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# Renewable Energy for Unleashing Sustainable Development

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*Those who are used to dream during the day know a number of things that are missed by those who dream only at night*

Edgar Allan Poe

*The only way to discover the true boundary of possible is to proceed a bit further into the impossible*

Blaise Pascal

*Dedicated to the memory of Abeeku Brew-Hammond, as a devoted champion of access to energy and development,*
*and…*
*to all those who dream and act for a more equitable distribution of resources,*
*to all those who believe that human capital is central to sustainable development*

# Foreword

The story of development is deeply rooted in the transformation of natural and human capital into socioeconomic value through a series of industrial revolutions. We are entering what some term the "third industrial revolution" now. This pathway is powered by the provision of energy services. Thus, access to reliable, sustainable, and modern energy services will help support and drive development and growth.

Today, unless we find ways of "greening" this engine of development, we cannot hope to achieve long-term and sustainable growth. This notion has gained significant ground over the last few decades, and we are now at an important inflection point. This is the impetus for moving the topic of energy up the development agenda and for the launch of the UN's *Sustainable Energy for All* initiative.

During the International Year for Sustainable Energy for All (2012), at the Rio+20 Conference, commitments were made, "*to act to make sustainable energy for all a reality and, through this, help to eradicate poverty and lead to sustainable development and global prosperity*". Building on these commitments, the Global Thematic Consultations on Energy has conducted a transparent, multistakeholder, global dialog on the reasons and the modalities of how energy should be addressed in the United Nations post-2015 Development Agenda. The dialog has demonstrated the universal support for the centrality of energy.

The design of a global energy goal and related targets will need to encompass all three dimensions of sustainability. This is required in order to identify the proper design and large-scale deployment of innovative and locally appropriate technologies, business models, financial mechanisms, regulations, and policies. We recognize that there is still a long way to go, but the goals we have set for ourselves are achievable and will have enormous benefits.

Dr. Kandeh K. Yumkella
Special Representative for Sustainable Energy for All[1]

[1] SUSTAINABLE ENERGY FOR ALL is an initiative launched by the United Nations Secretary-General and guided by his High Level Group that brings all key actors to the table to make sustainable energy for all a reality by 2030. http://www.sustainableenergyforall.org

# Preface

This book is intended as a contribution towards a more inclusive sustainable future. It conceptualizes energy as a central element of development and renewable as a key condition for sustainable development. By describing the technical, economic and policy conditions that are necessary for the successful deployment of renewable energy, it provides recommendations for unleashing, in developing regions, a sustainable development based on more equitable distribution of resources.

The need to provide universal energy access to reduce poverty while preserving the environment and limiting climate change requires a new paradigm in the way energy is produced, distributed and used. Decentralized renewable energy systems based on sound technical solutions, solid business models and enabling policies, need to be deployed. Energy is needed to satisfy basic living needs and to give access to public services that are relevant to human and social development. Energy also represents also an income opportunity for people as it enables new productive activities and thus triggers socio-economic development. Distributed renewable energy can and should become the first option for achieving universal energy access since it has proven to be in several cases the most cost-effective and affordable option.

Energy is a cross cutting enabler that should be integrated into wider social, economic and environmental policies. From this perspective, the book provides a comprehensive multi objective and multi criteria analysis that goes beyond the often shortsighted and simplistic financial analysis, with the aim to represent a step towards the achievement of innovative solutions.

A wide panorama of the contribution of renewable energy to sustainable development is presented in four of the five parts of the book, that readers might read separately, as each one stands on its own and tells a distinctive part of the story. The fifth part gives space to specific experiences coming from different stakeholders quite active in the field of access to energy.

The book brings together several authors from different parts of the world and professional backgrounds ranging from private sector to academia, international organizations, NGOs and governments to give a comprehensive view of the role of renewable energy in ensuring sustainable development. It is also builts on the long experience of the three editors in education and in the promotion and implementation of renewable energy projects in developing countries.

Emanuela Colombo
Stefano Bologna
Diego Masera

# Acknowledgments

This book is based on the discussion and achievements of an international conference "Sustainable Energy Strategies in Low and Middle-Income Economies: Blending Technology, Finance and Policy beyond 2012" organized by Politecnico di Milano in collaboration with the United Nations Industrial Development Organization (UNIDO) and held in November 2012 in Milano.

Emanuela Colombo, Stefano Bologna and Diego Masera designed the idea, directed the book and carried editorial responsibility. The introduction of the book on access to energy and sustainable development was co-ordinated by the three editors. In particular, Emanuela Colombo co-ordinated the technological part, Stefano Bologna the economic part and Diego Masera the policy part, Lorenzo Mattarolo co-ordinated the final part which presents the contributions of some Italian players in the field. Together these parts provide a panorama of the contribution of renewable energy to sustainable development, but readers do not need to read the parts in sequence, as each part may stand on its own and contributes to tell a distinctive piece of the whole story.

Special thanks are due to Kandeh K. Yumkella for his preface.

Thanks are due to the Italian Ministry for the Environment, Land and Sea, the Associazione Produttori Energia da fonti Rinnovabili (APER), **eni**, Enel and Enel Foundation, in particular to the authors of the fifth part of the book: Annalidia Pansini, Nino Frosio, Luigi Sampaolo, Gloria Denti, Valentina Patricola, Mariano Morazzo and Giulio Loiacono. Our gratitude goes also to the listed NGO representatives: Matteo Leonardi, Stefano Barazzetta, Paola Rosa Fava, Tiziana Vicario, Giorgio Capitanio, Giuseppe Biella, Serena Arduino, Claudio di Benedetto for their valuable contributions and kind availability.

The editors wish to acknowledge the precious input provided by Christina Becker-Birck and Toby Couture, Koffi Ekouevi, Gabriela Elizondo-Azuela and Emilio Simonet.

The book benefited from the substantial support and co-operation provided by the Department of Energy of Politecnico di Milano and its UNESCO Chair in Energy for Sustainable Development which devoted a number of professors, Ph.D. candidates and temporary researchers to this task: Alberto Berizzi, Mario Motta, Christian Bovo, Riccardo Mereu, Jerome N. Mungwe, Jacopo Barbieri, Stefano Mandelli, Godfrey G. Moshi, Marcello Aprile and Vittoria Paramithiotti. Special thanks are also due to the Department of Management, Economics and Industrial Engineering of Politecnico di Milano, to Marika Arena and Irene Bengo for their contribution on business models, as well as to Polisocial (Fondazione Politecnico di Milano), the program of social responsibility at Politecnico di Milano which contributed on improved cook stoves through Francesca Mapelli.

Thanks are due also to Engineers without Borders—Milano which contributed to a number of discussions; many of the authors within this book are also active members of the association.

Thanks to the creative contribution by Stella Cattani and Elisabetta Rossi who conceived the cover image of this book and some of the images in Chaps. 1 and 2.

The book would have not been published without the excellent hard work, the high commitment and the strong tenacity of Vittoria Paramithiotti, a fourth "in pectore" editor, whose support was essential to coordinate the contribution of all the authors, revise the chapters and shape the book as it appears now to the readers.

## Disclaimer

The views expressed herein are those of the author(s) and do not necessarily reflect the views of the United Nations. This document has been produced without formal United Nations editing and do not imply the expression of any opinion whatsoever on the part of the United Nations Industrial Development Organization (UNIDO) or the United Nation Educational Scientific and Cultural Organization. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO or UNESCO.

From the scientific perspective the book tries to cover the issue of sustainable energy for all by giving a comprehensive understanding of the main technological, economic and financial challenges and opportunities and by identifying policies and measures that may support the scaling up of access to energy. Each chapter is therefore designed to provide a general framework of each subject, giving also some research directions for future studies. To this purpose, extended references to the relevant and updated scientific literature are given in most of the chapters.

# Contents

# About the Editors

**Emanuela Colombo** She holds an M.Sc in Nuclear Engineering and a Ph.D. in Energetic at Politecnico di Milano. She is an Associate Professor in Energetic and Engineering for Cooperation for Development. She was named Chair holder of the UNESCO Chair in Energy for Sustainable Development in 2012. From a scientific perspective, her research focuses on system analysis for highlighting the interrelations between energy, environment, and development and on sustainable energy strategies for promoting access to energy in developing countries. She is author of more than 100 scientific papers and is currently the coordinator of two European projects in Egypt, Kenya, Tanzania, and Ethiopia. One of the founders of Engineers Without Borders in Milan, she was named Rector's delegate to Cooperation and Development in 2005 and more recently to the International Relationship with Africa. She coordinates the CUCS network of 27 Italian universities and is a member of the related working group at the Italian Ministry of Foreign Affairs. She is a member of the EDF panel on Sustainable Development.

**Stefano Bologna** He is currently Director, Operational Support Services at UNIDO and until 2012 Director of the International Centre for Science and High Technology (ICS-UNIDO), with the mandate to foster scientific and technical capacities of developing countries particularly in the areas of renewable energies and utilization of bioresources. Previously, he was UNIDO Representative and Regional Director in South Africa where, among others, initiated national programs on energy efficiency, climate change mitigation in industry as well as advanced manufacturing. In UNIDO, he also served as Representative in Kenya, Industrial Engineering Expert in the New Technology Unit. In his career, he worked for national and international organizations and private companies (World Bank, European Commission, UNEP, Price Waterhouse and Coopers, Italian Ministry of Foreign Affairs) in project design and management, strategic planning and evaluation, and financial and technical management. He devoted a large part of his profession in promoting the role of private sector in fostering sustainable business practices. He holds an M.Sc in Mechanical Engineering from the University of Ancona, Italy.

**Diego Masera** He is currently the Chief of Renewable Energy at UNIDO in charge of a global portfolio of 35 projects in developing countries and economies in transition with a value of over USD200 million. Diego Masera holds a Ph.D. on renewable energy that focuses on the development of a sustainable industrial model based on the use of renewable energies, carbon sequestration, and poverty reduction. He worked in the promotion and development of Renewable Energies and Appropriate Technologies in Africa for over 10 years. He served for 5 years as a Regional Coordinator for the Industry, Technology and Economics Programme of UNEP in Latin America and the Caribbean and a similar period as UNDP's Climate Change Regional Coordinator in the same region. Diego Masera has an extensive experience of hand-on renewable energy project implementation covering more than 40 countries. He is author of several articles and books on Climate Change, Renewable Energy, and Sustainable Production and Consumption.

**Politecnico di Milano**[2] is a scientific-technological university training engineers, architects, and industrial designers highly committed to the quality and innovation of teaching and research and to develop fruitful relationships with private industrial sector. The attention toward the today's challenges of global development has driven a strong international attitude at Polimi which today ranks 48 among the technical universities worldwide. The **Department of Energy,**[3] established in 2008 under the impulse of professors and researchers previously belonging to four departments traditionally related to the energy sector. The mandate is to provide, through an interdisciplinary approach, convenient solutions to the complex problems of the energy sector, now experiencing a strong strategic relevance at the global level. The Department of Energy aims to become an influent and independent advisor on the energy fields and is supported by 300 professors, technical and administrative staff, research fellows, and Ph.D. students. The **UNESCO Chair in Energy for Sustainable Development** has been established at Politecnico di Milano since March 2012. Curricula upgrading and staff exchanges with Developing Countries and North–South cooperation between universities are promoted through research projects granted by the European Union. The Chair cooperates with international organizations, civil society players, public institutions, and private enterprises on research projects on sustainable energy strategies. **Engineering Without Borders Milan**[4] (ISF-MI) is a nonprofit organization established in 2004 strongly cooperating with Politecnico di Milano. ISF-MI's mission is based on education (peer education based), technology transfer, and dissemination of sustainable development principles and related to water and energy. ISF-MI promotes microcredits and social enterprises for migrants, in Italy and in their native countries.

[2] www.polimi.it

[3] www.energy.polimi.it.

[4] www.isf.polimi.it

**United Nations Industrial Development Organization (UNIDO)** is the specialized agency of the United Nations that promotes industrial development for poverty reduction, inclusive globalization, and environmental sustainability. The mandate of UNIDO is to promote and accelerate inclusive sustainable industrial development in developing countries and economies in transition. In recent years, UNIDO has assumed an enhanced role in the global development agenda by focusing its activities on poverty reduction, inclusive globalization, and environmental sustainability. The Organization carries out two core functions: as a global forum, it generates and disseminates industry-related knowledge; as a technical cooperation agency, it provides technical support and implements projects. The Organization is recognized as a specialized and efficient provider of key services meeting the interlinked challenges of reducing poverty through productive activities, integrating developing countries in global trade through trade capacity building, fostering environmental sustainability in industry, and improving access to energy.

# Part I
# Access to Energy and Sustainable Development

Energy has been deeply linked to the history of mankind and to its development. Today, the correlation between access to energy and development is well-known, for billions of poor people the opportunity to overcome the development divide is strongly affected by the lack of access to energy.

The relevance of energy in the global scenario has constantly risen and the interconnections with the environment and the society have become increasingly evident. The need to fight poverty by increasing access to modern energy service is worldwide recognized.

Energy drives human progress, and now more than ever the world needs to ensure that the benefits of modern energy services are available to all and provided as cleanly, safely, and efficiently as possible. The transition to sustainable energy systems represents one of the key challenges of our global economy and, at the same time, the opportunity to rethink our energy models based on depleting resources and centralized systems. Renewable energies have a pivotal role to play within this challenge.

In Chap. 1, the link between energy and development is discussed, and the energy ladder is analyzed from the basic needs up to the productive usage of energy and income-generating activities. In this chapter, the concept of livelihoods strategies to increase local capitals for improving the quality of life is also addressed. Finally, capacity building, education, and research are discussed as long-term perspectives, which play a vital role for long-lasting and successful strategies. This chapter gives an overview on the different topics that are discussed with details in the other parts of the book.

In Chap. 2, the global dimension of universal access to energy is presented together with some correlations between energy availability and development. Energy is discussed in the framework of sustainability and therefore analyzed based on the three pillars of economic, social, and environmental dimensions. Access to energy is also discussed according to the two main challenges of electrification and biomass dependence. Efficiency and the main drivers and barriers toward local integrated renewable energy strategies are also discussed to widen the perspective.

# Chapter 1
# Renewable Energies to Promote Local Development

Emanuela Colombo, Diego Masera and Stefano Bologna

**Abstract** Energy has been deeply linked to the history of mankind and to its development. Some of the natural forces which are today referred to as renewable energies, such as solar, wind, hydro and biomass have been known and used for centuries. Among all the different sources of energy, renewables were the first to satisfy human energy needs. Today the opportunity to overcome the development divide strongly depends on the availability of energy, and hence, the nexus between energy and sustainable development needs to be better explored in order to understand how energy can contribute to poverty reduction. In this scenario, in the chapter it is shown how renewable energies and distributed generation play a key role as they allow the utilization of local resources while preserving the environment, creating employment, promoting income generation, capacity building and local empowerment.

## Energy and Development

### *Historical Background*

The discovery of how to use and manage the open fire dates back to a few hundred thousand years ago and represents the first manifestation of energy at the service of mankind. Thanks to the ability of controlling fire, heat and light were available on

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demand and a wider range of food from plants and animals could be preserved and consumed, thus reducing the urgency to procure it on a daily base.

Later on with the development of agriculture, direct solar energy added another important contribution to local development. Similarly, the domestication of animals allowed for additional energy to be used for farming and land transport.

Thanks to the increasing capacity to manage natural energy sources, humans started working with metals, ceramics or glass while also developing writing, literature, science and arts.

Energy and human development were linked in two interconnected ways:

- The availability of energy allowed human beings to extend their life and increase its quality, by saving time for activities other than subsistence;
- The consequent socio-cultural development allowed the discovery of new energy sources, processes and technologies for a more efficient use of energy.

These linkages became even more obvious with the first and second industrial revolutions, when the energy scenario shifted from low-power to power-intensive systems.

Fossil fuels entered the stage as novelty and, due to their high power density and ease of use, cast a shadow over renewable energy. In the first half of the twentieth century another discovery changed the energy scenario: the energy released from the controlled nuclear fission, which was millions of times greater than that related to the chemistry of fossil fuels, fascinated the global society driven by economic and industrial growth.

It is only in the second half of the twentieth century that increasing concerns about environmental preservation, depletion of fossil fuels, energy security and more recently on climate change, safety of nuclear plants, non-conventional oil spills and climate change drew the attention towards renewable energy [1].

Today, their increased contribution to the world's energy mix is a precondition for sustainable energy systems that can promote social and economic development, thus generating a more equitable society capable of meeting the needs of the current and future generations while preserving their environmental capital.

## *Energy as a Crosscutting Issue for Development*

Today, the opportunity to overcome the development divide strongly depends on the availability of energy. Access to energy can contribute to reduce poverty.

Energy drives human progress from job creation to economic competitiveness, from strengthening security to empowering women. Now, more than ever, the world needs to ensure that the benefits of modern energy services are available to all and that energy is provided as clean, safe and efficient as possible. Addressing a transition to a radically different and inclusive energy system is today a generational challenge. The issue of access to energy is central in the developing world [2], but new evidences of energy poverty are also appearing in Europe and in other industrialized regions [1]. This is mainly due to the shift to liberalized markets that were formerly strictly regulated and the current financial crisis. Energy poverty refers to a condition in which people cannot afford to use or have access to enough energy for their daily needs (i.e. cooking, lighting, heating, transportation, etc.). It is worth mentioning that energy poverty may also occur with people which are not experiencing economic poverty.

It is clear that an equitable distribution of resources need to take place not only between the economies of the South and the North but also within a country or a region. Access to energy is an instrumental right for the people to attain better living conditions and a global concern for which there is an emerging consensus to act cohesively and urgently. Moreover, an integrated approach needs to be sought in order to address simultaneously the problems of global warming, global inequality and poverty [3, 4]. Such long term challenges need to be addressed nowadays even in the context of the current financial crisis which may drive the attention elsewhere. In fact, the response to these challenges should be an essential part of the solutions that could ensure a more sustainable regional and global economy. Governments need to play a central, though not exclusive, role in integrating policies and assessing priorities to regulate the market, which alone can no longer represent a solution.

Within these priorities, the nexus between energy and sustainable development needs to be better explored in order to evaluate the multiple positive effects energy can have on poverty reduction, gender equality, health, water, food security, education, jobs, pollution and climate change. Some of these positive impacts are, for example, saving women's time for domestic tasks, enabling access to educational media and communications in schools and at home, mitigating the impacts of indoor air pollution on women and children, allowing access to better medical facilities for maternal care including refrigeration and sterilization and enhancing income generating activities.

Integrating sustainable energy strategies into national and regional policies and then implementing them is therefore truly urgent and is the direction that is suggested by the international community.

## *A Paradigm Shift*

The beginning of the Third Millennium has marked the central role of energy as a socio-economic asset within the global economy. In 2012, the "International year for energy for all" and the Rio+20 Conference held in Rio de Janeiro contributed to recognize that energy is a key driver for sustainable development [5–9].

The attention paid by the international community to the role of energy in poverty reduction is demonstrated by the Sustainable Energy for All (SE4All) initiative launched by the United Nations Secretary-General, which aims at ensuring universal access to modern energy services, doubling the rate of improvement in energy efficiency and doubling the share of renewable energy in the global energy mix by 2030.

To attain the vision of SE4All, the three core objectives of the international year have been disaggregated into 11 Action Areas addressing energy consumption, productive energy use and supportive mechanisms needed to overcome the barriers to any practical implementation [10].

Energy is the world's largest industrial sector, whose output is an essential input to almost every good and service provided in the current economy. The fragility of the current system based on fossil fuels is becoming evident due to the impact of climate change and energy security on the global economy. A paradigm shift is needed to lead to a new era driven more by people than by the market, more decentralized than centralized, more democratic than monopolistic, more inclusive than exclusive.

Within this new paradigm, green economies become central for a sustainable development capable of taking into account human physical, emotional and social needs, while equity becomes an essential element to manage resources distribution [11–14]. In this context, innovation becomes central not only as a technological driver, but also as the creative attitude towards new business models capable of fitting different frameworks and policies, thus making the local contexts very receptive [15].

A more inclusive and participatory approach can speed up the penetration of renewable energies, while the new concept of innovative democracy coupled with stable and financial support schemes may be one of the drivers allowing different players to engage in developing and developed countries [16, 17].

Therefore, in a more participative economy trust in science, technology and in the decision making process become an essential element. From these considerations on the paradigm shift towards a more sustainable economy, it emerges that the private sector local authorities and the civil society play a complementary role to central government's actions [18].

## *From the MDGs to the SDGs*

The evolution of the concept of development is quite complex, as described in the recent book by Kremel et al. [19], spanning from the economic assets of the post-world wars to the integrated and holistic approach of Amaryta Sen, where "development as freedom" is the central concept. Today, the fragile situation of natural resources prevents equitable growth and represents a difficult challenge. The linkages among the three dimensions of sustainable development call for more coherent policies and actions.

Within this context, the United Nations Conference on Sustainable Development held in Rio de Janeiro in 2012 resulted in an agreement by the Member States to launch a set of Sustainable Development Goals (SDGs), to overcome the limitations of the Millennium Development Goals (MDGs) that did not include some global challenges such as energy access. The Sustainable Development Goals are intended to advance sustainable development as a further integration to the economic, social and environmental dimensions, while also tackling other pressing issues at global level to include developing, developed and emerging economies.

