimum tilt, allowing 10 % for wiring and mismatch. Thus for each month the gross mean daily output was calculated, which was then divided from the annual mean daily load for the deficit month to calculate the number of strings in a parallel combination. The PV monthly array output was determined by multiplying the gross mean daily output with the number of modules in a parallel string with the number of days in the month (Eq. 46.8).

$$\text{PV monthly array output (kWh)} = \text{gross mean daily o/p} \times \text{modules in parallel} \times \frac{\text{days}}{\text{month}} \tag{46.8}$$

Battery Sizing

The battery capacity (Eq. 46.9) was determined keeping in mind that the battery had to cater for load at night, as well as for days of no power generation from the renewables. Ball and Risser (1988) stated that deep cycle batteries have a depth of discharge (DOD) of 80 %, which was considered to determine the battery capacity of the hybrid system.

$$\text{Battery Capacity (Ah)} = \frac{\text{Daily load (Wh)}}{\text{system voltage (V)} \times \text{DOD}} \tag{46.9}$$

Homer

In order to determine if the above system was optimum the simulation program Hybrid Optimization Model for Electric Renewable (HOMER) was used. HOMER has been reported as the most widely used simulation model in many case studies and designs (Erdnic and Uzunoglu 2012). For proper optimization of the system HOMER needs to be provided with different energy resources, economic and technical constraints and storage requirements; component type, capital and replacement costs, and operation and maintenance costs also need to be determined (Rehman et al. 2007). Methods outlined in the HOMER user guide (Getting Started Guide for HOMER version 2.1 2005) were executed to adequately design and optimize the system (Getting Started Guide for HOMER version 2.1 2005). Solar and wind resource data from 1 January to 31 December 2007, were used to carry out the simulation in HOMER.

Table 46.2 Monthly energy consumption

Month	Energy consumption
January	59.52
February	53.76
March	59.52
April	57.60
May	59.52
June	57.60
July	59.52
August	59.52
September	57.60
October	59.52
November	57.60
December	59.52

Results and Discussion

From Eq. 46.1 the daily energy consumption was calculated to be 1.6 kWh for AC loads. Thus the DC corrected daily energy consumption is estimated to be 1.92 kWh. Table 46.2 shows the monthly energy (DC) required for each month. On average, each month the system is required to produce at least 58 kWh to meet the demand. Annually the system has to meet a total load demand of 702 kWh.

Since the peak load to be catered for is 0.126 kW AC, a 0.2 kW inverter was sufficient to convert DC into AC power.

Resource Assessment

Resource analysis showed that on average the site received 3.8 kWh m^{-2} day^{-1} on a horizontal surface, which translates into 1,387 h of full sun in a year, producing approximately 1.4 MWh m^{-2} of global solar radiation yearly. Shaahid and Elhadidy (2007) stated that daily solar radiation averaging between 3.61 and 7.96 kWh m^{-2} indicates a potential site for harnessing solar energy. The study site had similar daily averages; hence it is categorized as a good solar potential site. The solar resource (Fig. 46.2) shows that solar radiation decreases from a maximum of 5.5 h day^{-1} in January to a minimum of 2.75 h day^{-1} in July, then gradually increases to 4.41 h day^{-1} in December. When studied together the wind and solar resource show a somewhat complementary nature, making the solar-wind hybrid system a viable option for the study site.

The time series plot (Fig. 46.2) shows that wind resource fluctuates throughout the year. Starting from January the wind speed decreases to a minimum of 2.6 m s^{-1} (the lowest wind speed in the year) after which the wind speed peaks in August at 5.2 m s^{-1} and gradually decreases until December.