The aim is to guide and contribute to the change, leading to rights-based, equitable and inclusive processes that will enhance sustainability at global, regional, national and local levels.[1]

## Beyond Electrification: Energisation and Total Energy Access

In the 1980s, the ‘‘energy ladder’’ was the precursor of the energisation concept: a variety of “energy supply choices” with different technological sophistication that can be used to promote access accordingly to the income level of the household (Fig. 1.1). Electricity stands at the top of the ladder, while the bottom end includes wood, dung, and crop wastes. From this first definition the concept of energisation has drawn the attention of a number of authors, as clearly stated by Nissing and Blottnitz [20].

According to their review, Ramakumar already stated in the 1990s that the concept of energisation is preferable to “electrification” and proposed an energy system design based on resource-need matching, capable of integrating all the locally available renewable resources (Integrated Renewable Energy Systems).

In the same years energisation referred to well-balanced energy solutions seen as a combination of different energy sources that take into account their efficiency and cost and not exclusively to electric energy. Liquefied Petroleum Gas, for example, is an excellent energy source for thermal applications such as cooking, while electricity keeps competitive advantages for lighting.

Following the definition of the MDGs, the concept of energisation refers more directly to sustainable development and includes the following:

- Matching of energy needs with appropriate energy resources;
- Improving the quantity and quality of energy supply;
- Promoting a combination of cleaner and more efficient fuels;
- Promoting mainly, though not exclusively, renewable energies;
- Meeting household needs, providing community services and promoting economic development;
- Aligning to the Millennium Development Goals;
- Emphasizing cultural and social aspects and local empowerment.

In their review, Nissing and Blottnitz provide a definition of energisation based on a process perspective: “Sustainable Energisation is the transitional process of

[1] The discussion on the specific contents of these SDGs is currently (summer 2013) opened and updated on http://sustainabledevelopment.un.org/.

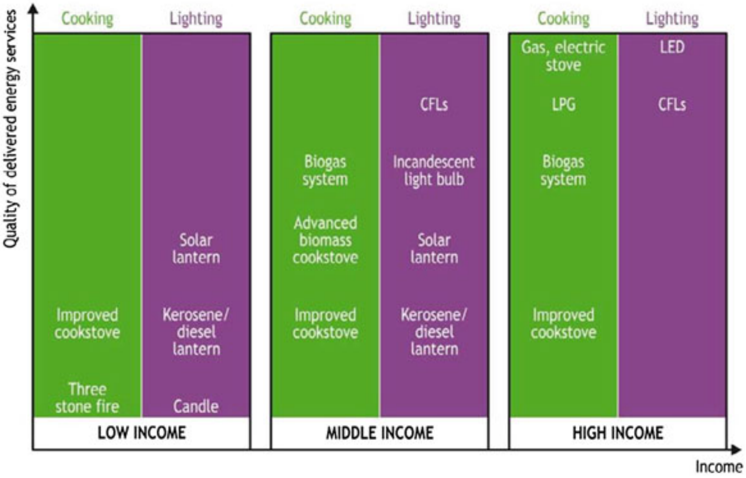


**Fig. 1.1** Energy service in relation with income rate. *Source* [21]

progressively meeting the primary and early secondary energy service needs of a poor economic subgroup through the delivery of an enhanced quantity, quality and/or variety of accessible and affordable energy services, enabling the sustainable development of the considered subgroup based on poverty alleviation and economic development, as well as the optimisation of the energy service supply network from a lifecycle perspective".

In this definition emphasis is given to the concept of integration and the notion of energy service is decoupled from whatever final energy carrier and end-user device.

Why this need for integration? Poverty is indeed a multidimensional problem where factors such as environment, income generation, housing, health and education are interlinked. Addressing any one of these factors affects the others and their combined effect determine people vulnerability and are central for their well-being.

Although energy poverty is widely recognized as a fundamental constraint to socio-economic development for the poor, there is yet no internationally agreed definition of energy access. Nevertheless, the way we define energy access is critical in determining how we tackle energy poverty. The UN Secretary General's Advisory Group on Energy and Climate Change (AGECC) defines energy access as "access to clean, reliable and affordable energy services for cooking and heating, lighting, communications and productive uses" [22]. Although this definition is the most comprehensive, it continues to focus on energy supply based on the connection to grid electricity and on the use of "modern" fuels, a coupling that is often not reflected by people experiencing energy poverty. It must be also noted that no definition is given for the acceptable levels of cleanliness, reliability and affordability that also take into account the local conditions.

An important effort to overcome this limitation has been made by Practical Action in the Poor People Energy Outlook (2010, 2012, 2013) [23–25], where energy access is defined as the accomplishment of the following condition: "households, enterprises and community services have sufficient access to the full range of energy supplies and services that are required to support human social and economic development".

Practical Action proposes the adoption of Total Energy Access (TEA) where household needs, earning a living and community services find their interconnection, and where the minimum standards that people need, want and have the right to is set [23] (Table 1.1).

The idea of energisation or the approach of Total Energy Access offers a more comprehensive understanding of the complex link between energy and development if compared to the electrification concept. This approach facilitates the understanding of the concept of energy ladder and its climbing. It also suggests the idea that solutions must always be designed according to the local conditions.

On the other hand, energisation is often done through electrification which, either distributed or decentralized, is often one of the most effective ways to provide energy and services for household, community and earning activities. So the two concepts are not mutually exclusive.

## Basic Needs and Services

A strong correlation between energy availability (primary or electric energy) and socio-economic development is proved by many evidences. Without energy, meeting basic needs and providing access to services is highly difficult.

**Table 1.1** Total energy minimum standards

| Energy service | Minimum standard |
|---|---|
| Lighting | 300 lumens for a minimum of 4 h per night at household level |
| Cooking and water heating | 1 kg wood fuel or 0.3 kg charcoal or 0.04 kg LPG or 0.2 l of kerosene or biofuel per person per day, taking less than 30 min per household per day to obtain |
| | Minimum efficiency of improved solid fuel stoves to be 40 % greater than a three-stone fire in terms of fuel use |
| | Annual mean concentrations of particulate matter (PM2.5) $<10\ \mu g/m^3$ in households, with interim goals of 15, 25 and 35 $\mu g/m^3$ |
| Space heating | Minimum daytime indoor air temperature of 18 °C |
| Cooling | Households can extend life of perishable products by a minimum of 50 % over that allowed by ambient storage |
| | Maximum apparent indoor air temperature of 30 °C |
| Information and communications | People can communicate electronic information from their household |
| | People can access electronic media relevant to their lives and livelihoods in their household |

*Source* [23]

As an example, the relation between the share of modern fuels and the malnutrition prevalence for children under the age of 5 years is represented in Fig. 1.2, showing a reasonable dependence between basic needs and energy supply.

In Fig. 1.3, the correlation between per capita electric energy and the rate of enrolment to secondary schools for several countries is represented and appears to be quite accurate, thus showing how energy availability is related to the opportunities for local people to achieve a higher level of education.

Providing basic needs and services to the people is linked to human rights and equity to which the international community is called to contribute in a responsible manner. After providing basic needs and services, a virtuous circle can be established and the energy-development loop can be activated, thus allowing income generating activities and local development.

In the next paragraphs we refer to the classification of energy services, made by Kaygusuz in 2011 [28], regarding both basic needs at the household and community level and also for productive uses including agriculture, rural industries and livelihood activities. Although a deep correlation between all of them exists, they will be discussed separately: each household needs income generating activities through the production of goods or services that in turn need energy for cultivation, processing, selling and distribution. Households and enterprises are part of a community that also needs energy for social services such a schools, health centres and telecommunications [23]. Access to adequate forms and levels of energy affects all the productive sectors, from agriculture to manufacturing and

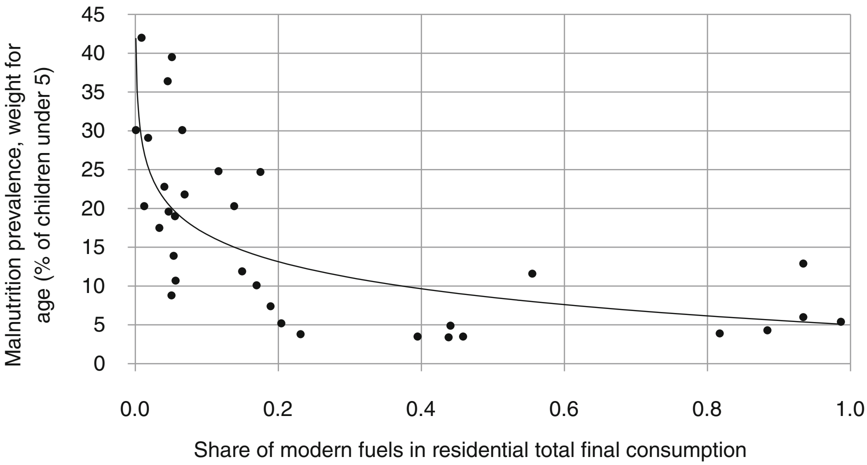


**Fig. 1.2** Share of modern fuels versus malnutrition prevalence. Authors elaboration based on [26, 27]

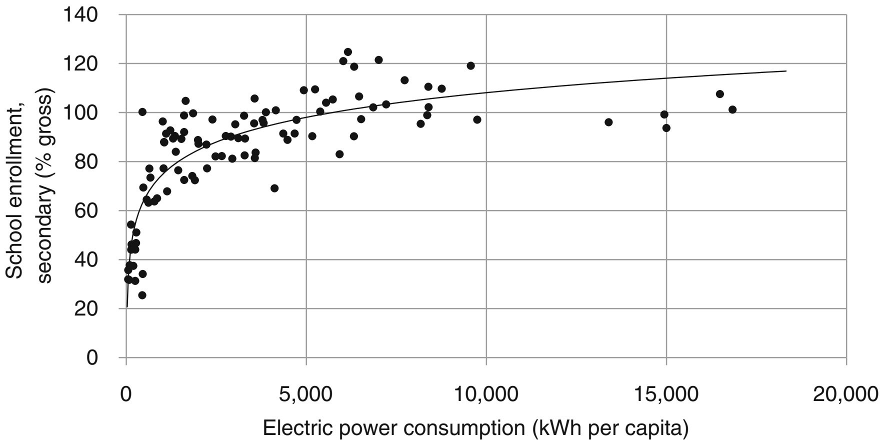


**Fig. 1.3** Energy consumption versus secondary school enrolment. Authors elaboration based on [26]

services, and generates additional activities deriving from the production, distribution and services related to energy.

## *Household Needs*

The use of charcoal, coal and unprocessed biomass for cooking and heating purposes in households releases health-damaging pollutants that cause respiratory problems and high levels of mortality. Access to more efficient and cleaner technologies for cooking, boiling water and space heating decreases health risks and environmental degradation.

Indeed, the use of traditional devices (three-stone fire) with traditional biomass (wood, charcoal or dung) has deep health, economic, social and environmental impacts. Due to inefficiency of the stoves, these fuels release significant quantities of smoke and particulates that have adverse effects on the health of people, particularly women and children. Improved stoves have multiple advantages: reduced emission of noxious gases resulting in better health condition, reduced cooking time and reduced fuel consumption, reduced cost of fuel and reduced drudgery of colleting fuel by women and children [29].

Although in some emerging countries the situation in the last decades has improved, the rural household or the urban poor have often scarcely benefited from it since modern energy services have higher initial and operating costs compared to cheap and locally available wood or charcoal.

Nevertheless, it is recognized that without a progressive shift to modern fuels (biogas, LPG and electricity) or improved cook stoves the ideal vision of development which stands behind the MDGs and that will be driving the incoming

SDGs will not be achieved. A 2006 study by the World Health Organization and the IEA [30] confirmed this assumption and found that introducing cleaner cooking stoves improves livelihoods, stimulates development and contributes to environmental sustainability, while also improving health and reducing illness-related costs.

A deeper discussion on the household needs and the relevance of improved cooking stoves is given in Chap. 3, where biogas systems are also introduced.

## *Community and Social Services*

As far as community services are concerned, energy is a key factor for improving the quality and the quantity of the access to other social services, Education and Health being the most important:

- **Education**: electricity is needed for households and schools to attract teachers to rural areas. After-dark study requires illumination. Many children, especially girls, do not attend primary schools since they are busy providing water and food to meet the family subsistence needs.
- **Health**: diseases caused by un-boiled water and by the effects of indoor air pollution from traditional fuels and stoves directly affect infant health and mortality. Women are disproportionately affected by indoor air pollution and water or food borne illnesses. The lack of electricity in health clinics and illumination for night time deliveries, together with the daily drudgery and physical burden of fuel collection combined with poor transport means all contribute to poor maternal health conditions. Healthcare facilities, doctors and nurses require electricity since a lack of energy access prevents adequate treatment and care to be delivered.

The availability and the affordability of energy within a community and the shift toward modern energy services would instead trigger a positive feedback on other social issues such as:

- **Gender equality and women empowerment**: lack of access to modern fuels and electricity contributes to gender inequality. Women are responsible for most household cooking and water boiling activities. This takes time away from other productive activities as well as from educational and social participation.
- **Digital divide**: Access to information and communication systems is crucial to reduce the digital divide in the global world, and could also offer a valid alternative to access education and health in those countries with weak or inadequate infrastructure.
- **Climate change and environmental preservation**: energy production, distribution and consumption have many adverse effects on the local, regional and global environment including indoor, local and regional air pollution, local particulates, land degradation, acidification of land and water and climate

change. The shift to modern energies with a relevant share of renewables can contribute to reduce the footprint of the energy systems on the environment and to provide solutions for mitigation and prevention.

Electricity is often the most common carrier used to meet these needs. Moreover, in remote areas distributed and decentralized electricity can be generated with innovative mini and smart grids, fuelled mainly through locally available renewable energies [31, 32]. A deeper discussion on such systems is given in Chap. 4.

## Productive Uses and Income Generation

As suggested by Abeeku Brew-Hammond [2], productive usage of energy for income generation must be more and more enforced "in order to break the vicious circle of low incomes leading to poor access to modern energy services, which in turn puts severe limitations on the ability to generate higher incomes". Increased access to energy may create new earning opportunities in two ways:

- New business options for micro, small or medium enterprises in the manufacturing, agriculture and service sectors;
- Additional employment opportunities in the energy supply chain may be created if universal access is reached.

### *Agriculture*

For almost half of the developing world's population, agriculture still remains the primary earning activity. The average contribution of this sector in agriculture-based countries is 29 % of the GDP and 65 % of the total labour force [33]. These figures show the relevance of improving agricultural practices for the socio-economic growth of developing countries. Moreover food security, income generation and rural area development highly depend on agricultural productivity. An increased use of modern energy services can contribute to add value all along the food supply chain (from production, post-harvest processing and storage to market) and to move away from subsistence agriculture as suggested in the Poor People's Energy Outlook by Practical Action [23].

Indeed, industrialized countries have taken advantage of energy availability for agriculture, while many developing countries have lagged behind in modernizing their energy inputs to agriculture. Empirical evidence suggests that the availability of modern energy has proven to be essential in increasing the productivity of the agricultural sector in industrialized countries. In terms of the energy used per agricultural worker the differences are even more dramatic, with developing countries using less than 5 % of the energy per agricultural worker compared to industrialized countries [34].

Energy services for agriculture may be of two types [34]:

- Direct use: land preparation, cultivation, irrigation, harvest, post-harvest processing, storage, and the transportation of agricultural inputs and outputs;
- Indirect use: fertilizers and other products, sometimes necessary, such as weedicides, pesticides, and insecticides.

Direct usages are essential for moving from human and animal labour-based agriculture to a more productive mechanization. However, indirect usages are those that can make the most relevant difference since poor farmers cannot afford the cost of fertilizers. Besides being essential for nutrition in general, agriculture delivers a wide range of non-food goods and services (fibres for clothes, biofuels). Furthermore, small farmers are often also part of a wider group of micro and small enterprises (MSEs). A massive penetration of modern energies coming mainly from renewable sources can therefore contribute to its cost effectiveness by enabling the farmers to:

- Reduce dependency on the cost of centralized electricity or fuels;
- Increase productivity and yields by efficient land preparation, planting, cultivation, irrigation, and harvesting;
- Improve processing quality and quantity of products while saving time and effort;
- Increase earnings through new market opportunities.

## *Rural Industries*

Population pressures on finite agricultural land invariably impel a gradual extension of rural economic activities into non-farm enterprises, broadly defined as rural industries. The development of rural industries is thus an essential component of rural economic transformation to supplement agriculture-based incomes and to mitigate rural–urban migration [35].

In the Poor People Energy Outlook 2012 [23], Practical Action clarifies the mechanisms connecting energy access and income generating activities:

- Creating earning opportunities which would not be possible without energy access;
- Improving existing earning activities by increasing productivity, lowering costs and improving the quality of goods and services;
- Reducing opportunity costs, reducing drudgery, and releasing time to enable new earning activities.

MSEs are often run by people experiencing energy poverty in both rural and urban areas. Some of these entrepreneurial activities that can be promoted with access to energy also have a double benefit on the local community. For instance, operating grain mills can be a productive activity for women's promotion and reduction of drudgery while at the same time contributing to improve product quality [36]. Moreover, each MSE has its own specific requirement and therefore specific energy services. Within each category the amount of power and the form of energy supply may vary depending on the activities, on the scales of operation, and also on local culture and traditions.

Important categories of energy services include process heating and cooking, mechanical processing, cooling, manufacturing, repair and powering ICTs services [37].

To better integrate energy needs with enterprises requirements Practical Action [23] proposes the Enterprise Energy Matrix that classifies the energy supply (electricity, fuels, mechanical power and appliances) based on four criteria (reliability, quality, affordability and adequacy), giving for each coupling (criteria-supply) a number of specific indicators. Improved energy services mainly for MSEs can indirectly support product manufacturing or service delivery while also contributing to improve process efficiency, thus increasing indirect returns for the enterprise.

It is important to consider that for the start-up and the successful operation of an enterprise energy access is a necessary condition though not a sufficient one. Indeed, other factors such as accessibility of the market and sufficient and long-lasting demand play a non-marginal role. Only when these factors are combined together, a virtuous circle may be set up between energy and sustainable development: the market generates socio-economic returns to poor people to whom products and services are delivered. Moreover, when renewable energies are used environmental benefits are generated and local resources are also better valorised.

### *Livelihood Activities*

Energy can serve in the rural areas of developing countries to support livelihood strategies (market and non-market oriented) adopted to improve the quality of life.

Indeed, the poor's ability to generate income through activities other than those related to agriculture is constrained by several factors including energy, and not all of them can be easily controlled. The poor therefore tend to adopt livelihood strategies that aim to sustain and improve their "capitals". This comprehensive stock of assets is built by both tangible (physical and financial capital) and non-tangible (human and social capital) dimensions. Poverty reduction implies both the accumulation of new assets over time and their maintenance.

Consequently, focusing on the livelihoods of the poor provides a means whereby the balance between "productive" and "social" uses of energy can be better understood. To grasp the potential role of energy services in poverty reduction, it is essential to have a clear understanding of the currently adopted livelihood strategies. This is necessary to determine whether the lack of access to

**Table 1.2** Livelihood strategies enrolment

| Livelihood strategy | Means |
|---|---|
| Gaining additional income by retailing energy services up the "energy ladder" | • Fuels (wood, charcoal, dung, crop residues, kerosene, LPG)<br>• Conversion technology (stoves, lamps, batteries, motors, PV systems) |
| Gaining access to improved energy services at the household level by saving time, or switching fuel | • Improved biomass stoves<br>• Improved lighting (from candles to kerosene to electricity initially from batteries) |
| Gaining access to improved energy services, by increasing production efficiency | • Improved energy services result in increased productivity (e.g., through mechanization), which results in a greater ability to pay for improved energy services. Opportunities range from the lowest technologies and the smallest scales upwards (for example, agro-processing, small and microenterprises) |
| Grouping with others to obtain access to improved energy services, for production, household consumption or for community services (health centres, schools, security lighting, and information and communication technology) | Community-based activities enable labour to be converted into capital (e.g., through civil works) and capture the economies of scale associated with energy supply technologies, such as connecting to the grid (transformers and distribution systems) and installing micro hydro generators, small diesel engines or acquiring mechanized transport services, and the like, or "pooling demand" to provide political or commercial pressure to gain access to energy services |

*Source* [28]

specific energy services may be limiting the range of livelihood strategies available to the poor, thus reducing both income and the possibilities for asset accumulation. Examples of energy-related livelihood strategies for the poor and the main associated means are listed in Table 1.2.

## Not Only Energy: the Water, Energy and Food Nexus

### *Conceptualizing the Nexus*

Although the Water, Energy and Food Nexus could have been properly discussed in previous paragraphs since it is related both to the basic needs and services for the people and to income generating activities and livelihood life, a dedicated paragraph has been added to conceptualize it more in detail, following the raising attention that it has been receiving over the past 2 years.

As stated in [38], there are some common elements for the three resources included in the nexus:

- their access is not granted to millions of people;
- their needs are growing;
- they are under constraint at a global level;
- they have different availability at regional level;
- their exploitation impacts environmental preservation;
- their management often operates in a regulated market;
- their supply has implications on global security.

Each of the single resource affects the others, and therefore ignoring this interdependency could lead to policies or technological solutions unfulfilling the sustainability requirements [39, 40]. Indeed, standalone solutions that result to be appropriate for one single resource might lead to negative impacts on the other two.