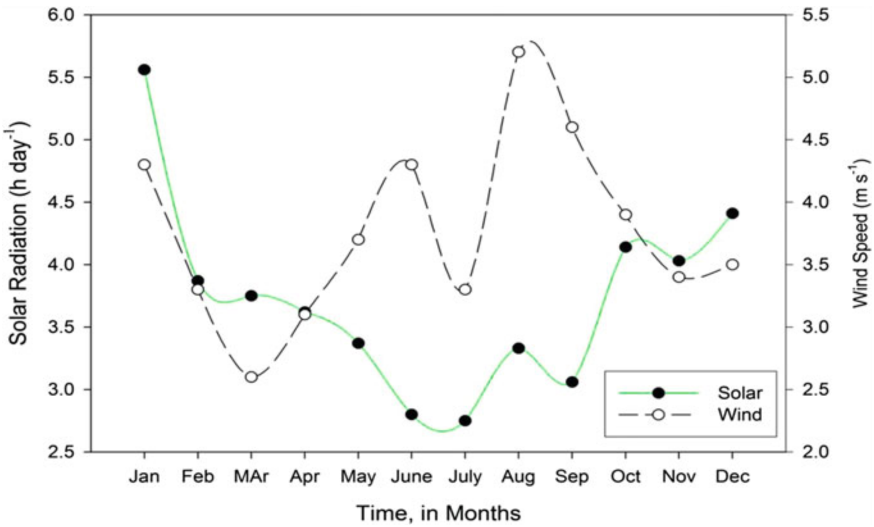

Fig. 46.2 Solar and wind resource distribution at the study site

Annually, the site receives monthly mean wind speeds of 3.88 m s^{-1} at 10 m above ground level, which, extrapolated to 15 m (Table 46.3) (the hub height of the wind turbine), gives 4 m s^{-1} with a power density of 70 Wm^{-2}. With this wind resource and assuming Rayleigh distribution, a Whisper 100 wind turbine would be in operation for approximately 4,767 h (50.4 %) in a year.

Table 46.3 Extrapolated wind speeds at a hub height of 15 m

Month	Wind speed (ms^{-1})	Hours of wind turbine operation
January	4.56	479.5
February	3.50	319.5
March	2.76	214.5
April	3.28	305.3
May	3.92	408.2
June	4.56	465.9
July	3.50	357.3
August	5.51	549.1
September	4.87	491.3
October	4.13	436.0
November	3.60	362.1
December	3.71	378.6

Table 46.4 Average monthly output of Whisper 100 wind turbine

Month	Energy output (kWh)	Surplus
January	66.17	6.65
February	24.38	−29.38
March	16.73	−42.79
April	38.45	−19.15
May	42.15	−17.37
June	67.45	9.85
July	52.54	−6.98
August	69.69	10.17
September	79.51	21.91
October	70.59	11.07
November	57.06	−0.54
December	50.60	−8.92
AEP	635.32	

Monthly Wind Power Output

The monthly energy output (Table 46.4) of a Whisper 100 wind turbine was determined. Statistical analysis predicted an annual energy production (AEP) of 635 kWh for the wind turbine, which just falls short of the 702 kWh needed to meet the demand. From February (Table 46.4) to May, as well as in July, November and December, the wind turbine is not able to meet the required demand. This means that either two Whisper 100 wind turbines must be used or the wind system, or they must be coupled together with a PV system to meet the required demand. Using two Whisper 100 wind turbines would make the system very expensive (Table 46.1), and will also generate more than the required energy; the option of coupling it with a PV system is therefore the one to consider.

PV Array Sizing

Using the steps outlined in 2.3.1 the PV array was sized. The system voltage was chosen to be 12 V, since a 200 W 12–240 V inverter was chosen to convert DC voltage to AC voltage. The number of panels in a series string was calculated to be one, since the module working voltage obtained from the I–V curve of the 135 W panel is 15 V. Wenham et al. (2006) stated that conversion of radiation from a horizontal surface to a tilted surface is computationally extensive and better left to available PV programs; therefore for this study RETScreen software was used to convert the horizontal radiation for the month of March (largest deficit) to the optimum tilt angle in order to carry out the calculation for the gross mean daily output. For the month of March the average daily solar radiation on a tilt of 20° was found to be 3.76 kWh m^{-2} day^{-1}, which, multiplied by the I_P of 7.0 A, yielded a gross mean daily output of 24 kWh. Note that the PV array needs to cater for a load of 42.79 kWh, thus dividing the load by the available array output. Two panels in parallel are required in order to meet the requirement.

With 2 × 135 W panels, the PV array was predicted to produce an annual energy production (AEP) of 312 kWh, determined by multiplication by the number of hours of full sunshine in the year (corrected by allowing 10 % for dirt losses and mismatch). If the PV alone were to meet the load demand, the number of panels in a parallel string would increase, as the DC bus voltage does not change. Thus the load to be catered for by the PV array would be 59.52 kWh, requiring three panels.

Battery Sizing

The battery bank has to cater for the load at night, as well as one day's worth of no generation by renewables for a hybrid system. Thus the battery needs to cater for a total load of 3,840 Wh. The battery bank capacity was calculated to be 417 Ah. Since the chosen battery is 110 Ah, four batteries were needed to meet the capacity, making the total storage capacity 440 Ah.