The connection between water, energy and food may be easily visible in the closed cycle that directly links the three elements of the nexus (Fig. 1.4). These linkages can be simply explained as: "food needs crops and crops need to be irrigated". Water is globally used mainly for irrigation, and irrigation requires energy. When irrigation is insufficient, food security is then threatened.

In addition to this direct link, more specific and indirect elements connecting water, energy and food in multidirectional ways may be highlighted sector by sector.

In the energy sector, for instance, thermal power plants require water for cooling and, hydropower interferes with water flows and land use thus incubating the seeds of potential conflicts. Most of the processes in the energy values chain, from the upstream down to the final use, cannot operate without water. In the same way, energy is also in many ways deeply linked to the food chain and land usage [41–44]:

- over-usage of traditional biomass for cooking may lead to environmental problems, while fuel wood substitution can lead to environmental benefits;
- policies promoting biofuels need to be carefully planned, including attention to deforestation, biodiversity, water management, impacts on food production, lifecycle emissions and land use change.

In the water sector energy is required for extraction, purification and distribution and also for treating and recycling wastewater. Therefore, energy and water policies need to be integrated since food security may be compromised without irrigation [45].

Food-related energy use is today mostly devoted to the post-harvest stages and to the preparation of products such as fertilizers, and it is now proved that oil price and food price are indeed correlated. Without energy, food security is under threat [46].

The need for an integrated planning approach is clear, especially if one wishes to implement solutions or policies that can be effective in promoting both equitable and sustainable exploitation and management of natural resources.

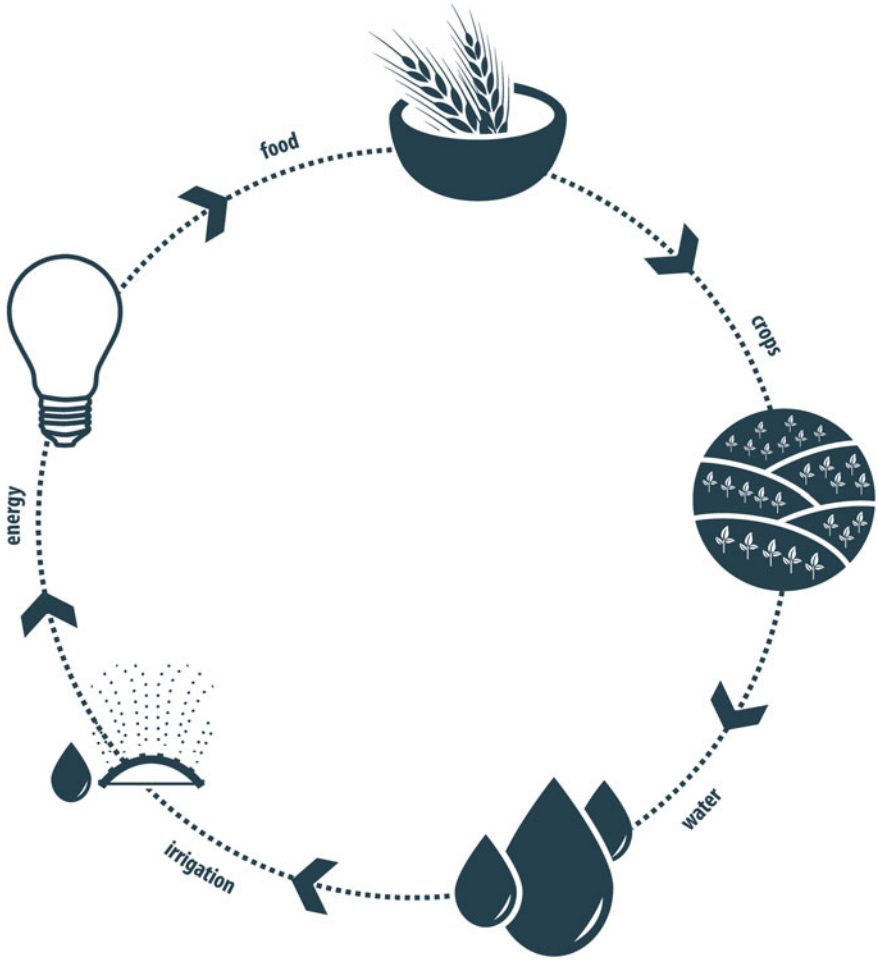


**Fig. 1.4** Water energy food direct cycle

## *Integrated Management of Resources*

Although there is a general consensus on the links within the energy, water and food nexus, governmental structures tend to adopt separated policies for different reasons:

- Different ministries and administrative entities are usually responsible for energy, water and agriculture. As a result, a global coherence cannot be designed and decisions by one ministry or department can conflict with the objectives of others. Moreover, these ministries can have different associated power in different countries, thus resulting in policies driven only by one of the three resources.

- Analytical tools and conceptual models able to manage the nexus are still limited. Analysis of individual systems such as energy and water systems are undertaken routinely but they focus on one resource, thus neglecting the effects of some scenarios that would not be sustainable in the long run.

As far as the first point is concerned and as reported in [38], despite this consensus there are today different strategies that still need to be promoted for properly facing the nexus, such as:

- support decision making at the nexus level;
- support system thinking within the policy making process;
- increase the number of interdisciplinary experts in all the three areas; and
- analyse solutions from a sustainable development perspective.

As far as the second point is concerned, as suggested by the International Atomic Energy Agency [47], an integrated analysis tool including all aspects (climate change, land, energy, water) would be needed in order to produce a multi-resource and interlinked representation accessible also to developing country analysts. Such a tool would help decisions and support the achievement of the future sustainable development goals.

## Capacity Building

As very recently stated by Sovacool [43], facilitating technology transfer from developed to developing countries is one of the key factors for the success of energy projects. The same consideration has been somehow implicit in the eighth MDGs, more recently recalled at the UN Conference on Climate Change in Bali in December 2007 and lately remarked at the Vienna Energy Forum in May 2013.

Technology development and transfer as well as proper knowledge mapping [48] are today addressed to promote mechanisms for facilitating the transfer process and enforcing cooperation in R&D on joint technological development.

While the current situation clearly requires more technology transfer, this [49] needs to be redesigned as a cooperation process rather than a "one-way" process.

In this scenario, energy access provided mainly by renewable energies may have a direct impact on human development and capacity building since, as already stated in the chapter, it is instrumental for achieving access to other services.

For instance energy raises the willingness and the opportunity for education, and therefore human development is promoted. As an example, the deployment of renewable energies and energy access in general can have an impact on gender equity. Furthermore, time saved from primary needs satisfaction may be dedicated to other productive activities. Table 1.3 is a summary of those potential benefits (direct/indirect/strategic) for women as reported in [36].

**Table 1.3** Improved position of women through modern energy services

| Modern energy services | Direct benefit | Indirect benefit | Strategic benefit |
|---|---|---|---|
| Gas for cooking | (i) Less time and effort in gathering and carrying firewood (ii) Reduced indoor air pollution and improved health through smokeless services | More time for productive activities | Lesser deforestation |
| Electricity for lighting | Increase in working/studying hours, and improved conditions during evening hours | Increased possibility of activities during evenings and nights | Streets become safer by encouraging participation in other activities (e.g., evening classes and women's group meetings) |
| Electricity for water pumping | Pumped water provides better hygiene and water quality | Reduced need for haul and carry | Better health standards, check on water-borne diseases |
| Mills for grinding and other mechanical works | Reduces the burden of grinding rice at home | Increases variety of enterprises and increased incomes | Greater access to commercial and socio-political opportunities |

*Source* [36]

## *Education and Research*

High attention to the development of human and institutional capacities needs to be given in order to allow for effective and long lasting technology transfer results. There is therefore an urgent need to develop skills to design or redesign, produce, market, install, operate and maintain sustainable energy technologies in developing countries, as stated by Sovacool [43]:

- renewable energies technologies require specific skills at the local level;
- training is needed to have the required work force;
- different levels of training are needed from vocational to higher education;
- research and innovation capacities need to be developed within academia.

Improving human capacities comes to be a key element for the success for any initiative within sustainable energy in any framework: "Human capacity building is the process of equipping individuals with the understanding, skills and access to information, knowledge and training that enables them to perform their tasks effectively. Human resource is therefore vital in the process of making technology choices and promoting sustainable development" [50].

Due to the complexity of the problem of access to energy in developing countries, as reported in [50], technical competences are required to design, manufacture and adapt new technologies, to install, operate and maintain energy systems and also to properly manage the daily activities, to plan operations and to run the business.

The ability to solve conflicts between the many different players (NGOs, CBOs, private sector, government agencies, and individual end users) is also crucial. A facilitator attitude, together with communication and learning skills are essential for coordinating negotiations, promoting public participation and building consensus within the rural community and between leaders.

The local model of education needs to be designed and implemented according to the different regional needs and also to be thought both inside (formal) and outside (vocational) the education system. For instance, in the rural area, capacity building may be delivered through specific training carried out at the community level. Indeed, community-based organizations and self-help groups (SHGs) can play an important role in empowering the community and making it responsible for managing public goods, as suggested by Reddy et al. [51] or by Adkins et al. [52]. It is also very important to understand that when capacity building occurs within local communities and companies, other benefits may be added to employment opportunities: policies and strategies can be better assessed, local acceptance is easier to be established and local technical reliance is more prompt.

Within the framework of sustainable energy for all and its related strategies, there are opportunities to strengthen R&D activities in energy technologies both at national and at regional levels. R&D capacity requires substantial financial resources, highly trained and motivated scientists and international cooperation and partnership for carrying on state-of-the-art strategic joint projects. This topic is investigated with major details in Chap. 15.

The coordination between the education system, the national energy institutions or the local energy agencies, the private sector and the civil society is essential to facilitate the innovation process and to clarify the needs for training and research that the education system has to meet, thus contributing to the reduction of the perceived gap between academia and local community (society and enterprises) which is still very deep in many developing countries.

In this context, the role of academic cooperation becomes increasingly relevant and many are the opportunities to establish effective North–South and South–South partnerships.

## Final Consideration

The transition to sustainable energy systems represents a key opportunity for the global economy. Despite the progress made in the last decades, barriers still exist to promote sustainable energy solutions; actions are needed in all the areas ranging from technology development to policies and regulations, from improved business models to governance structures.

Renewable energies are increasingly seen as a vital catalyst to achieve universal access to energy and a wider social and economic development by enabling education, health and sustainable agriculture, by creating green jobs and by promoting equity.

However, energy is not an end in itself. Energy for productive uses is particularly important to enable local business innovation and creation of a more vibrant economy, while providing societal benefits to all. In this context, energy access contributes, not only to economic development, but enables the poor also to accumulate the stock of assets to improve their quality of life.

In this scenario, a key role for renewable energies is defined. Although renewable energies may not be the only answer when the continuity of supply must be ensured or when high energy density is required (i.e. industrial processes, transportation), they allow for the use of local resources and the preservation of the environment, together with the promotion of human and local development through capacity building and local empowerment.

The dissemination of distributed generation based on renewable energies represents an economically viable and effective way to promote sustainable development in rural areas. Furthermore, the experience gained in developing countries could also contribute to the paradigm shift needed in the energy sector at global level.

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# Chapter 2
# Global Dimension of Universal Access to Energy

**Emanuela Colombo, Lorenzo Mattarolo and Stefano Mandelli**

**Abstract** The development of human society has been marked all throughout history by the role of energy resources. The importance of energy in the global scenario has constantly risen and the interconnections with the environment and society have become more evident. The need to fight both poverty through eradication of energy insufficiency and to increase access to modern energy service is recognized worldwide. The designation of Year 2012 as the International Year for Sustainable Energy for All and the subsequent Sustainable Energy for All initiative [1] promoted by the UN Secretary General Ban Ki-moon to foster access to energy, energy efficiency and renewable energies has raised awareness in the international agenda on these issues and has opened a wide window on the problem for the coming decades. The size of the problem and some of the key challenges are discussed in the chapter.

## Energy Challenges

### *The Correlation Between Energy and Development*

Access to modern energy is today considered essential to encourage development and to fight poverty, which is seen mainly as a lack of opportunities [2]. Sustainable energy as a basic condition to enable access to services, resources and public goods therefore constitutes an essential prerequisite for human empowerment and social progress, along with respect for the environment. Access to energy is essential for clean water supply and sanitation, for the development of agriculture (irrigation, mechanization, food processing and transportation), for the support of information and communication technologies and for enabling access to

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healthcare, education and other basic social needs. As indicated in the World Energy Outlook 2012 by the International Energy Agency, almost 1.3 billion people have no access to electric energy, almost 1.0 billion people are connected with unreliable electric grid and 2.6 billion people rely on traditional biomass such as firewood for cooking and lighting [3].

International organizations have devised indicators to assess development with a comprehensive approach that goes beyond the single economic perspective: the Human Development Index (HDI) and the Energy Development Index (EDI).

HDI was first presented in the UNDP Human Development Report (HDR) in 1990 [4]; its aim is ''to shift the focus of development economics from national income accounting to people centred policies'', considering aspects such as life expectancy, access to knowledge and standards of living.

EDI has recently been devised by IEA [5] and further revised [3] in order to better identify the role that energy plays in human development. It traces the countries' progress related to the electric energy penetration and to the shift towards modern fuels. It is a combination of four indicators, addressing different aspects of energy poverty mainly related to electricity and modern fuels.

The correlation between EDIs and HDIs indexes is evident (Fig. 2.1), thus confirming the importance that access to energy has acquired as a key strategy to eradicate poverty, enable human promotion and foster sustainable development.

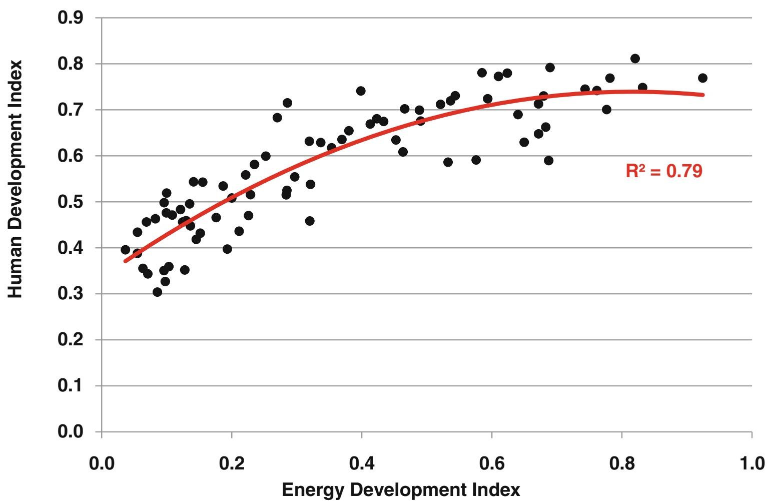


**Fig. 2.1** Comparison of the HDI to the EDI. According to data available. IEA evaluates EDI for low and medium HDI only

## *Different Faces of the Energy Challenge*

Energy consumption is increasing and, according to international forecasts, it is expected to increase further in the next decades. Energy has a global perspective, but it presents different faces according to the aggregated regions considered (Fig. 2.2).

In line with the classification of the World Bank, three macro regions can be identified depending on their GNI per capita.

In countries with high-income economies, energy is available and relies mostly on fossil fuels. Current challenges are oriented to enhance sustainability through specific policies aiming to increase the share of renewable sources and to improve efficiency, while also reducing the impact on the environment.

Emerging countries with middle-income economies are facing high growth in both energy consumption and economic development. Their technologies often need to improve both in security and in reliability and the challenge of sustainable energy is directly related first to the efficiency and secondly to the environmental and social impact of their energy systems. These countries are now encouraged by the international community to focus their efforts on safety and environment, since the need to involve them in the global effort to reduce pollution and greenhouse gas emissions is becoming more and more urgent.

In line with this direction, China and Brazil have promoted a number of national policies aiming at reducing their growth in emissions by 2010. More specifically, since the 2007 National Action Plan on Climate Change, China has committed to strongly reduce its energy intensity by 2010. Updated statistics from the IEA show that the energy intensity has been reduced by more than 20 %, thus

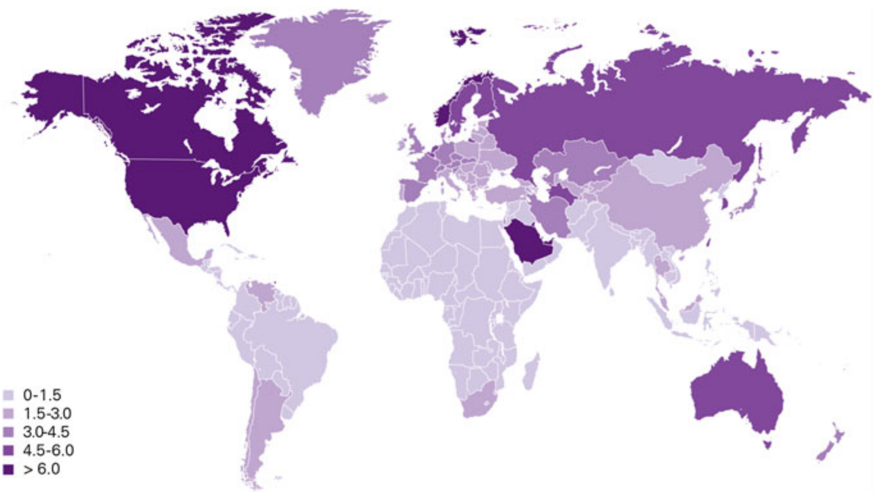


**Fig. 2.2** Total primary energy consumption—TPES (toe/per capita). *Source*: [8]

reaching the declared target. As a consequence, a greater reduction in $CO_2$ intensity was experienced despite the plan did not include any quantified targets for carbon dioxide emissions [6, 7].

Developing countries are characterized by low-income economies, with low energy consumption per capita. Access to electricity and use of modern energy service are not available for the majority of the population, especially in rural areas. Although these countries are often rich in primary resources, these are rarely used at local level. Current energy systems are still weak and characterised by low reliability. These countries are identified by a general low electrification rate and by a high percentage of population still relying on traditional biomass for cooking and lighting.

## Energy and Sustainability

Sustainable energy strategies are often related to three main principles of "*access*", "*affordability*" and "*equity*". Innovative solutions require appropriate technologies, proper business models to deliver energy and provide opportunities for the users, adequate and stable policy framework with the necessary commitment of local institutions.

As discussed in the previous paragraph and more extensively in [9], the energy challenge presents different faces at the global level and strategies therefore need to be tailored to the specific context where they have to be applied. Moreover, when looking for durable and long-term solutions that aim at empowering capabilities and promoting integration and acceptability within the local context, such strategies have to be tackled from a perspective that includes the three main dimensions of sustainability (economic, environmental and social).

### *Economic Dimension*

Energy and economy are interrelated. As shown in Fig. 2.3, in all high-income countries the total primary energy supply (TPES) per capita is above 2 toe[1]/per capita, while the remaining countries are mostly below this threshold.

Correlation is more evident and distribution less scattered at low Gross National Income (GNI), where developing countries are located.

Considering the energy intensity (TPES per unit of GDP, Fig. 2.4), Africa, China, the Middle East and non-OECD Europe and Eurasia lead the classification with the highest values. Energy intensities in developing countries are affected by

[1] tonne of oil equivalent (toe) is the amount of energy released by burning one tonne of crude oil, approximately 42 GJ.

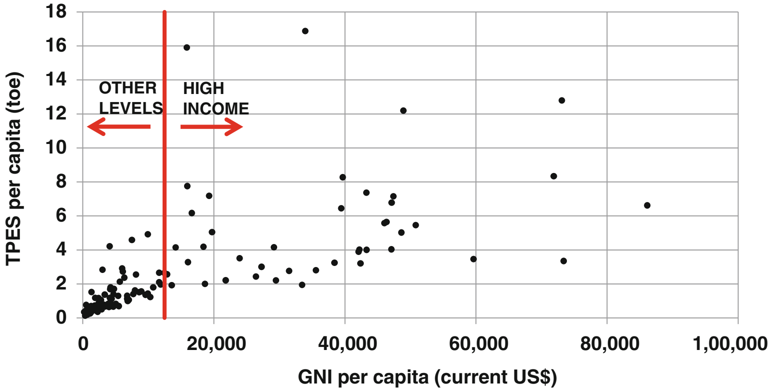


**Fig. 2.3** World countries distribution according to GNI per capita and TPES per capita. *Source*: [10]

underdevelopment of productive sectors (i.e. services, trades, industry) and high conversion system inefficiencies. As an example poor households often use three-stone fires for cooking, with very low efficiency. Furthermore the national electric grid, when available, is also affected by a high percentage of outages which make the provision of electricity unreliable, with dramatic consequences on the local productive systems and economic stability.

## *Social Dimension*

According to the World Health Organization (WHO), nowadays more than 1.4 million deaths per year (more than malaria and tuberculosis) are related to the effect of breathing smoke emitted by three-stone fires and the number is expected to increase in 2030 to the point of overcoming deaths for HIV [11, 12].

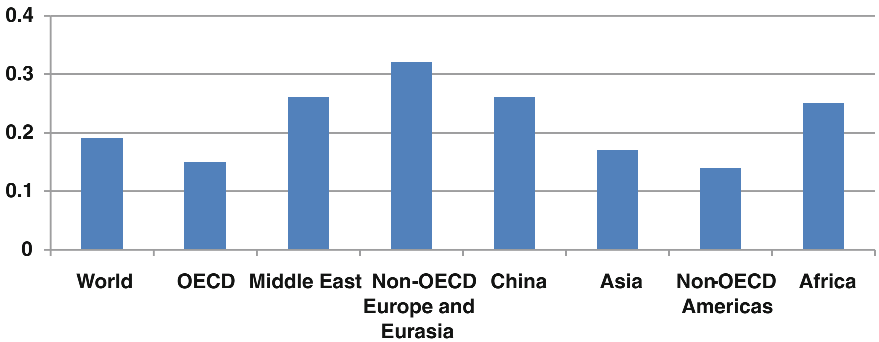


**Fig. 2.4** Energy intensity for the world's aggregated regions. *Source*: [7]

**Table 2.1** Number and rates of deaths and DALYs per million population attributable to indoor air pollution from solid fuel use, for all causes (pneumonia, COPD, lung cancer), based on UNDP's classification of developing countries and the UN's classification of LDCs [12]

| | Attributable deaths per year | | Attributable DALYs per year | |
|---|---|---|---|---|
| | N° (thousands) | Per 1 M population | N° (millions) | Per 1 M population |
| Developing countries | 1944 | 378 | 40,5 | 7878 |
| LDCs | 577 | 771 | 18,4 | 24606 |
| Sub-Saharan Africa | 551 | 781 | 18 | 25590 |
| South Asia | 662 | 423 | 14,2 | 9075 |
| Arab States | 35 | 114 | 1,1 | 3489 |
| East Asia and Pacific | 665 | 341 | 6,5 | 3308 |
| World | 1961 | 305 | 41 | 6374 |

Health-related impacts associated with household fuel use include: burns and scalds from open fires or semi-open stoves; poisoning of children who drink kerosene fuel stored in soft drink bottles; risk of injury and violence (primarily on women who walk far from their home to collect wood and other solid fuels).

The connection between solid fuel use and three diseases is particularly evident: child pneumonia, chronic obstructive pulmonary disease, and lung cancer [13]. The issue is relevant for developing countries, where more than 99 % of the worldwide deaths attributable to solid fuel use occur (Table 2.1).

A broader measure of the diseases is the 'disability-adjusted life years' (DALYs). As shown in Table 2.1, of the approximately 40 million DALYs worldwide attributable to solid fuel use, almost 18,4 million (45 %) occur in LDCs and 18 million (44 %) in sub-Saharan Africa. Since DALYs indicator detects the number of years lost due to deaths from child pneumonia, the highest impact of solid fuel use on health occurs in poorest countries where children under 5 years old are mostly affected by pneumonia.

Traditional fuel usage leads to considerations on the "burden" of biomass and raises a problem of equity, since low energy availability contributes to limiting development and increasing disparities between classes. In developing regions women and children are in charge of fuel collection [14], a real drudgery, which exposes them to health hazards and various risks. Furthermore, this activity prevents women and children from accessing education and being involved in income-generating activities, thus having an important social impact.

## *Environmental Dimension*

In line with the 7th Millennium Development Goal which aims to ensure environmental sustainability, the promotion of energy usage has to be evaluated also in terms of ecosystem and environment damages.

On one hand, renewable energy technologies are generally perceived as more sustainable compared to non-renewable sources, due to their reduced environmental impacts and benefits for local development [15]. However, renewable energy technologies also have some effects and therefore careful planning to address possible environmental impacts all along their life cycle is essential. For instance, the installation of large hydropower systems may significantly affect the ecosystems and have consequences on the downstream availability of water (see discussion on Water, Energy and Food Nexus in Chap. 1).

On the other hand, the use of fossil and traditional energy sources in developing countries impacts global biodiversity, where ecosystems may be affected by an unregulated exploitation: an energy mix strongly unbalanced towards the use of traditional and non-commercial biomass can lead to local pollution and, if not properly controlled, to heavy consequences such as land degradation and deforestation.

Although the use of traditional biomass such as wood or charcoal is not the only contributor to deforestation at a global level, in some countries the link is more direct and evident. Production of charcoal from forest areas in response to urban demand, particularly in sub-Saharan Africa, may not be sustainable and could lead to localized deforestation and land degradation around urban centres. Scarcity of wood typically implies a greater use of agricultural residues and animal dung for cooking. However, when dung and residues are used as fuel, soil fertility is reduced and propensity to soil erosion is increased [16–19].

Overuse of natural resources through deforestation or increased extraction rates of forest biomass has a negative impact on soil quality, carbon stocks and biodiversity.

For instance, clearing of land for agricultural activities and production of timber for export are relevant causes of deforestation in developing countries [20]. Other causes leading to deforestation and forest degradation are also represented by weak governance structures for forest conservation and by the absence of a sustainable management of forest resources, in particular in developing countries [21]. A large number of countries are joining intergovernmental initiatives to establish criteria and indicators to monitor sustainable forest management, but they are not entirely based on common principles and do not yet have a mechanism for verifying compliance with the agreed principles.

The adoption of sound land-use planning through the application of good management practices and use of well-adapted indigenous energy crops (use of perennial instead of annual species) [22] can certainly contribute in addressing the problem.

## Electrification and Modern Fuels: Current Situation

Two main problems need to be discussed with respect to energy access:

- Access to electric energy, achievable through the extension of the national electric grid and/or by fostering distributed generation,

- Shift to modern fuels (electricity, gas, LPG kerosene, including paraffin, ethanol, biogas and biofuels) and efficient use of traditional biomass (firewood, charcoal, dung, and crop residues).

The increasing attention given by the international community during the past 5 years, which culminated with the declaration of 2012 as the International Year for Sustainable Energy for All, has supported a number of activities and projects for fighting against the energy poverty [1]. Despite the growth in the world's population, people without access to electricity and without access to improved or modern energy services for cooking have decreased respectively by 50 million and almost 40 million according to 2012 and 2011 IEA data [3, 23]. Main improvements occurred in countries such as India, Indonesia, Brazil, South Africa and Ethiopia, with the rest of Sub Saharan Africa remaining almost unaffected.

At the end of 2012, almost 1.3 billion people were still living without access to electric energy and 2.6 billion did not have access to improved or modern energy services for cooking [3]. Roughly 99 % of this population live in developing countries in Sub-Saharan Africa, Asia and Latin America and 80 % of them live in rural areas.

## *Electrification*

The World Energy Outlook 2012 [3] foresees an increase in the electrification rate in developing countries from 76 % in 2010 to 85 % in 2030.

The IEA projection states that in 2030 1 billion people will still be without electricity: Latin America will achieve universal access, developing Asia will halve the number of people affected while sub-Saharan Africa will keep a negative trend at least until 2025.

Access will increase mainly in urban areas, where providing services may be easier and more profitable for public utilities and private suppliers. In rural areas population with access to electricity is considerably lower than in urban areas (the ratio is 1 to almost 8) and providing electric energy to small and scattered settlements is more complex.

Various options for supplying electricity need to be considered, including grid connected, mini-grid and off-grid systems (for further details refer to Chaps. 5 and 6), with respect to the following factors.

- Cost of energy delivered through an established grid may be cheaper but the cost of extending the grid to sparsely populated areas can be very high and long distance transmission systems can have high technical losses [24].
- Stand-alone renewable energy technologies can instead provide cheaper electricity to rural communities, even though they require high investment costs. These systems can range from small home based systems relying on a single source to mini-grids that can integrate more than one source of energy (hydro, biomass, wind and solar and geothermic plants) [25].

- Integrated mini-grids seem one of the most promising approaches to rural electrification since they rely on local resources, reducing the discontinuity of supply and the need for batteries [26].
- Mini-grids today can benefit from smart metering and control research in developed countries (if properly adapted). They can therefore be designed and optimised at the local level (bottom-up approach) and then scaled up by connecting isolated systems into a "regional" or "national" grid (top-down approach) [27].

### *Biomass Dependence*

The World Energy Outlook 2012 [3] foresees an increase in the share of the world population with access to improved or modern energies for domestic cooking from 51 % in 2010 to 61 % in 2030. However, due to demographic growth, the total number of people with access will only slightly rise.

According to IEA, the most significant improvement by 2030 will occur in Asia (led by China) while in sub-Saharan Africa the numbers will decrease by about 25 %.

Biomass in developing countries is currently considered as locally available solid biomass, which is burnt into low-efficient and high-polluting conversion devices.

In 2010 biofuels and waste accounted for 10 % of the world TPES, almost 80 % of which coming from non-OECD countries. This high share of biofuels and waste supply confirms the reliance of developing countries on non-commercial biomass (wood) or locally available low-cost charcoal.

Modern technologies refer to more efficient and cleaner cooking devices compared to the traditional three-stone open fires, such as improved or advanced cook stoves, gas or electric cooking stoves and domestic or community biogas systems. Although based on simple design, these technologies allow considerable effective improvement, primarily in domestic activities with a positive effect on health, environment and the household economy. They are user friendly, easy to maintain, low-cost and may fit into the local cultural framework.

- Improved Cook Stoves are based either on a more efficient combustion of traditional biomass or have chimneys, or a combination of both resulting on economic savings and reducing pollution. While their real impact is still being analysed, experimental field campaigns are needed to prove their effectiveness and acceptability [28].
- Advanced Biomass Cook Stoves usually work on innovative principles, such as the gasification of solid biomass, leading to high efficiency and clean conversion, although pilot experiences and research activities are still needed [29].
- Small-scale bio-digesters produce biogas by anaerobic fermentation of different organic waste origin (human and livestock, domestic, agricultural), thus allowing smokeless combustion and use of lighting devices [30].

In line with the international community requests for the use of modern fuels, the efficient use of biomass as a fuel for Improved Cook Stoves and small-scale bio-digesters should also be considered. Indeed, the use of biomass can be an important energy solution when sustainable biomass production and conversion systems are developed and applied. Indeed, sustainable forest management, sustainable agriculture techniques and technological solutions are required to ensure a positive social economic and environmental impact of biomass energy systems.

## The Role of Efficiency Within Access to Energy

Efficiency is often called “the sleeping giant” in the energy sector. From the primary energy sources to the final consumption, energy efficiency has a significant and high-potential role in improving energy security and reliability, reducing the environmental impacts and increasing the number of reached beneficiaries and available services.

Low and middle-income countries started to consider energy efficiency only recently. Nevertheless, the promotion of both efficiency and energy access should follow a more sustainable approach in order to avoid the recurrence of negative experiences of other economic regions: for example Europe, which after increasing its energy use for decades is now asking for a more rational use of it [31].

Improving efficiency has a great potential in developing countries from many perspectives. For instance, it can increase accessibility both on the supply side, extending the provision of energy to households and reducing technical losses in generation and distribution, and on the end uses side, which is often neglected due to other major constrains.

Efficiency can also increase affordability and equity thus facilitating the lower income households to pay their energy bills.

In [3] IEA states that in certain countries, including India, the energy that could potentially be saved through efficient uses would be enough to provide the additional electricity required to satisfy the basic energy needs for the entire population in 2030. Although in almost all countries these savings would not be sufficient to cover the energy needs, nonetheless they could free additional financial resources that could be dedicated to address energy poverty.

As barriers to energy efficiency depend on many circumstances a portfolio of measures needs both to be promoted by individual countries or regions and supported by global commitment. For instance, the improved energy performance of a device needs to be recognised by the market and by the Government, energy-efficient technologies must become the standard, any improvement in energy efficiency must be monitored and investments in energy efficiency must be rewarded by appropriate financial mechanisms.

In this way efficiency can become a powerful ally for the strategies towards universal energy access.

## Drivers and Barriers Toward Local Integrated Renewable Energy Strategies

Limited access to modern energy services is far from being a real lack of energy resources. Developing countries are often endowed with natural resources, but unable to exploit them to improve their national energy systems. Reasons are different and have both endogenous and exogenous origins.

At the institutional level, awareness and importance of access to energy as an essential element for development have only recently arisen in local governmental institutions. Together with international agencies, they have started to support energy policies in order to strengthen the fight against poverty.

At a cultural level, low-income countries, with sometimes limited specific scientific and technical knowledge, have to strengthen their ability to promote and support applied researches and innovation ability. The international community has to play a pivotal role within capacity building.

At an economic level, unavailability of funds is the main limitation for investments in renewable energy facilities. Appropriate energy technologies, which fit in the local infrastructure, involve the local human capacity and valorise local natural resources should be prioritized.

In this complex scenario, the commitment of the international community to endorse progress toward universal access has to face the challenges of access to energy in all its perspectives, from sources to supply chain, from conversion systems to end uses.

Energy systems design must therefore be based on the most suitable and efficient "demand–supply" coupling. In developing countries, while dealing with appropriate technologies, the coupling may also be referred to as "Need-Resource" coupling, thus underlining the relevance of the local context. Indeed, behind a *demand* there is a (specific) *need* and in order to provide a *supply*, a (specific) *resource* must be used.

This design can be referred to as "integrated renewable energy systems" approach (Fig. 2.5) and appears today as the smartest solution for remote locations where even small amounts of energy can have a significant impact on the living environment, thus influencing availability, affordability and security of other resources and goods such as water and food.

This approach represents an appropriate opportunity since the design of the related energy systems is sized to tailor the services needed to support local development. It also contributes to harness locally available renewable energy resources, offering key advantages such as improvement of the human living environment, creation of jobs in remote areas, mitigation of mass migration to urban areas, decrease of the dependence on imported fuels, better use and management of resources such as animal and agricultural waste and preservation of the environment.

Finally, since this approach and the related energy systems need to be designed, maintained and optimized at local level (due to the Need-Resource based

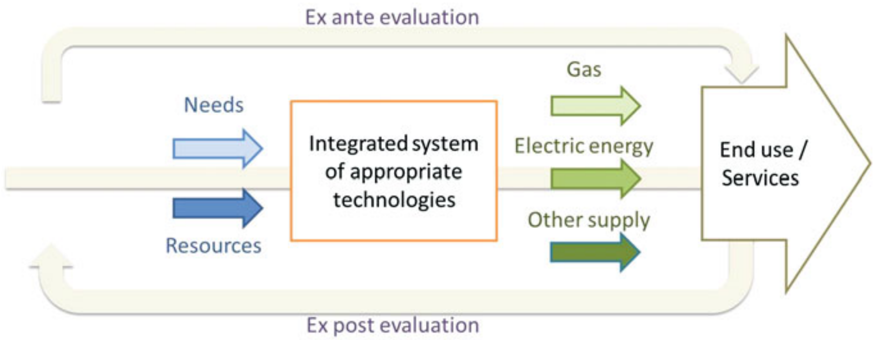


**Fig. 2.5** Need-resource or demand-resource based scheme for integrated renewable energy systems (elaborated from [31])

coupling), they can contribute to support the local green economy, thus promoting income-generating activities and enforcing research and innovation within the local scientific and entrepreneurial community.

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# Part II
# Energy and Technology: Tailoring Strategies and Technologies to Enhance Livelihood

The first part of the book drew attention to the size of the social challenges related to sustainable energy access for all. Energy technology in developing countries is often extremely backward, especially in rural areas where the majority of the population cannot rely on modern energy services. This affects human development and prevents people from lifting out of poverty.

It is evident that a paradigm shift is required to match the growing needs and local demands with available resources. There is great space for change and innovation promoting appropriate technologies. These technologies need to be designed to fit a particular context in a sustainable way, thus expanding the cost/efficiency ratio beyond technical and financial choices so as to include social, environmental, and overall economic considerations.

In order to propose the appropriate strategies for a specific context, it is crucial to clearly define the energy demand of the final users in terms of energy. Energy can then be provided in its various forms as heat, light, movement, or electricity according to the needs, the availability of resources and the absorptive capacity to use and take effective advantage of the adopted technology. Although a wide range of resources is available, a focus is here given to renewable sources since they present a number of advantages especially for rural areas. However, fossil fuel cannot be excluded a priori. The following chapters are thus meant to provide a comprehensive overview of the most appropriate strategies that can be deployed to couple local resources with sound technologies.

In Chap. 3 , the problem of access to modern energy services is first addressed since it affects 2.6 billion of people and is related to their basic daily needs; solutions such as improved cook-stoves and small-scale biogas plants that can be deployed by using traditional biomass or other residues are discussed. Chapter 4 and Chapter 5 focus on access to electric energy. In particular, Chap. 4 discusses off-grid systems, from home-based and community-based systems to microgrids, and introduces a new taxonomy for distributed generation systems.Chapter 5 discusses deep technical details on control and management related to independent microgrids and their interface with the main-grid. Chapter 6 gives a technical overview of the main small-scale renewable technologies used in the systems described in the previous chapters: solar photovoltaic, wind, hydro, bio-mass gasification, storage systems, and hybrid configurations. Chapter 7 completes the technological overview giving some details on solar thermal systems and their application for heating and cooling.

# Chapter 3
# Modern Energies Services for Cooking: from Improved Cook-Stoves to Domestic and Community Biogas Based Systems

**Francesca Mapelli and Jerome N. Mungwe**

**Abstract** Energy is crucial for a better quality of life and for sustainable human development. This has been demonstrated in previous chapters. It has been widely recognized that food and water security, productivity, health, education, climate change, and communication services are greatly affected by the quality and the quantity of energy services. The lack of or insufficient access to clean, affordable, reliable energy carriers is a major obstacle to reduce poverty and to improve the conditions and standard of living for the majority of the world's population, thus hindering economic and social development [1–4]. Increasing access to sustainable and modern energy services will enable income generation; it will also reduce the time and drudgery of collecting fuel wood; support cleaner and more efficient cooking and heating options; and finally, it could also provide indoor lighting security at night, thus enabling children to study in the evenings [3, 5–12]. Yet many in the world, especially in the developing countries, still have insufficient access to sustainable energy services. This chapter presents Improved Cook-Stoves (ICS) and domestic biogas plants as technological options to improve access to sustainable energy services at both the household and community levels. The relevance of the technology, its performances, impacts and dissemination are discussed.

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## Energy Services Required at the Households and Community Level

According to [13], there are six key energy services that all people need, want and have a right to. These services include lighting, cooking and water heating, space heating, cooling, access to information and communication technologies, and energy for earning a living. At the community level, these services are needed in four main areas, namely health care (hospitals, clinics and health post), education (schools, universities and training centers), public institutions (Government administrative offices, police stations, religious buildings, prisons, community centers, public libraries, orphanages, sport facilities, etc.), and infrastructural services (street lighting and water pumping) [13, 14]. However, basic energy services required at the household level include cooking, space heating and lighting, while at the community level the basic services are public lighting, water pumping, operation of basic appliances in health clinics and schools, and common facilities for social interactions [15, 16].

### *Relevance of Improved Cook-Stoves and Biogas Technology*

Most of the people without access to modern fuels lives in rural areas of sub-Saharan Africa, East and South Asia, and Latin America; they rely on traditional biomass (wood, charcoal, dung and agricultural residues) [17]. These people are unevenly distributed in the developing regions as shown in Fig. 3.1.

There is also an uneven distribution of the use of various traditional fuels as shown in Fig. 3.2.

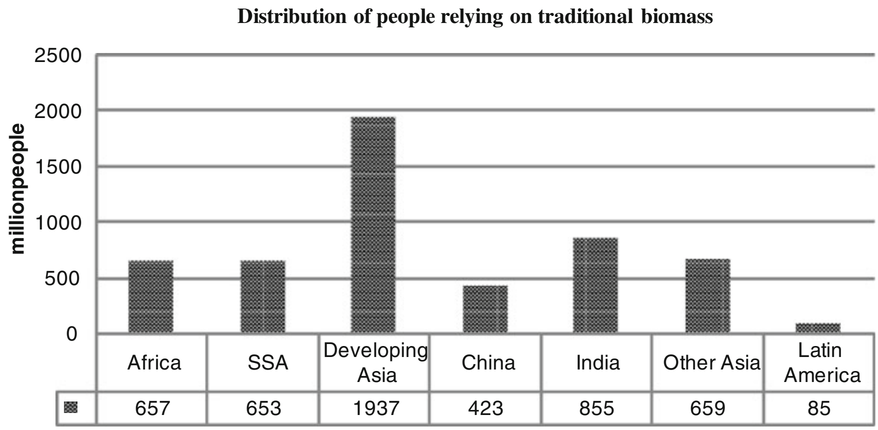


**Fig. 3.1** Distribution of people in developing countries relying on traditional biomass. *Source* [3, 6]

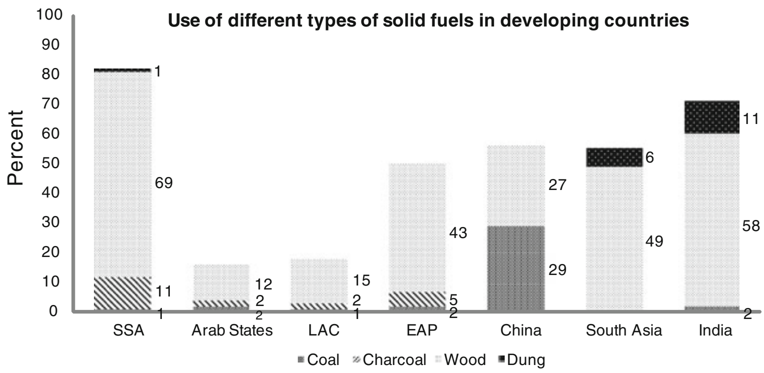


**Fig. 3.2** Proportion of different types of solid fuels used in developing countries (adapted from [6])

While in developing countries, more than 40 % of people have access to modern fuels, only 9 % in the least developed countries and 17 % in sub-Saharan Africa have access [6]. The households' heavy dependence on traditional biomass has negative economic, social and environmental impacts. The usage of inefficient conversion technologies (predominantly the three-stone fires and inefficient cook-stoves) leads to a high fuel consumption, deforestation, massive emissions of $CO_2$ and black carbon, and indoor air pollution, resulting in 1.4 million annual deaths, mostly amongst women and children. Moreover, the women are in charge of the arduous burden of collecting biomass, trekking long distances carrying heavy loads, and spending much of their time in search for the needed fuel [3, 5–12, 18, 19]. Besides this, the handling of human and animal excreta can pose serious health issues [20], in which case biogas technology can help to limit these negative impacts, while exploiting biogas as a modern fuel and reducing traditional biomass consumption.