For a PV-only system it was determined that the site has to be able to deal with at least four days of no sun. Thus the total load delivered was 5,760 Wh, yielding a battery bank capacity of 800 Ah. This meant a total of 8 × 110 Ah batteries, a large battery storage for a small load requirement that was not critical. This was grossly over-sized, so a PV-only system was not considered any further. The PV-wind hybrid combination seemed the better option.

HOMER Simulation and Optimization

After resource assessment and manual system sizing HOMER was used to carry out the hybrid design. The input parameters for HOMER (Fig. 46.3) show equipment and resources to consider for the hybrid design.

The search space (Fig. 46.4) shows a number of possible combinations for HOMER to consider. Using the list of possible combinations, HOMER carried out simulations to derive the most favorable system to cater for the load. With the current search space HOMER executed 432 different combinations to obtain the optimal system to meet the demand. The optimal system was then decided, bearing in mind the capital cost and the cost of energy.

HOMER predicted the two most systems (Table 46.5) likely to meet the energy demand with the lowest energy and capital costs.

Option 1 was chosen based on the cost of energy and capital cost. HOMER (Fig. 46.5a) predicted that the PV array would meet 32 % of the load while the wind turbine would meet 68 % of the load for Option 1. The capital cost of the

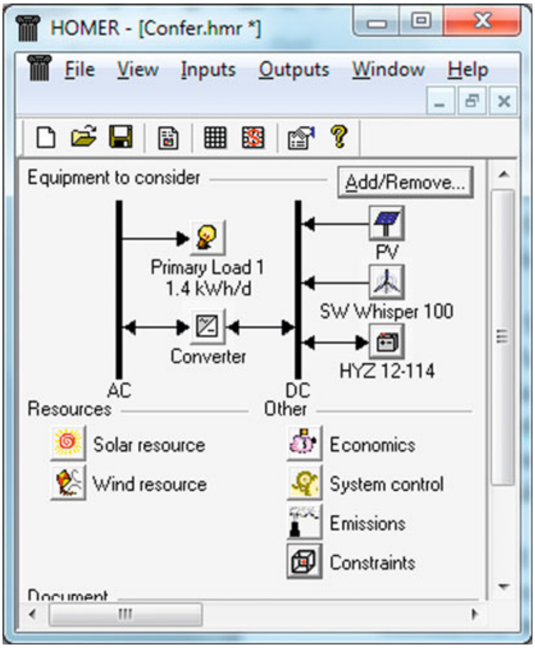

Fig. 46.3 HOMER inputs

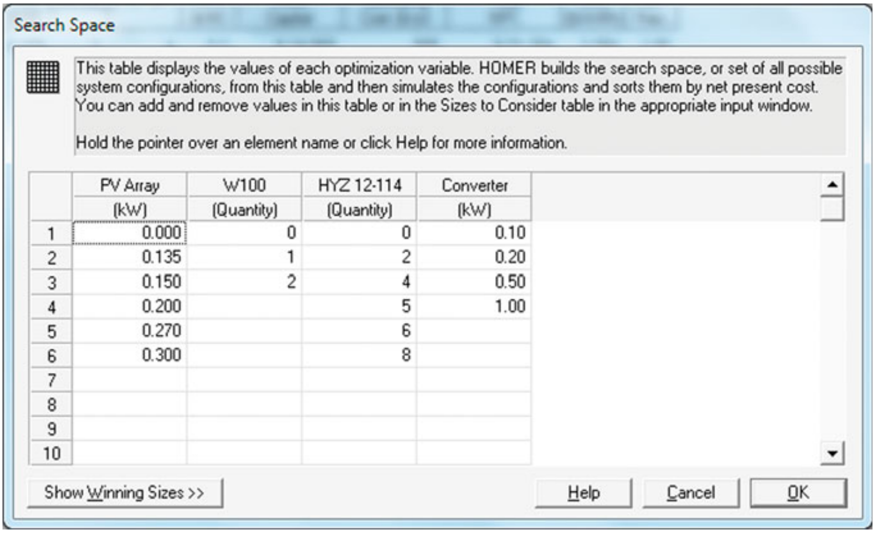

Fig. 46.4 HOMER search space

Table 46.5 HOMER optimal system

Option	PV (kW)	W100	HYZ 12-114	Converter (kW)	Initial capital	Operating cost ($/year)	Total NPC	COE ($/kWh)	Renewable fraction
1	0.27	1	4	0.2	$14,800	505	$21,254	3.254	1
2		1	8	0.2	$16,400	625	$24,390	3.737	1