Modern energy services offer numerous opportunities for livelihoods and access to cleaner fuels higher up in the energy ladder and are a means to get the poor out of the vicious cycle of poverty [13]. In the next decades, households in developing countries will continue to rely on traditional fuels as the main source of energy for cooking, doubling the primary energy used in an unsustainable way and accounting for 50 % of primary energy and 52 % of $CO_2$ from energy consumption [3, 13]. Hence, in order to support sustainable human development, technologies that increase access to sustainable energy services are required in order to employ solid fuels and to manage human and animal excreta in a healthier, more efficient and sustainable way.

# Improved Cook-Stoves: A Review

## *The Technology*

Although a precise definition of Improved Cook-Stoves does not exist, the United Nations have defined some criteria that they have to respect to achieve the goal of reducing health damages, environmental threads and the other aforementioned risks. Specifically, they have to be sustainable (by the social, environmental and economic point of view) so as to meet the social, resource, economic, and behavioral needs of users, and to reach high levels of technological design and performance.

In order to evaluate stove performances, several methods are available, but the most widely recognized is the Water Boiling Test (WBT). It is a laboratory standardized and replicable protocol, which can be used to assess and compare the performance of different models of stoves in various contexts. The WBT is composed by three phases: cold-start, hot-start, and simmer test; the amount of fuels used and emissions generated for the three stages are measured and evaluated as a weighted average to define the WBT key indicators [21].

### Cook-Stoves Classification

Cook-stoves could be fed by a wide range of fuels and other energy sources such as biomass (mainly wood), kerosene, natural gas, or by solar energy and electricity. Consequently, a great variety of stove's models are available on international and local markets, in addition to the self-made ones. This paragraph aims to provide a general assessment of the existing types of cook-stoves, in order to help the reader to select an appropriate device for a particular context. In the present taxonomy, the stoves are subdivided based on the different fuels exploited; this criterion is used as the selection of a suitable stove for a specific context mainly depends on locally available fuels. The most employed fuels and energy sources [6] are:

1. wood and often residues, dung and other waste materials;
2. charcoal;
3. gaseous fuels, such as liquefied petroleum gas (LPG) and natural gas;
4. liquid fuels, such as kerosene (including paraffin), alcohols (such as ethanol and methanol) and biofuels;
5. solar energy;
6. electrical energy.

These fuels can be traditional, such as non-commercial biomasses (categories 1 and 2), or modern (categories 3, 4, 5 and 6).

Moreover, the stoves can be further subdivided according to their level of performances; in case of traditional fuels, the stoves can be traditional or improved. It is worth saying that increasing performances follow increasing technological levels of the devices.

Hence, here below, stoves are firstly classified according to the fuel, and then in each category, stoves are subdivided according to their level of performance.

### Wood Stoves

Wood is likely the most used fuel for cooking in developing countries and, as a consequence, countless wood stove models exist. They range from the most traditional ones, the three-stone fire, to the most developed ones, such as the gasifiers (which are considered "advanced biomass cooking stoves" [22]) and ones that also allow electricity production. Below, a further subdivision of the wood stoves is presented, in order of increasing performances.

- Three-stone fire: a fire lit directly on the ground or simply supported by stones, bricks or a mud base (Fig. 3.3). It is the most traditional cooking device, and it is commonly used in developing countries. It presents very low performances, both in terms of fuel consumption and of pollutant emissions [23–25]. It is often considered as the baseline for the evaluation of other stove performances.
- Traditional stoves: they are among the most diffused cooking devices in developing countries. Some of the most used models are the Kalan stove [26], the Takate stove [27], the fixed clay stoves [28], and others mentioned in [24, 25, 29]. Generally, they have a metal or ceramic combustion chamber of a cylindrical shape (Fig. 3.4). On average, traditional stoves have emission levels and thermal efficiencies that are still distant from adequate standards, even though they achieve better performances than open fires, except for particulate matter (PM) emissions; PM production is due to insufficient air draft or cold zones in the combustion chamber, that are phenomena caused by an improper design [24].
- Improved Cook-Stoves: they should meet the criteria established by the UN, enabling a more efficient combustion, reducing fuel consumption and pollutant emissions. Several models exist, built using different materials (e.g., Jiko [30], VITA [31], Vesto [32], Basintuthu [33], Shisa [34], Tsotso [35]), but the rocket type ones are worth to be mentioned. In order to be classified as a rocket designed model, the stove should have a combustion chamber made up of two orthogonal parts: an insulated upright chimney (having a height of two or three


**Fig. 3.3** Three-stone fire made of stones (**a**) and bricks (**b**) [126, 127]

**Fig. 3.4** Traditional wood stove. *Source* [128]

times the diameter) and a horizontal zone where wood sticks are placed (Fig. 3.5). This greatly helps combustion efficiency; hence, this configuration is often exploited in ICS' design [23, 24, 36–38]. Rocket stoves were first conceived by Dr. L. Winiarsk, from the Aprovecho Research Center, who defined 10 principles they have to respect, reported in [39].

- Stoves with chimney or fan: the presence of a chimney could greatly help in reducing harmful emissions, driving away pollutant substances; nevertheless, the heat reaching the pot is diminished, as the hot gases are not in direct contact with it, causing an increase in fuel consumption [24, 40, 41]. For this reason stoves with a chimney have much better results if sunken pots or skirts are used. Hence, stoves with chimneys are suitable for a different kind of cooking: they are not the best ones for boiling or simmering food, but they are highly performing for frying. In the same way, fan-assisted stoves [24, 29, 42] allow for the control of fuel burning thanks to forced air convection, that permits reducing CO and PM emission levels over 90 % in comparison with three-stone fires. On the other hand, they need to be fed with electricity, which is not always available and reliable in developing countries.
- Gasifiers or wood-gas stoves: the working principle of gasifiers is the realization of a multistage combustion. Solid biomass combustion is a sequence of four phases (drying, pyrolysis, char-gasification and gas-combustion) that often overlap each other [43]. Gasifiers allow separating these stages in space and time, permitting a great improvement in combustion efficiency (e.g., Sampada gasifier [44], rice husk gasifier [45], My Little Cookstove [46], or others

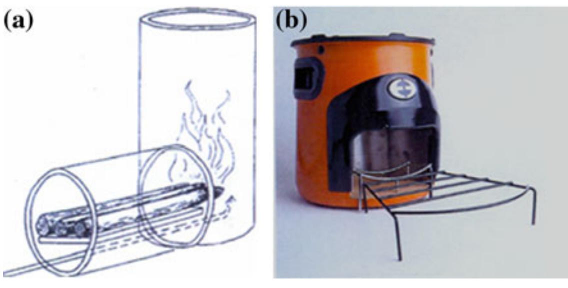


**Fig. 3.5** Combustion chamber **a** and an example **b** of a rocket stove. *Source* [36, 39]

**Fig. 3.6** Gasifier. *Source* [43]

mentioned in [23–25, 47]). Another advantage of the gasifiers, in comparison with the other cooking devices, is that gases burn above the generating zone, next to the stove top, and therefore heat can directly reach the pot, avoiding further thermal losses (Fig. 3.6). Nonetheless, gasifiers generally present costs higher than the previous models, also due to the complexity of the design.

Besides this, the phase of char-gasification can be suppressed if the hot char is not exposed to a sufficient air draft; in this case, there is biochar production and, consequently, these stoves are usually named biochar-making pyrolytic gasifiers [43, 48, 49]. Biochar can be employed to be burnt in other stoves, having a higher calorific value than raw wood, or to improve soil productivity, as a natural fertilizer (doing this, the carbon contained in the char is fixed in the soil) [50]. In the last case, since char combustion is avoided, less $CO_2$ emissions are released. However, this technology is not yet mature and needs to be further investigated.

- Stoves with TEG modules: cook-stoves can be provided with thermoelectric generator (TEG) modules, which could produce small amounts of electricity exploiting the Seebeck effect [24, 42, 51]. This allows ICSs to meet users' needs in a more complete way, as the generated electricity could be employed to feed LED lights or small electrical devices (Fig. 3.7). However, stoves with TEG modules are rather more expensive.

**Fig. 3.7** Improved Cook-Stove with TEG modules charging an electrical device. *Source* [51]

### Charcoal

Before presenting the classification, some general remarks about charcoal burning stoves are reported. Heat transfer mechanisms are similar to the ones occurring in wood stoves, but some differences exist, such as the fact that the combustion chamber's dimensions could be smaller for charcoal stoves, thanks to the higher heating value of the fuel. Besides this, it must be suspended on a grate to assure a proper air draft. It is worth noting that charcoal stoves performance evaluation does not take into account the process necessary to produce charcoal from raw wood. The effective available energy in charcoal is only 30–50 % of the original energy available in wood biomass; therefore, energy use in charcoal stoves should be more than doubled. In the same way, emissions would be doubled, as the charcoal-making process is highly pollutant [24]. However, stoves fed by charcoal can be subdivided in a way similar to the one for wood devices.

- Traditional charcoal stoves: several stoves of this kind are diffused in developing countries, mostly in urban areas, where charcoal is mainly used (some examples are the muddy charcoal stove [52] and the Zambian charcoal stove [53]). Although their performances are higher than for three-stone fires, they are still far from adequate standards.
- Charcoal Improved Cook-Stoves (Fig. 3.8): in the same way as the wood ICSs, charcoal improved stoves present high performances, allowing an efficient combustion and reducing health, environmental and social risks (e.g., hybrid charcoal and wood stoves [54], Maputo charcoal stove [55], institutional charcoal stove [56], Senegal Diambar stove [57], Burundi charcoal stove [58]). Also some rocket charcoal stoves exist [36].
- Gasifiers: even some charcoal gasifiers are present on the market. Most of them can be fed either by charcoal or by wood [59].
- Stoves with TEG modules: in the same way as the wood stoves, it is possible to couple TEG modules with ICSs, in order to produce small amounts of electricity.

### Liquid Fuels

Liquid fuelled stoves (Fig. 3.9) utilize kerosene (including paraffin), alcohols (ethanol and methanol), and biofuels, which are modern fuels. As a consequence, their thermal efficiency is generally high and pollutant emissions level is very low,

**Fig. 3.8** Charcoal improved Cook-Stove. *Source* [36]

**Fig. 3.9** Liquid fuelled stove. *Source* [129]

even though the latter may be higher in case of oil from jatropha or in case of improper use of kerosene [21, 24]. For instance, there are hybrid stoves fuelled by kerosene and vegetable oil [60, 61], paraffin [62] and ethanol [63–65]. However, these stoves are not adopted by the majority of people in developing countries due to the unavailability and the high cost of the fuels. It is worth noting that an interesting option for developing countries is to use liquid fuels locally produced from agricultural residues (see paragraph Small scale biogas technology).

### Gaseous Fuels

Like liquid fuelled stoves, cooking devices fed with gaseous fuels (Fig. 3.10) present high performances [21, 24, 25, 66], although sewage derived biogas stoves could generate significant pollutant emissions if not properly designed and utilized. At present, even gaseous fuels are often not affordable and not available in developing countries' rural areas. However, the opportunity to produce and to use biogas in developing countries has to be further investigated (see paragraph Small scale biogas technology).

### Solar Energy

Solar cookers are devices which utilize the energy from the sun to cook food; usually, they are not defined as stoves, since there is no combustion phase. A very wide range of solar cooker models exist, but most of them can be classified into

**Fig. 3.10** Gaseous fuelled stove. *Source* [130]

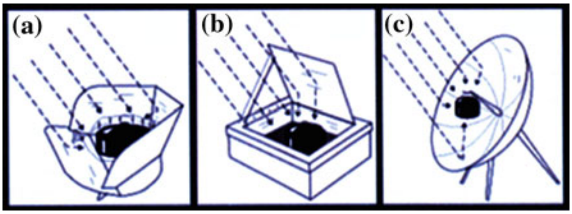


**Fig. 3.11** Categories of solar cookers (adapted from [67])

three main categories: (i) panel cookers (ii) box cookers, and (iii) parabolic cookers (Fig. 3.11).

- Panel cookers: they are generally recognized as the most common type of solar cookers, since they have a widespread distribution, thanks to low costs and ease of construction [67]. On the other hand, they can provide just small amount of thermal power, as it is generated simply by the sunlight concentration on the pot, which is eventually enclosed in a transparent plastic bag. Some of the existing models are the Cookit [68], the HotPot [69], the DATS [70], and a hybrid solar-biomass cooker [71].
- Box cookers: this kind of solar cooker is made up of an insulated box, whose walls are usually black to maximize the absorption, with a glass cover; all around there are reflective surfaces to direct sunbeams onto the pot [72–76]. As each component of the cooker has a relevant influence on the heating power, an accurate optimization of these parameters is essential.
- Parabolic cookers: they are simply parabolic reflectors in which the pot is located at the focus point, thanks to a stand system to support it. The main advantage of this model is the excellent performance: it can quickly reach very high temperatures. On the other hand, it leads also to significant risks of scalds and of burning the food. The first model was designed by Ghai [77] in the 1950s in India; thereafter, other parabolic cookers were developed, such as a small portable one [78], a cooker with a tracking system [79], and a recycled fiberglass satellite dish [29].

### Electrical Energy

Electric stoves transform electrical energy into heat. Clearly, their use is confined to areas where electricity is available, preventing several communities from their adoption; particularly, rural areas are often excluded. Indeed, although these stoves are commonly employed in the developed world [80–82], they are scarcely diffused in developing countries [25]. Electric stoves do not produce any emissions, but electricity generation could do [83]. However, since they have very high quality standards, they are considered modern cooking devices; consequently, their dissemination in developing countries should be fostered even if it depends on the availability of electricity.

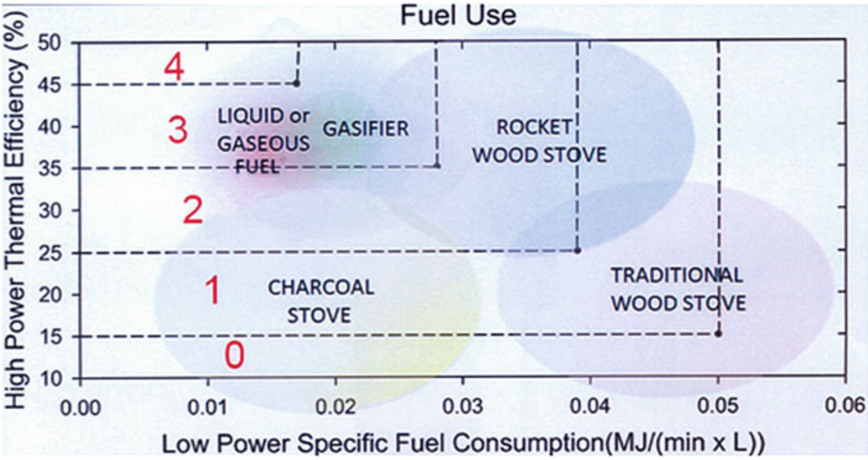


**Fig. 3.12** Stove subdivision in tiers (adapted from [84])

Finally, it is worth noting that other criteria to classify stoves exist. At present, several among the most influencing stakeholders in the process of ICSs' development are working to define precise and widely shared standards to classify stoves, according to fuel consumption, emissions and safety. They try to subdivide stoves into "tiers", which partially overlap with the above-mentioned categories [84]. Figure 3.12 synthesizes the possible subdivision based on different levels of fuel consumption.

Besides this, a growing attention is also given to the issue of safety; indeed, women and children are often exposed to burns and scalds because of the inadequate safety standards of cooking devices. Hence, ICSs should be designed with adequate safety standards, in order to protect the users also from this kind of risks.

As shown in Table 3.1, it is clear that many models of traditional stoves are used, although they are actually far from the satisfactory quality standards; on the other hand, modern fuels stoves also exist, but they are not really adopted in the developing countries due to the unavailability of those fuels. Hence, ICSs can be employed as a more efficient way to utilize traditional fuels.

## Drivers and Barriers for Improved Cook-Stoves

Some of the criteria required for the selection of a suitable stove to be disseminated in a certain area are synthesized below. These criteria should assure that the selected stove is appropriate from technical points of view, while also considering the economic, environmental and social aspects. These criteria include:

**Table 3.1** Summary of the existing stoves' technologies in developing countries

| Fuels | Existing technologies | Short description | References |
|---|---|---|---|
| *Wood* | Three-stone fires | Widely used; very low performances | [23–25] |
| | Traditional stoves | Widely used; low performances | [24–29] |
| | Improved Cook-Stoves | Being disseminated; good performances | [23, 24, 30–39] |
| | Stoves with chimney or fan | Not very diffused; good performances | [24, 29, 40–42] |
| | Gasifiers | Not very diffused; high performances | [23, 24, 43–49] |
| | Stoves with TEG modules | Not very diffused; high performances, with electricity production | [24, 42, 51] |
| *Charcoal* | Traditional stoves | Mainly used in urban areas; low performances | [52, 53] |
| | Improved Cook-Stoves | Mainly used in urban areas; good performances | [36, 54–58] |
| | Gasifiers | Mainly used in urban areas; high performances | [59] |
| | Stoves with TEG modules | Not very diffused; high performances, with electricity production | |
| *Liquid fuels* | | Not very diffused; high performances | [21, 24, 60–65] |
| *Gaseous fuels* | | Not very diffused; high performances | [21, 24, 25, 66] |
| *Solar energy* | Panel cookers | Widely used; low performances | [68–71] |
| | Box cookers | Quite diffused; good performances | [72–76] |
| | Parabolic cookers | Not very diffused; high performances | [29, 77–79] |
| *Electricity* | | Not very diffused; high performances | [80–82] |

- fuel: the stove has to be fuelled by a material which should be easily accessible in the area of interest. Furthermore, the fuel should be collected without causing environmental concerns;
- quality standards: the stove must reach high performances and must help to reduce the above-mentioned risks related to improper cooking activities (technical aspect);
- economic aspect: the stove should be affordable to local populations;
- users' needs: the stove should meet the users' requirements and respect local cultures of the populations adopting it.

ICSs can be exploited in order to meet adequate quality standards; however, some issues about the adoption of ICSs arise. First of all, to assess the actual stove performances, the WBT could be insufficient as field tests should also be carried out. Field performances are greatly influenced by users' behavior (e.g., how often and how well women use ICS and carry out the maintenance) [85]. In addition to this, other tests should be employed: for instance, the Control Cooking Test (CCT) and the Kitchen Performance Test (KPT) better evaluate the performances of different kind of stoves, such the frying ones. Furthermore, although these cooking appliances can be considered potentially successful, they often present an important weakness in comparison with traditional devices: they do not provide sufficient light in the households, due to their closed combustion chamber. A possible solution to this is to consider stoves equipped with thermoelectric generator modules, producing electricity that could feed small LED lights. Last but not least, a further improvement could be to foster the dissemination of locally produced ICSs, thus promoting income generating activities in the developing countries.

## Strategies for Improved Cook-Stoves Dissemination

Although the awareness of environmental and social costs caused by using traditional fuels and inefficient cooking devices has grown and studies about this issue have been carried out, at present the most widespread stoves in developing countries are not efficient at all. Some programmes aimed at providing the poorest people with ICSs are being implemented, but much work is still necessary. A meaningful example of the efforts made is the Partnership for Clean Indoor Air (PCIA). The PCIA was launched in September 2002 as an institution supported by the U.S. Environmental Protection Agency, having several UN agencies as partners. This voluntary association is made up of more than 160 governments, public and private organizations, multilateral institutions and industries. Its goal is "to increase the use of affordable, reliable, clean, efficient, and safe home cooking and heating practices", including ICSs [21]. Another interesting example is the Global Alliance for Clean Cook stoves (GACC), which was founded in September 2010, from an initiative of the U.S. Government, whose main aim is to provide 100 million homes with clean and efficient stoves and fuels by 2020 [83]. Regional programmes devoted to promote ICSs' dissemination also exist, such as the ones by the German agency GIZ HERA [86]. There are also some academic research groups for ICSs, such as the Aprovecho Research Centre [87] or the Engines and Energy Conversion Laboratory from the Colorado State University [88]. Some private companies are also working on the issue of proper cooking devices, such as Envirofit International [36], Biolite [51] and StoveTec [37]. The main stakeholders which promote the diffusion of ICSs are looking for a convergence on a common strategy, as demonstrated by the ISO International Workshop on Clean and Efficient Cook-stoves held in February 2012 [84].

## Small Scale Biogas Technology

### *The Technology*

Biogas technology provides a short to medium term solution towards switching to cleaner and more efficient energy services. The bio-digester, or simply digester, is the essential component of biogas technology and it offers a great opportunity to improve access to sustainable energy in developing countries. The goal of this section is to briefly define what biogas is, to give a short description of the gas production process, and to highlight the different categories of digesters that could be used at the household and community levels.

#### Biogas

One of the main products of the digester is biogas. Biogas is a renewable and clean fuel obtained from the biochemical decomposition of organic matter in a digester. It is composed of several gases as showed below in Table 3.2 [89–92]. It has a calorific value of 21–37.5 MJ/$m^3$ [91–93]; hence, 1 $m^3$ of biogas is equivalent to 5.5 kg of firewood and burns with a blue flame. The gas can have various end-uses which include cooking, water heating, lighting, running of engines for various applications (for example electricity production), milling, grinding and transportation.

Almost everything considered as waste that is organic, including household residues, agricultural residues, animal dung, human excreta and municipal organic waste, can be used for the production of biogas in the digester.

#### The Anaerobic Process

Biogas is produced thanks to the biochemical process called anaerobic digestion, a process that takes place in the absence of oxygen in an enclosure called bio-digester (simply a digester), or in a reactor.

**Table 3.2** Composition of biogas

| | Chemical formula | Percentage |
|---|---|---|
| Methane | $CH_4$ | 25–75 |
| Carbon dioxide | $CO_2$ | 30–40 |
| Hydrogen sulphide | $H_2S$ | 0.1–0.5 |
| Water vapor | $H_2O$ | 1–2 |
| Ammonia | $NH_3$ | 0.1–0.5 |
| Carbon monoxide | CO | 0–0.5 |

*Source* [89, 110]

**Table 3.3** The anaerobic process

| Stage | Input material(s) | Bacterial community | Output material(s) |
|---|---|---|---|
| Hydrolysis | Complex organic substrate (e.g., carbohydrates, proteins, lipids) | Extracellular and/ or acid forming bacterial | Simple organic substrate |
| Acidogenesis (fermentation) | Simple organic substrate | Fermentation bacteria | Volatile organic acids (e.g., acetic acids), $H_2$, $CO_2$ |
| Acetogenesis/ dehydrogenation | Volatile organic acids (e.g., acetic acids), $H_2$, $CO_2$ | Acetates | Acetic acids, formic acids, $H_2$, $CO_2$ |
| Methanogenesis | Acetic acids, formic acids, $H_2$, $CO_2$ | Methagenic bacteria | Methane, $CO_2$, $H_2S$, water vapor |

The anaerobic process consists of essentially 4 sub-processes or stages, namely hydrolysis, acidogenesis (fermentation), acetogenesis/dehydrogenation and methanogenesis [94–97]. Each of these sub-processes uses different bacteria communities. The different stages of the process are illustrated in Table 3.3.

Different bacteria function under different temperature ranges. Hence, the digester operation is very much influenced by temperatures [98]. Three temperature ranges are often used to characterize the process [96]:

- Psychrophilic <20 °C.
- Mesophilic 20–40 °C.
- Thermophilic 40–60 °C.

In the case of domestic and community biogas systems, the operating temperature range is often close to ambient temperature. Due to this temperature influence on the functioning of the digester, different operation modes and models have been developed.

### Classification of Biogas Digesters

The biogas digester is the fundamental component of a biogas system usually referred to as the biogas plant. The biogas plant for the household and community level comprises the following essential components:

- the inlet: for the input of the raw material referred to as feedstock;
- the digester: hosts the feedstock and is where the anaerobic process takes place;
- the gas holder: stores the gas produced for later use;
- the outlet or compensation tank: collects the digested material from the digester;
- the pipeline: conveys the gas to the consumption point.

As aforementioned, bio-digesters have many environmental, economic, and social benefits at many levels, from households to communities [89, 96, 97, 99–103]. However, the technology has also some shortcomings [91, 104], which include:

- relatively high investment cost for the poor living in rural areas;
- very demanding operation and maintenance activities;
- not suitable in some regions, especially cold and arid ones;
- need of a high and reliable source of feedstock supply;
- low efficiency.

Digesters' geometry has evolved from simply rectangular shaped digester through cylindrical and spherical or oval, to tubular models. The configuration of the digester together with other components has also evolved. The evolution has been motivated by the search for greater efficiency, suitability of operation under different temperature regimes and simplicity of operation and maintenance. Hence, based on operation mode, digesters may be grouped into three main categories, namely batch, semi-continuous and continuous modes [89, 93, 95, 98, 102, 105–107].

#### Batch Mode Digesters

The operation mode of this category is periodic load and discharge of the feedstock. Once loaded, the feedstock is allowed to be digested until no gas is produced. The feedstock used in such digesters ranges from fruits, vegetables, straw, animal dung, human excreta to municipal organic waste [91, 108, 109]. The configuration of the system could be such that the gasholder or storage is separated from the digester. The digester usually requires little space. The operation and maintenance of such digesters is laborious. Batch digesters could be very cheap and affordable to households; however, their size may limit the quantity of gas produced. They are not so popular amongst the models promoted at household level in rural areas of developing countries; nonetheless, they may be applicable in urban households where space is an issue.

#### Semi-Continuous Mode Digesters

The operation mode of this category is frequent (usually daily) loading of the digester through an inlet and automatic discharge of slurry through the outlet to the slurry (compensation) tank. Once loaded, the feedstock circulates in the digester for a period of time called Hydraulic Retention Time (HRT), during which it is digested. Semi-continuous digesters are usually designed as mono-feedstock (pig, cattle or fowl) digesters; however in practice two or more other feedstocks may be included. This model of digesters for household application is more expensive, less laborious for O&M, and usually requires more space than the batch type. The configuration of the system could be such that the gasholder or storage is separated from the digester. Whenever the digester and the gasholder constitute single units, the latter may be of variable or fixed volume: this gives rise to two sub-types, namely floating drum (or dome) and fixed dome types.

- Floating drum model: it was first developed by the Khadi and Village Commission (KVIC) in India and was standardized in 1962. It is characterized by a variable volume gasholder. Its main advantage is that the gas pressure at the point of use is fixed, thus enabling effective functioning of the burner. It has a relatively high maintenance (associated with steel dome's renovation) and construction costs, and requires relative skilled labour to realize the construction [91, 93, 107, 110, 111]. The preferred feedstock is animal (pig, cattle or cow) dung. Several variations of the design for different geographical locations include the KVIC, Pragati, Ganesh, and Ferro-cement models [106].
- Fixed dome model: it is characterized by a fixed volume gasholder. Its main advantage is the relatively low maintenance and construction cost, and relative less skilled labour necessary to realize the construction. The preferred feedstock is animal (pig, cattle or cow) dung. Even for this model, different variations for the various locations exist, such as the Indian fixed dome (e.g., Janata I & II, Deenbandhu), the Chinese fixed dome (e.g., Akut, CAMARTEL), the Nepali (GGC2047) models, and the Vietnamese models [90, 91, 93, 103, 107, 111]). While the installation for the fixed dome model is cheaper than for the floating drum type, the cost varies amongst the different fixed dome varieties with the Indian Deenbandhu model claimed to be the cheapest.

Any of the above-mentioned models (floating or fixed dome) are applicable to households and community (schools, hospitals, prisons, etc.) levels, the discriminating factor being only the size. Usually, digester sizes of 4, 6, 8 and 10 $m^3$ are applicable at the household level, while the ones greater than 10 $m^3$ are applicable at the community level.

### Continuous Mode Digesters

Unlike the batch mode digesters, where the feedstock remains stationary in the system until it is completely digested, this category is characterized by the continuous flow of the feedstock through the digester. It can use feedstock with dry matter content of 20–40 %. There are two sub operational modes available, namely plug-flow (tubular) and well (completely)-mixed systems [112].

- Plug-flow (tubular) digesters: this model has been in application on the industrial scale in developed countries. It is the youngest arrival amongst the different models applicable at the household level in developing countries. The digester is usually in a tubular form and the construction material is mostly polythene (hence it is often referred to as the polythene or plastic digesters). Its configuration is such that the tube can either be vertical or horizontal, with the latter most applicable in developing countries. The gasholder is usually detached from

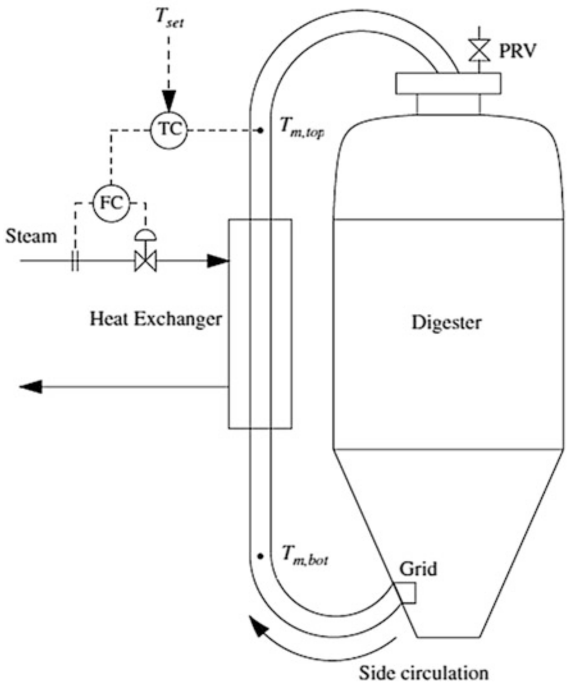


**Fig. 3.13** Schematic of a batch digester. *Source* [131]

the digester. It is the cheapest amongst the models promoted in developing countries in terms of construction and O&M; however, it is very fragile and its daily gas yield is low [107, 109, 111].

- Well (completely)-mixed: mostly applicable on a large scale, though, it could be employed at the community level for the digestion of municipal waste. Its O&M is relatively complicated and costly, so it is not suitable for developing countries.

The drawings below (Figs. 3.13, 3.14, 3.15, 3.16, 3.17) show the different models of digesters applicable at the household and community levels in the developing countries.

### *Measured Benefits of Biogas Technology*

Since its introduction in the late 60s and early 70s and its evolution till present days, biodigester technology has made diverse benefits at the household, community, national and international levels. In this section the benefits of the technology, from field experiences, are highlighted.

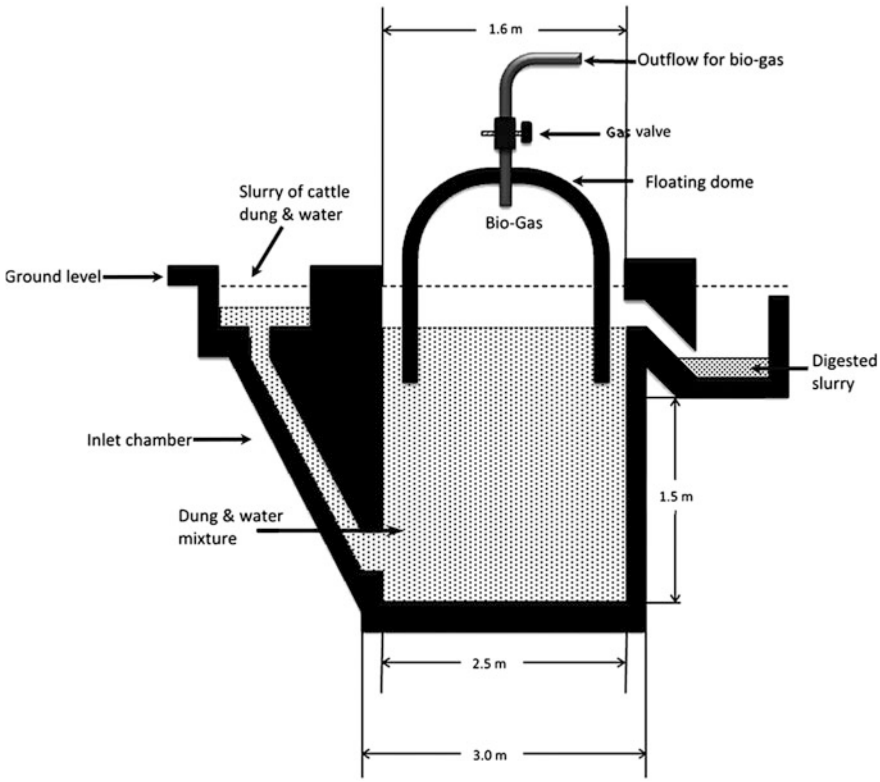


**Fig. 3.14** Floating dome biogas digester. *Source* [132]

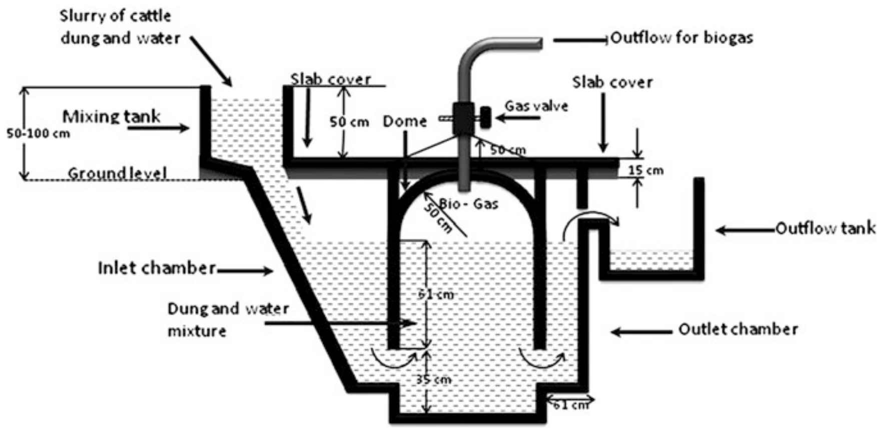


**Fig. 3.15** Typical fixed dome digester. *Source* [132]

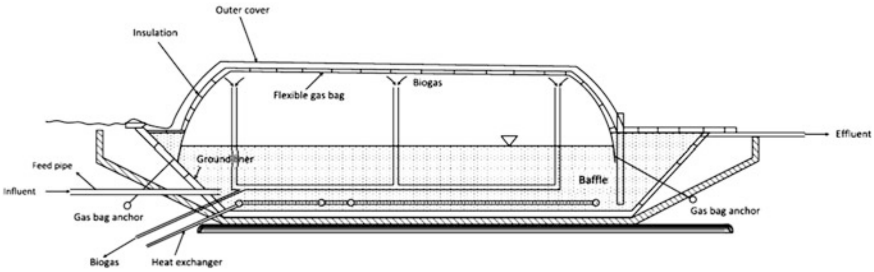


**Fig. 3.16** Schematic of a plug-flow digester. *Source* [132]

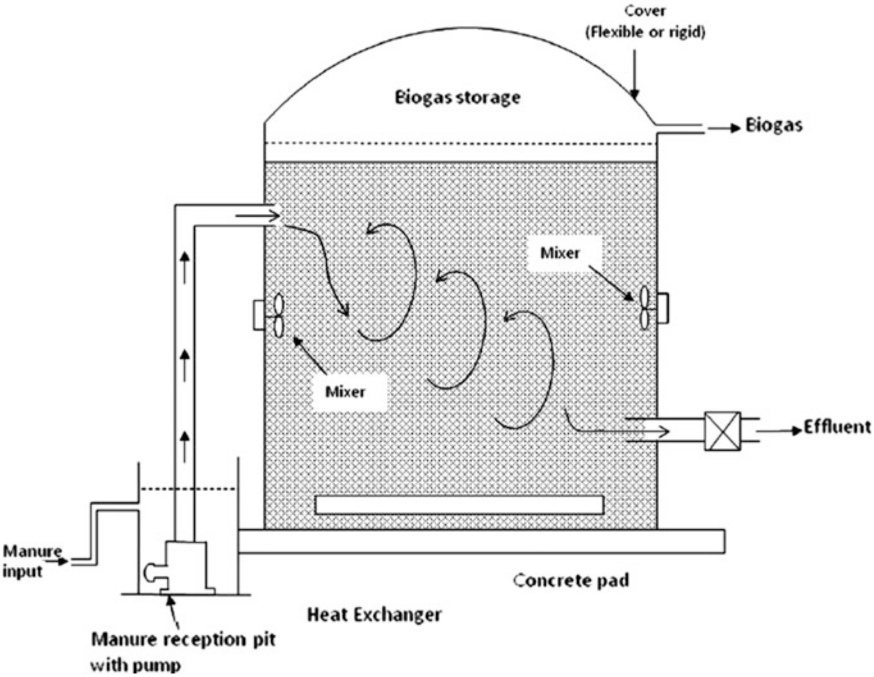


**Fig. 3.17** Typical continuously mixed digester. *Source* [132]

In terms of numbers, more than 43 million small (household) scale bio-digesters exist in the developing world, with China and India having the largest number of installed digesters (over 38 million and 5 million, respectively), with annual gas yield of over 14.5 billion $m^3$ of biogas [91, 113]. The gas, as a high quality renewable energy source, is used for various applications, ranging from heat for cooking and heating to electricity generation at the household and community level. Many environmental, economic and social benefits of the technology are reported. These benefits vary from country to country and even amongst communities and households. Some of these benefits are summarized below [95, 100, 113–116].

- Environmental
  - reduction in GHG emission through the production of clean energy;
  - reduction in deforestation;
  - better management and treatment of waste;
  - significant contribution to the transformation of household energy consumption structure;
  - more efficient use of natural resources through recycling;
  - improvement of pest control through the use of slurry as pesticide;
  - reduction of indoor air pollution;
  - reduced per capita energy consumption due to its higher heating value than other fuels lower down in the energy ladder.
- Economic
  - reduction in expenses for chemical fertilizers in agriculture;
  - increased agricultural yields;
  - creation of employment;
  - alleviation of poverty;
  - cost and time saving from firewood;
  - increased income and employment from integrate cattle rearing and farming.
- Social
  - time saving for women;
  - reduction of drudgery for women.

The performances of the technology greatly determine its chances for adoption by the target users. Small scale biogas technology, in application in developing countries, has recorded more than satisfactory performances.

## *Technology Performance*

The performance of small scale biomass technology may be viewed from several angles, which include the effectiveness and efficiency of the digester and its durability. The functional state and reliability of gas production is a measure of the effectiveness of the technology; the sufficiency of the produced gas is a measure of the digester's efficiency, determined by the gas yield. The life span of the digester is a measure of its durability. In this section these parameters are used to discuss the performance of the technology.

### Functional State and Reliability of Gas Production

The functional state of the digester simply refers to whether the digester is in use and is producing gas. From literature, the functional state of digesters varies between 30 and 81 % depending on the age and the design of the digester. The reasons for digesters' failure include: insufficient operation (irregular feeding of the digester), lack of repairs because users are usually not trained to do them, use of non-standardized models and insufficient feedstock [91, 117, 118]. The functional state depends on the operation and maintenance activities which in turn depend on who are responsible for these activities, and on the use of standardized models. Reliability of gas yield per day largely depends on the type of model used. Amongst the models promoted in the developing countries the fixed dome model (all varieties inclusive) has the highest reliability (95 % and annual reliability of 86 %), followed by the floating drum model with the reliability of 80 % (70 % per annum) and the inflatable tubular digester (29 %).

### Gas Yields

A key performance indicator is the quantity of produced gas. The gas yield depends on the design and the type of feedstock [107, 113]. For a given type of feedstock and digester design, the gas yield is influenced by several parameters, which include the operating temperatures, pH (acid-base concentration of the slurry), the Hydraulic Retention Time (HRT) and agitation [94].

From the reviewed literature, laboratory studies show that the potential gas yield of biomass feedstock ranges between 300 and 500 l biogas/kg total solid. Table 3.4 shows the gas yield for common feedstocks [91].

**Table 3.4** Feedstock production and gas yields from various common sources

| Substrate | Daily production kg/animal | % DM | Biogas yield $m^3$/kg DM | Biogas yield $m^3$/animal/day$_a$ |
|---|---|---|---|---|
| Pig manure | 2 | 17 | 3.6–4.8 | 1.43 |
| Cow manure | 8 Table 3 | 16 | 0.2–0.3 | 0.32 |
| Chicken manure | 0.08 | 25 | 0.35–0.8 | 0.01 |
| Human excreta/sewage | 0.5 | 20 | 0.35–0.5 | 0.04 |
| Straw/grass | | 80 | 0.35–0.4 | |
| Water hyacinth | | 7 | 0.17–0.25 | |
| Maize | | 20 | 0.25–0.40 | |
| Rice straw | | 87 | 0.18 | |
| Rice husk | | 86 | 0.014–0.018 | |
| Bagasse | | | 0.165 ($m^3$/kg organic DM) | |
| Leaf matter | | | 0.6 ($m^3$/kg) | |

DM = Dry Matter, a = based on mean biogas yield ($m^3$/kg DM)

The quantity of gas yields varies amongst different models. For the most popular models, the yield is higher for the fixed dome model (82 %), followed by the floating drum model (70 %) and the tubular model (14 %) [111]. Various techniques have been used to increase the gas yield, such as the design of model variations (for instance the fixed dome has several varieties including the Chinese, Deenbandhu, Janta, and Nepali (GGC2045) versions), the design of completely new models (for example the inflatable tubular model), the use of admixture (so called co-digestion) of biomass feedstock in viscous animal dung slurry fermented in conventional digester or even slurry recirculation [119].