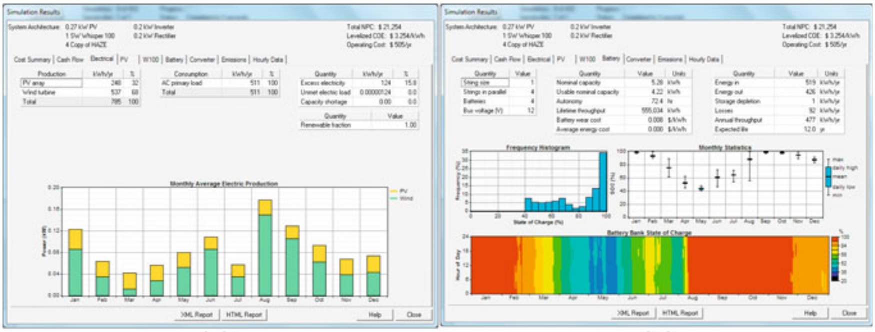
(a) (b)

Fig. 46.5 HOMER simulations output

overall system was calculated at $14,800, with an energy cost of $3.25 per kWh. The system is predicted to meet the energy demand with no capacity shortage. Overall, the battery SOC (Fig. 46.5b) reached a minimum of 40 % in May, which is still over the 20 % allowable limit (Ball and Risser 1988).

The annual energy production from the hybrid system was expected to be 785 kWh, which is greater than the annual energy demand calculated earlier. From the monthly average production graph (Fig. 46.5a), for most months the wind contribution is more than the PV contribution. However, during the months of March and April PV is the major contributor. During these months the wind speeds are quite low—this is considered to be the "calm" period for the wind turbine.

The battery SOC, when studied for Option 2, showed that the SOC dips below the 20 % limit, not only making Option 2 expensive but also unreliable. After carrying out manual calculations and simulations using HOMER, it can be seen that the optimal system to serve the load demand is a hybrid consisting of a single Whisper 100 wind turbine coupled with a 0.27 kW_p PV array and 440 Ah of battery storage. The wind turbine alone or the PV-only system are both expensive in terms of capital (Table 46.5) compared to the hybrid combination, and require more storage capacity. Once again the hybrid system seems more feasible.

Table 46.6 Results summary

Output	PV	Wind turbine	Batteries	AEP (kWh)		
				Wind	PV	Overall
HOMER	0.27	1	4	537	248	785
Manual	0.27	1	4	635	312	947

Comparison

Once an optimized system had been attained from HOMER it was compared with the manual sizing to see if the two were similar. Parameters of interest were the number of wind turbines, PV array and battery bank size, and the AEP. Table 46.6 summarizes the parameters of interest for each method.

The configuration of the hybrid system from both methods (HOMER and manual) is comparable with slight difference in AEP. It should be borne in mind that for manual calculation the AEP is predicted by average values, whereby HOMER used daily data analysis to predict the AEP. Since AEP is more than the demand for both calculations, it is safe to assume that the system configuration meets the requirements.

Conclusions

Site-specific solar and wind resource assessment was carried out in order design a solar-wind hybrid system to power street lights around a USP car park with a total daily load requirement of 1.6 kWh AC. The study utilized the solar wind data (from 1 January to 31 December 2007) collected by the School of Engineering and Physics metrological data bank.

From the plotting of the time series, the seasonal variation of the two resources revealed a complementary relationship between solar and wind at the site, making it a potential location for generating electricity through a hybrid system. With annual average solar radiation of 3.8 kWh m^{-2} day^{-1} the site is predicted to receive 1,387 h of full sun annually. Hence, the 2×135 Co-energy PV module is expected to produce approximately 300 kWh annually. Statistical analysis of wind speed at the site showed an annual average of 3.88 m s^{-1} at a height of 10 m, and Whisper 100 will be in operation for more than 50 % of the time, indicating good potential for wind. The Whisper 100 is predicted on average to produce approximately 800 kWh annually.

System design was carried out using two different methods, and the results were compared. Both methods (manual and HOMER) yielded an optimal and feasible combination of a single Whisper 100 wind turbine together with a 0.27 kW_P PV array with a battery storage capacity of 440 Ah. Since the design criteria from both methods were the same, the above configuration was accepted to be the optimal one, adequate to meet the required load. Battery simulation done using HOMER showed that for the optimal system the battery SOC would remain above the critical level of 20 %.

Hence, for remote areas in Fiji wind-PV hybrid systems should be considered to produce affordable, reliable and clean energy. Further monitoring of RE resources around the Fiji islands is crucial for future design of adequate renewable systems, since wind and solar resources are site specific.

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