**Durability**

The durability here simply refers to "being able to remain functional over a long time". It also represents "the life time" of the technology. The durability of the household scale digester, as the main component of the biogas system, depends on the kind of plant and essentially on the type of materials used. From literature, in the developing world the most popular digesters' life span ranges from 2 to 15 years as follows: inflatable tubular (plug flow) digester 2–5 years, floating drum up to 15 years and fixed dome 15–20 years [107]. It is necessary to standardize digesters both at the household and community levels in order to ensure good quality and long operational life. Learning from the Chinese experience, a standard system comprising 4 categories, namely basic standards, product standard, technical qualification and construction specification [113], with the associated criteria, can serve as a starting point.

## *Drivers and Barriers for Domestic Biogas*

Within the context of sustainable development and Sustainable Energy For All, the bio-digester is a mature and appropriate technology for improving access to modern energy services for a majority of the "energy poor". It therefore merits large scale dissemination. However, the implementation of such a large (National) Biogas Programme (NBP) is far from "plain sailing". There are both technical and non-technical constraints to be considered in such ventures; hence, a smart strategy is required. This section presents some of these constraints and proposes a strategy for a successful implementation of the NBP.

From a technical point of view the following constraints have to be contemplated [105, 117, 120]:

- climatic conditions: determine the digester operating temperature range;
- availability of the feedstock: in quantity and variability which dictate the digester's optimal size and design;

- availability of water: a very important input for the feedstock preparation;
- local construction materials: affect the cost of the system and hence its affordability to the target users;
- local technical capacity: for the proper construction of the digester and operation and maintenance services.

The non-technical constraints may be financial, social and institutional [91, 111, 121–123], as highlighted below.

- Financial
  - level of disposable income of the target users;
  - availability of subsidies;
  - availability of loan facilities;
  - availability of alternative energy sources (cost).
- Social
  - gender issues, decision making at the household and community level;
  - integration of the technology in the daily routines;
  - awareness of (alternative) technologies;
  - willingness to use biogas (from excreta) as energy source.
- Institutional
  - political will of the central government;
  - dissemination infrastructure (stakeholders such as NGOs).

### *Strategy for Implementation of National Biogas Programmes*

A lot can be learnt from the Asian experience with National Biogas Programme, especially the far more successful Chinese, Indian and Nepalese programmes. The Chinese experience can be traced back to 1929 with the creation of the first biogas company; design and construction trainings became available from 1935. Until 1970 the efforts in the dissemination of the technology were mainly made by NGOs. Between 1970 and 1980 the central government stepped into promote the technology in rural areas as a way for an agricultural resources effective utilization and forest protection. From this point on, it was instituted as a professional management organization of the sector, with the emergence of leading groups of biogas development, professional research and training institution (e.g., Chengdu Biogas Institute). Thus, a national policy was designed. The Indian experience started with research and design in 1950. In 1980 the NBP was instituted based on subsidies and on a multi-stakeholder and multi-design approach, leading to the improvement of the design and programme organization [106]. The Nepali involvement started in the 1980s as a technological research project. It was then expanded into a National Biogas Support Programme in the 1990s. Within a short period of 13 years over 140,000 digesters were built, employing 11,000 people. This success is largely attributed to the joint efforts of a variety of private and public actors that include the government, the business community, civil society organisations, and financial institutions [124].

From these experiences the followings should be incorporated in a strategy for the large scale dissemination of biogas via a programme [102, 105, 117, 120, 124, 125]:

- involvement of the central government (for policy issues and subsidies);
- provision of subsidies;
- awareness creation (through media, conferences, seminars, workshop, and feasibility studies);
- integration of relevant sectors, for instance agriculture and health;
- capacity building of both construction service providers and end-users;
- appropriate identification of users and their needs;
- quality control mechanism and local standardization of the technology.

Figure 3.18 [106] is an illustration of the organization of a NBP adapted from the Indian model.

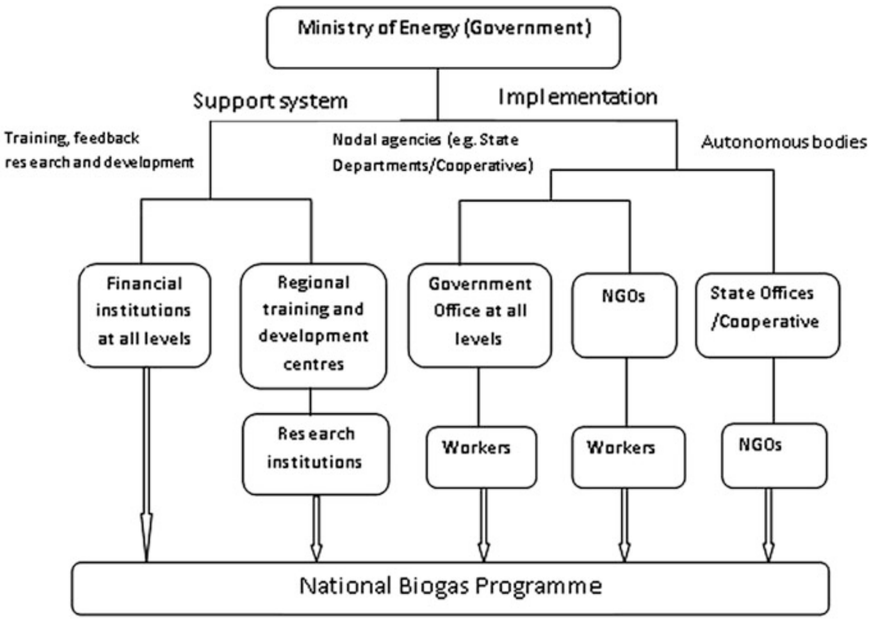


**Fig. 3.18** A model organizational structure of a national biogas programme

## Conclusion

Improved Cook-Stoves and biogas technologies can be a solution to enhance access to sustainable energy services for the 2.6 billion people in the world currently lacking access. While biogas systems could be considered a mature technology for the production of a very clean and efficient fuel, ICSs simply provide a partial solution to the health, environmental and social issues related to improper use of traditional biomass. While still having some technological and socio-cultural challenges and drawbacks, in some specific contexts, they can be an adequate solution to provide a first access to sustainable energy for cooking needs. Besides this, biogas, a high quality fuel from digester operation, can be used for fuelling of stoves, for lighting and for heating of households. Biogas could also be used to run engines for various income generating activities at the community level. Many environmental, economic and social benefits can be derived from the wide dissemination of these technologies. Several international efforts have been deployed for their wide adoption in the poorest countries. As already discussed, many improved stoves have been disseminated in the poorest regions of developing countries. Thanks to private and public partnerships, more than 40 million small scale digesters are currently in existence, of which more than 50 % are functioning and producing sufficient gas. Nevertheless, the wide distribution of these technologies is still slow in many developing countries, especially in Africa, due to both technical and non-technical constraints. For an effective dissemination a good strategy that brings together both the public and the private sector is required. Such a strategy should consider both an organizational structure and an appropriate financing mechanism to offset the initial high investment cost of the technologies to make them more affordable to the majority of poor people who are in dire need. Finally, further research and development is necessary to improve the design of ICSs and biogas digesters in order to suit different combinations of available resources, users' needs and contexts, and hence their actual adoption. This would greatly help to reduce the difficulties in having access to modern energy services in developing countries at the households and the community levels. The output of research and development of these technologies would greatly contribute to the satisfaction of basic human needs, such as health, education, employment, cooking, and communication, and hence improve the quality of life and foster global human development.

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# Chapter 4
# Distributed Generation for Access to Electricity: "Off-Main-Grid" Systems from Home-Based to Microgrid

**Stefano Mandelli and Riccardo Mereu**

**Abstract** Addressing the issue of rural electrification means contributing to poverty alleviation for one billion people in the World. The traditional approach for increasing electricity access in rural areas is grid extension, nevertheless large parts of these areas have low accessibility, low values of load demand and load factor. For these reasons, grid extension often results to be economically unfeasible. In this case Distributed Generation systems become the most appropriate technology option since they can be installed close to the load, they can be sized in order to best fit with local load demand, and they can be fuelled by local resources (i.e. renewables). This chapter introduces Distributed Generation (Paragraph "Electrification: the parabola of Distributed Generation"), it proposes a definition and a classification of Distributed Generation tailored to developing countries (Paragraph "Definition and classification for developing countries"), it presents the context of rural areas which are the targets for electrification strategies based on "off-main-grid" systems (Paragraph "Energy in rural areas: the target context for "off-main-grid" systems"), and finally it describes the main technical features and parameters that characterize "off-main-grid" systems (Paragraph "off-main-grid" systems).

## Electrification: The Parabola of Distributed Generation

Distributed Generation (DG), for the moment briefly defined as small-scale electricity production near to the consumer, is gaining more and more consideration in

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electric utility planning of both developed and developing countries. Nevertheless, this is not a new approach.

At the sunrise of the electrical era in Europe and US the electricity sector were quite decentralized. The generation plants supplied electricity only to limited areas of dense load, such as major cities or industrial sites, close to the power plant. Grids were DC based and therefore the distances that could be covered were limited; while batteries partially compensated demand and supply [1]. Firms operating in the electrical industries were largely privately owned and own-production was common [2].

The "first era of Distributed Generation" ended with the emergence of AC grids and technical advancements in generation plants which allowed to transport electricity over long distance and to lower production costs. The resulting structure of the electrical industry (generation, transmission, distribution and supply) was the *state-owned vertical integrated regulated monopoly* [3] which can be loosely considered as the classical paradigm of *centralized electrical system* (Fig. 4.1): large power plants working in a central location that deliver energy via great transmission and distribution networks to a large number of consumers covering a wide area [4].

This approach had been followed both in (currently) developed and developing countries, but while developed countries were able to extend the coverage area of the electric grid also to rural areas [2], developing countries faced, and still are facing, considerable difficulties in increasing power production and country electrification rates. Poor performance of the centralized electric system in developing countries had been partially linked to the little or no autonomy of the vertically integrated monopoly enterprises from the government and the weak

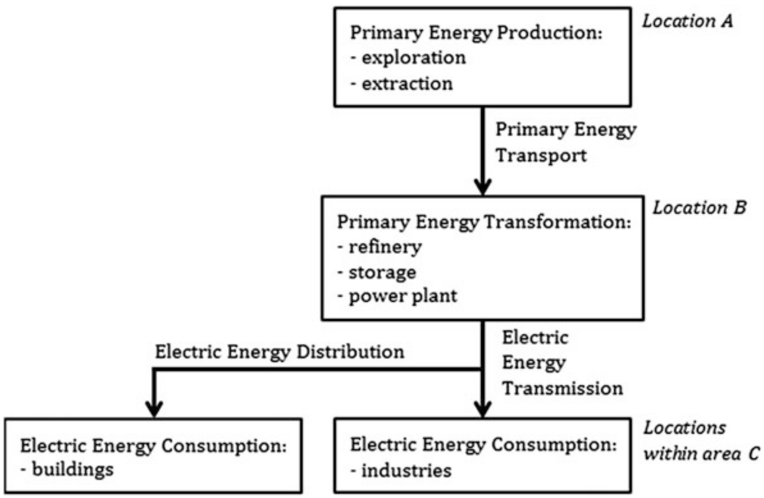


**Fig. 4.1** Graphic representation of centralized electrical system. Reproduced with permission of [4]

financial capacity for infrastructure development. Moreover, aid financing was often used for maintenance rather than for capital expenditures, thus limiting the growth of the electric system [5]. Rural areas were the most afflicted by this situation since governments focused their resources on urban areas where economic activities of the countries were more significant. Moreover, rural electricity supply results to be generally the most expensive element within the traditional approach of central grid extension, which actually was lead in the past by technological possibilities followed by economic aspects. The utilities were hence reluctant to extend the service to rural areas.

Common actions taken up by developing countries governments for rural areas, following industrialized countries' lead, was the establishment of separate organizations (usually named Rural Electrification Agencies) that were made responsible for rural electrification programs whether on grid extension or DG implementation [3]. On the other hand, the private sector itself tackled the issue with own-generation, actually DG based on gensets, despite high marginal costs and difficulties to acquire spare parts [5, 6].

The primacy of the centralized electrical system ended firstly in developed countries and later in developing countries, with the introduction of competition into the electricity industry that spread through the World from the 1980s. Factors that built up pressure to reform the power sector vary from country to country according to their starting situation [2]. Although there were several reasons that brought about the new paradigm of competition, two were the main objectives: (i) to improve the operational and investment efficiency of the existing industries and (ii) to attract private capital in order to reduce the pressure on state budgets [3, 7]. It can be undoubtedly stated that developing countries pursued reforms (often under international pressure) mainly to attract foreign private capitals in order to make more effective and efficient the already existing power system and to increase the efficiency in expanding access (i.e. rural electrification) [3]. On the other hand, the reform calls for a fragmentation of the overall electricity sectors that brings about risk of insufficient coordination between sub-sectors. Such a situation involves further risks for the immature expanding electrical systems of developing countries which are facing big demand growth too.

Nevertheless, a "second era of Distributed Generation" seems to arise in the new post-reform frame [1, 8, 9]. Besides the introduction of competition in the electricity industry, other factors contributed to renew the interest in DG in developed countries. They can be grouped according to five main dimensions: environmental, economic, technical, political and social (Table 4.1).

Some of the listed factors, such as the environmental concerns, the infrastructural costs reduction, the fossil fuels imports decrease, the primary source diversification, the technology advancements and the trend towards "green technologies" [7, 10–12], are driving force towards the spread of DG in developing countries too. Nevertheless, further reasons can be recognized specifically for developing countries:

**Table 4.1** Major factors that contributed in a renewed interest for DG

| |
|---|
| *Environmental* [1, 8–10, 47, 76–78]: |
| Growing concern as for the greenhouse gases emissions |
| Public awareness of the impacts of the electric industry |
| Opposition to building new transmission lines |
| *Economic* [1, 7, 8, 76, 78, 79]: |
| To avoid transmission and Distribution related costs |
| To tackle the current risky nature of large scale plant investments |
| To reduce power plants costs with combined heat and power generation |
| To better exploit profit margins within the competitive market |
| *Technical* [1, 2, 4, 8–10, 78, 79]: |
| Increased performance of the small power technologies (both fossil and renewable based) |
| Development of electronic metering and control equipment |
| Increased consumer demands for highly reliable power supply |
| *Political* [4, 7, 76–78]: |
| To decrease dependence from fossil fuels |
| To increase primary source diversification |
| To reduce vulnerability of the supply chain in centralized systems |
| *Social* [4, 8, 77]: |
| Increasing public desire to promote "green technologies" |
| Growing interest towards energy autonomy communities and sustainability |

1. *accessibility*: DG mainly based on Renewable Energy sources is preferred for remotest locations with low demand [2, 13–16];
2. *poverty reduction*: the shift by international institutions after 1995 towards poverty-based strategies and launching of initiatives such as the Millennium Development Goals in 2000 or the designation of 2012 as the ''International Year of Sustainable Energy for All'' by the UN Secretary-General, drew the attention on the links between access to modern energy and poverty, mainly in rural areas. This lead to consider energy as a main component within development rural programmes and DG as the preferable options to appropriately address the issue [5, 10, 17].

It has often been doubted that DG can become the ordinary, since a central grid has to be available as back-up supply and economies of scale are in favour of the centralized electrical system [1, 4]. Most probably the electrical systems are evolving to a mixture of centralized and DG systems. In particular for developing countries, DG mainly based on renewable energy plays a pivotal role when addressing the issue of access to energy in rural areas. Here the limits of small scale systems and renewables are compensated by the benefits that provide the "first kilowatt-hour" supplied to the modern-energies-poorest consumers [16]. Therefore DG can act, at least, as pre-electrification option, or as a building-block for the main grid development.

## Definitions and Classification for Developing Countries

In the previous section, Distributed Generation was briefly defined as small-scale electricity production near to the consumer. This definition refers to the generation capacity and the location of the plant. Nevertheless, DG is a new approach arisen, at least in developed countries, from the context of the electric system competition reform which is leading together with other factors to a substantial evolution of the electric industry. It follows that the definitions developed so far are oriented, next to more technical features, also to market mechanisms, operation control or to the broader concept of DG as a parallel approach to centralized electrical system. Thus, is it possible to provide a specific definition?

A literature review shows that no consensus has been reached yet both for a definition as well as for a classification of DG. Moreover, the most part of the definitions and classifications available in literature address DG within the context of electric system in developed countries. As for the different local context, problems and current conditions of the electric systems between Developed and developing countries, it is reasonable to state that these definitions and classifications do not suit developing countries. Therefore, to the purpose of setting a frame for the following analyses, it is worthwhile to revise and to clarify the *concept* of DG and then to develop a specific *classification* of DG for the context of developing countries.

In order to revise and to clarify the concept of DG we adopt the approach proposed by [4]. Here three main concepts for electricity generation are described: (i) centralized system, (ii) distributed systems and (iii) decentralized systems.

A system is considered decentralized when it is made up by autonomous units, thus having no interaction with other units. Energy consumption is decentralized by nature, while transmission and distribution depend on the location of production and conversion units. Therefore, the differences among centralized, distributed and decentralized are given by differences in the production, conversion, transmission and distribution. We previously described centralized electrical systems, while examples of decentralized and distributed electrical systems are illustrated in Figs. 4.2 and 4.3.

Decentralized systems, as mentioned before, are made by autonomous units where production, conversion and distribution have no interaction with other units. Such systems are *locally-based* and *need-oriented*: they are usually tailored to specific local needs of a relative restricted number of consumers and they can be based on local available energy resources (i.e. renewables). This concept includes systems for single or a block of buildings as well as systems for industries.

Distributed systems are based on decentralized production and conversion units, but they interact through a distribution (and transmission) grid. The result is a *virtual power plant* that consists of several generation points and a centralized control unit that receives data about the operational status of the system and determines how to satisfy the electric needs. Distributed systems can be

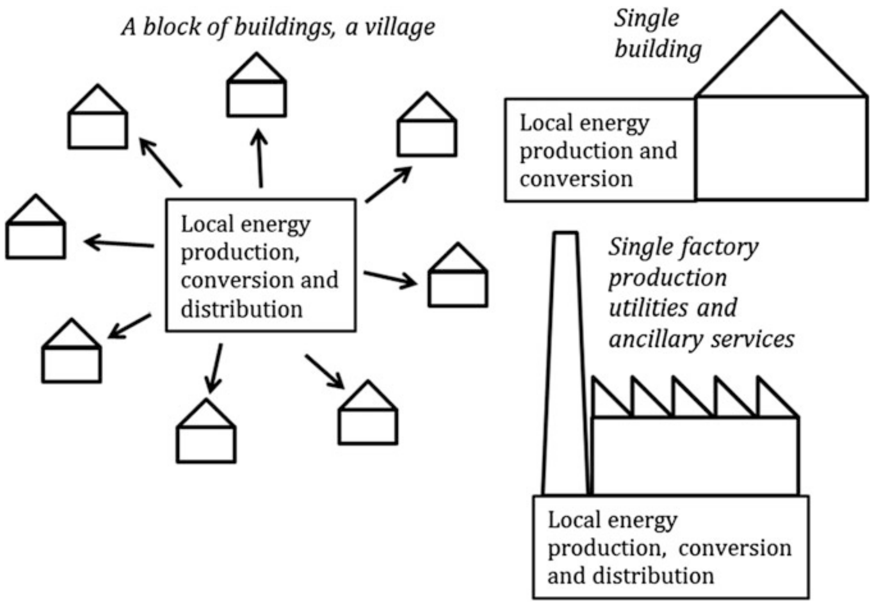


**Fig. 4.2** Graphic representation of decentralized electrical system. Reproduced with permission of [4]

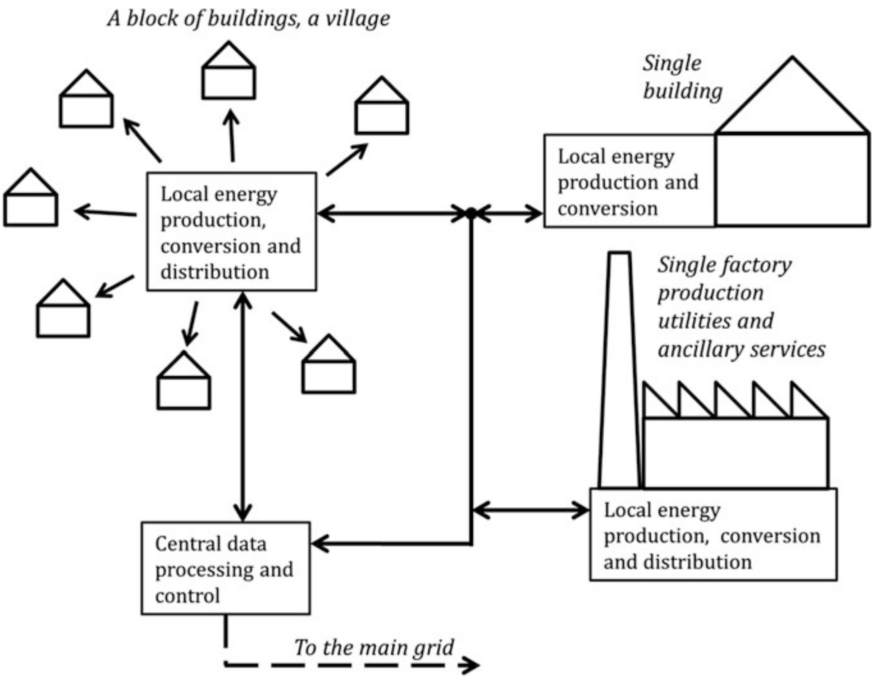


**Fig. 4.3** Graphic representation of distributed electrical system. Reproduced with permission of [4]

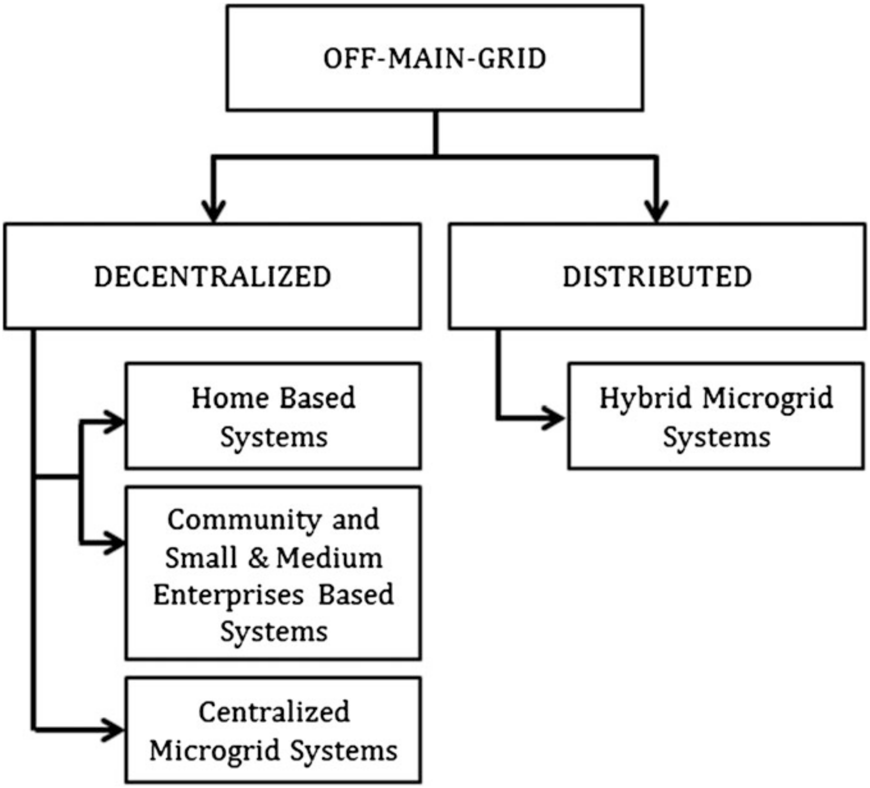


**Fig. 4.4** Proposed classification for "off-main-grid" electric systems in developing countries

decentralized *per se* (i.e. decentralized as for other distributed or the centralized systems) or connected to the main grid.

In the light of the definitions that have just been introduced, a possible classification for developing countries is shown in Fig. 4.4.

The conditions that favour DG[1] in developing countries (accessibility, load demand, poverty fight and leapfrogging) lead to consider that poor remote and rural areas, which are not electrified or have low modern energies consumption, are the main target contexts for DG. Since for these areas centralized systems do not often represent the best options [6, 15, 18–23], we consider in our classification only systems that operate detached from the main electrical grid, that is "off-main-grid". Therefore, "off-main-grid" systems results to be the general frame of the classification, and it actually substitutes what we had reckoned until now as Distributed Generation. As for the previous definitions, "off-main-grid" is already

[1] Here DG keeps the general meaning given at the beginning of the chapter.

the case of decentralized systems, while for distributed systems it means that the possibility to be connected to the centralized national or regional grid is excluded.

The distinction between *decentralized* and *distributed* is based on the concept of *virtual power plant.* Distributed systems are those that require a *central brain* coordinating the operation of the different generation units, hence composing a sort of unique plant. A decentralized system is based on a single generation unit instead.

The distinctions within decentralized systems are consumer/need oriented: *Home Based systems* and *Community and Small & Medium Enterprises (SMEs) Based systems* address a single consumer of a single typology with its specific needs, while *Centralized Microgrid* addresses several consumers, even of different typologies with their specific needs. We consider as Home Based a system that supplies electric needs to a household, as Community Based a system that supplies electric needs to a local service and as Small and Medium Enterprises Based a system that supplies electric needs to a local income activity. Since technology types and system power rates have definite differences between Home Based and Community/SMEs Based systems, Home Based systems can be considered as a single category. Regarding the *Centralized Microgrid* category, it refers to systems that address several consumers, where a production and conversion unit stands alone and a local grid provides electricity to consumers, hence this system is the centralized version of decentralized electric systems.

We consider as distributed system the *Hybrid Microgrids*: several production and conversion units, even based on different energy sources and managed by a central control unit, that supply electricity to several consumers, even of different typologies, with their specific needs.

The definition of the three concepts for electric systems (centralized, distributed and decentralized) and the classification are definite. Nevertheless, we introduce a condition on the maximum system rate in order to limit to some extent the definition of microgrid, which otherwise can lead to a province or regional-wide grid, thus becoming the *centralized main-grid* itself. To this purpose we consider the categories introduced by *Ackermann* et al. in [24] and we limit our systems rate to 5 $MW_{el}$, that is the limit of *small distributed generation* as defined by Ackermann.

## Energy in Rural Areas: The Target Context for "Off-Main-Grid" Systems

"Off-main-grid" systems, mainly based on renewables, are often considered an appropriate technology option to foster electrification in the conditions of rural areas of developing countries [15, 21, 25–27]. A rural area is defined as a region which is not urbanized and usually mostly devoted to agriculture; nevertheless also arid regions are considered as rural areas [28]. Hence, there is not a consensus about a definition of rural areas that suits all regions in the World and it actually varies from country to country according with national statistical offices.

Rural areas in developing countries are generally scattered populated, geographically isolated and difficult to access [20]. One of the most critical aspects in the rural areas is the very low access to modern and efficient sources of energy. Electricity main-grid connection in rural areas is generally limited to those towns and villages along major roads or near cities. When it is available, often only in high-income households, a few SMEs and community services can afford connections [6, 29–31] since electricity may cost as much as 10 times more than in urban areas [32]. When there is no grid connection, electrification is based on “off-main-grid” systems, historically based on diesel fueled gensets [6, 33] and more often on renewable based, usually aid-financed decentralized systems [34]. In this case too, it might happen that only the wealthiest population can permanently afford and adopt the electric supply [35].

Energy uses in rural areas are generally subdivided into three main categories [31, 32, 36]: (i) energy for households (i.e. basic living), (ii) energy for agriculture and (iii) energy for SMEs.

*Households* account for the majority of energy consumed in rural areas. They require energy mainly for cooking, lighting and space heating. Up to 80–100 % of energy consumption is devoted to cooking that, in cold climates, indirectly supplies also space heating [31, 32]. Such a high share is partly due to low efficiency of the employed technology (the traditional three-stones fire) and to the limited scope of other end-uses [30]. The rest of the energy consumed is for lighting, while further appliances (fans, radios, TVs, etc.) are employed only when electricity is available and households can afford it.

Traditional biomass (i.e. firewood, crop residues, dung, etc.) is the most common and traditional source of energy for cooking, the predominant role can be attributed to its availability as a “free” source. The cooking fire itself, kerosene lamps, candles or electricity are used for lighting purposes.

Several estimates have been proposed to set basic household power and energy needs in order to develop academic analysis or electrification planning at governmental level. Examples of power estimates to supply basic energy needs (cooking, lighting, space heating) range from 250 W per capita assumed by the Advisory Board on Energy for energy demand modeling in India [37], to 1750 W per capita obtained by [38] within a model to estimate future economic requirements. As for electricity-based needs (lights and various appliances) examples of power estimates for household used in literature are: 75 W for hydropower options comparison in developing countries [39], 400 W for cost estimation of rural electrification [10], 500 W for selection between decentralized renewable energy sources and grid extension [21] and 675 W for identifying areas in India where decentralized energy options are economically more attractive than grid extension [23].

It should be noticed that since the proportion of energy expenditure in the household budget can be significant, the employed sources strictly depend on the income level of the households (given the availability). Indeed, it generally

**Table 4.2** Human power consumption for farming activities [31]

| Activity | Gross power needed (W) | kWh consumed (assume 7 h working day) |
|---|---|---|
| Clearing bush and scrub | 400–600 | 2.8–4.2 |
| Felling trees | 600 | 4.2 |
| Hoeing | 300–500 | 2.1–3.5 |
| Ridging, deep digging | 400–1000 | 2.8–7.0 |
| Planting | 200–300 | 1.4–2.1 |
| Ploughing with animal drought | 350–550 | 2.45–3.85 |

**Table 4.3** Power requirements for agro-processing [31]

| Agro-processing needs | Average effective mechanical power (kW) |
|---|---|
| Rice mills/groundnut hullers | 14 |
| Flour mills | 73 |
| Cotton gin mills | 33 |
| Saw mills | 13 |
| Power mills | 2.2 |
| Oil mills | 163 |

happens that as incomes increase, the use of modern energies (fossil fuels and electricity) becomes more prevalent (Table 4.4).

The ordinary energy needs for *agricultural activities* in rural areas vary from power for transport and water pumping, to land preparation, primary and seedbed cultivation, weeding, planting, harvesting, post-harvest processing, storage, and the transportation of agricultural inputs and outputs. Use of modern energy resources in the agricultural sectors is very limited and human labour continues to be an important source of power. Human labour has limited output when compared to mechanized power, resulting hence in subsidence farming. On the other hand, humans are flexible, skilled and can make sophisticated judgments and adjustments as they work [40]. Table 4.2 shows estimates for human power requirements for various human activities. Women play a pivotal role in agriculture too: they are mainly involved during peak agricultural periods in planting, harvesting, transport and marketing the production [41]. When considering the daily per capita calories contained in food intakes, it would appear that calories consumption in rural areas is insufficient in agricultural activities. This situation may explain the low levels of agricultural productivity in much of Sub-Saharan Africa where labour heavily relies on women that are overburdened and have low calorie intakes [29].

According to the local availability and traditions, animal traction is another important source of power. Cattle and donkeys provide transport, pull implements, water lifting, and support in processing activities. According to Karekezi and Kithyoma [31] the use of animals is more popular in Asia than in Sub-Saharan Africa where animal diseases have high impacts. Reliance on hand tools is

**Table 4.4** Rural energy patterns in developing countries [31, 32]

| End uses | Income level | | |
|---|---|---|---|
| | Low | Medium | High |
| *Household* | | | |
| Cooking | Wood<br>dung<br>residues | Wood<br>charcoal<br>dung<br>residues | Wood<br>charcoal, coal<br>kerosene<br>LPG, biogas |
| Lighting | Candles<br>kerosene | Candles<br>kerosene<br>portable electric torches | Kerosene<br>electricity<br>batteries |
| Space heating | Wood<br>dung<br>residues | Wood<br>dung<br>residues | Wood<br>dung<br>residues<br>coal |
| Other appliances | None | Electricity<br>batteries | Electricity<br>batteries |
| *Agriculture* | | | |
| Tilling | Human labour | Draft animals | Animal<br>gasoline, diesel |
| Irrigation | Human labour | Draft animals | Diesel<br>electricity |
| Processing | Human labour | Draft animals | Diesel<br>electricity |
| *Industry* | | | |
| Milling/mechanical | Human labour | Human labour<br>draft animals | Diesel<br>based electricity |
| Process/heat | Wood<br>residues | Coal<br>charcoal<br>wood<br>residues | Coal<br>charcoal<br>wood<br>residues |
| Cooling/<br>Refrigeration | None | None | Electricity<br>LPG<br>kerosene |
| *Services* | | | |
| Transport | Human labour | Draft animals | Gasoline, diesel |
| Telephone | None | Batteries | Electricity |
| Community uses | None | Kerosene | Electricity |

generally common mainly in Sub-Saharan Africa [40]: here tractors resulted to be about 540,000 in 1994 (half of which were in Algeria, Egypt and South Africa) compared to about 1,215,000 in the same year in South America [42]. Similarly to households energy patterns, modern energies (diesel and electricity) substitute human and animal power as income increases (Table 4.4).

*Small and Medium Enterprises* in rural areas are largely household-based, often result to be owned and managed by women [31] and rarely rely on non-household members. They can be categorized into agro-based and non-agro-based enterprises. The former includes saw/rice/grain milling, fruit and vegetable processing, tobacco-curing, and pottery making, while the latter includes a range of household businesses such as small shops, beer halls, inns, charcoal and brick manufacturing, potteries, bakeries, blacksmiths, etc. [31, 32]. Biomass is the main energy source for many poor processing SMEs as well as human and animal power are the main energy source for mechanical ones. Typical power requirements for agro-processing are shown in Table 4.3. Again as income levels increase modern energies substitute traditional ones (Table 4.4). A further needs category refers to *services* (Table 4.4) which can be grouped into transport, telecommunications and community uses (public lighting, water pumping, IT, cooling, etc. in schools, hospitals and public offices).

## "Off-Main-Grid" Systems

As mentioned and explained previously, the "off-main-grid" systems are considered an appropriate solution for electricity DG in rural areas in developing countries. Specifically centralized systems ranging from Home Based to Centralized microgrid systems are introduced here following the classification presented in Paragraph "Definitions and a classification for developing countries", and limiting the power system to 5 $MW_{el}$.

Further disquisitions that contribute to complete the overview of "off-main-grid" systems are provided in the following chapters that deal with technical issues related to microgrids (Chap. 5) and small-scale renewable technologies and their configurations within Home-based, Community-based and microgrid systems (Chap. 6).

Different options are available for generating electricity in rural areas in developing countries. The choice of appropriate technologies strongly influences the end users living conditions. It depends on technical-socio-economic factors such as type of available energy sources, characteristics of the end-use application, economic feasibility, economic development of the local context, and government energy policies [43–46].

Looking at the technological aspect, rural electrification systems can be classified by generation technology and system layout design.

Generation technologies can be identified as conventional (running fully on fossil fuel, such as diesel), non-conventional (running exclusively on renewable energy resources), and hybrids (running with mixed sources, such as renewables coupled with diesel) [26, 47, 48] based on the energy source used, as shown in Fig. 4.5.

In the scheme of Fig. 4.5 the storage category includes components exploiting potential energy (e.g. pumped-hydro, compressed-air), kinetic energy (e.g. flywheels), and chemical energy (e.g. hydrogen from fuel cells, batteries, etc.) [47, 49, 50]. In this classification batteries are reported as part of the storage systems even though in some cases they are considered in rural contexts as the main source of electricity [6, 48]. The batteries can be recharged by using different kind of

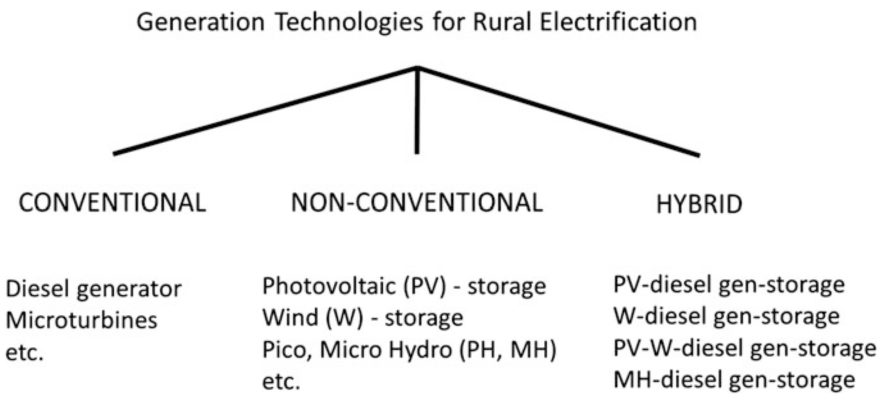


**Fig. 4.5** Generation technologies classification

sources (renewables or not) and for this reason they are not included as independent source, but only considered as storage components in non-conventional and hybrid systems.

Conventional rural electrification systems are mainly represented by diesel-powered generators (gen-sets). They have been widely used to improve the access to electricity for rural communities and for emergency applications in the last decades. Diesel-powered generators have the advantage to be dispatchable on demand, to be a simple technology, to require reduced civil work and time for installation, to meet low rural power demand, and to have a low capital cost per kW. Nevertheless, gen-set technology use is limited by high maintenance and fuel costs, high noise generation, and by low efficiency when operating far from nominal conditions. The fuel cost is further increased in some regions by transportation costs for the presence of basic transport infrastructures making the gen-set the most expensive option for generating electricity [51]. Furthermore, diesel generator is generally dimensioned to cover the power peak load whether it operates most of the time at 20–30 % of the nominal conditions, strongly decreasing the efficiency of the system. Finally, local and global environmental aspects related to fossil fuels use have become more relevant in the recent years reducing the interest on diesel generators [6, 26, 51, 52].

On the other hand, non-conventional energy systems in rural communities are mainly represented by Renewable Energy Technologies (RETs) such as photovoltaic (PV), wind, pico and micro-hydro (PH, MH) systems. These technologies are selected based on existing practices, policies, and technological maturity for application in developing countries and rural areas.

In this analysis biomass-based technologies are not considered even if biomass is considered one of the most important renewable sources in the near future. Main reasons for excluding biomass from the selected technologies are the minimum plant size for electricity production and the complex source supply chain. This source is indeed largely used on small-scale energy systems for thermal applications, while for power generation a large-scale combustion/gasification plant is necessary [53]. The minimum scale for electricity production from biomass gasification is estimated to be 10–100 kW [54–56], fitting the microgrid scale but not the home-based and community-based typical scales. The steam cycle technology is available for loads higher than 5 MW, suitable for grid-connected generation plants [54]. Furthermore, the extremely complex and multidisciplinary biomass supply chain requires specific deep analyses that are not tackled in this chapter.

RETs are gaining more and more importance in rural electrification, especially in the last years since their efficiency and reliability are continuously increasing while prices decrease. Among the reasons of RETs increasing spread the independence of the resources, present at local level, lower energy prices over the long term, high power flexibility and modularity, low maintenance, and reduced environmental impact are the most relevant [26, 57]. At the same time a common limit for RETs is the aleatory nature of the sources, especially solar and wind, making the storage a necessary component of the electricity generation system. The strong dependence on weather conditions (e.g. solar, wind technologies), seasonal (e.g. hydro, wind technologies) and daily cycles (solar technologies) requires to pay particular attention to the peak load demand and to the temporal load distribution designing a system able to recharge the storage components during low load demand in order to use them when required. The use of storage components, usually batteries, increases the complexity of the system, the maintenance, and the long-term costs [49, 58–61]. A schematic summary of advantages and limits of gen-set and selected RETs is reported in Table 4.5.

The limit of un-dispatchable electricity generation, common to most of the RETs, is usually overcome by using hybrid systems, where diesel generator technology is coupled to the main RET-based system, as shown in Fig. 4.5. Main advantages of hybrid systems are the high reliability and continuity of supply keeping the positive peculiarities of RETs use and the reduction of the storage system size. Indeed, the RET-diesel generator and multiple RETs coupling reduces the batteries' stress (limiting the state of charge variation with respect to pure mono-source renewable power system), increasing batteries lifetime and reducing operation costs. Disadvantages of hybrid systems consist of the higher investment and maintenance costs than pure RET use. Furthermore, hybrid solution increases the complexity of the system and requires the management and maintenance of different technologies, requiring specific skills for each of them.

Even though there is not a standard generation share for hybrid systems typically they are characterized by 75–99 % use of renewable energy supply. Indeed, in some cases the gen-set is installed as part of the system, but rarely used due to the high performance of the RETs [57].

In terms of layout, all the described technologies can be used from autonomous Home Based to Centralized microgrid systems with specific characteristics for each category.

Home and Community Based systems are often the solution to provide energy access to isolated households and villages. In these decentralized configurations

**Table 4.5** Technology peculiarities for off-grid applications

| Technology | Strengths | Weaknesses |
|---|---|---|
| Diesel-powered generators | Dispatchable (energy availability on demand)<br>Low investment costs (low cost per kW)<br>Reduced installation work and non-qualified maintenance | High dependence on fuel supply (availability and cost)<br>High pollution (local and global level)<br>High maintenance<br>High noise generation |
| Solar photovoltaic systems | Adapted to isolated rural contexts<br>High modularity (energy expansion opportunity)<br>Reduced maintenance<br>Absence of direct environmental impact (local and global level) | Aleatory nature of the source (daily cycle and weather conditions)<br>Large area—power ratio<br>High investment costs |
| Wind systems | Small area—power ratio (limited land use)<br>Absence of direct pollution (local and global level) | Aleatory nature of the source (high fluctuation of the wind speed)<br>High investment costs<br>High qualified maintenance |
| Pico/micro hydro systems | High efficiency<br>Cost-effective technology<br>Absence of direct pollution (local and global level) | Aleatory nature of the source (seasonal cycle)<br>High specific characterization of local site conditions<br>Absence of modularity (reduced energy expansion)<br>Possible environmental impact (local level) |
| PV–W-diesel hybrid systems | Dispatchable (energy availability on demand)<br>Higher capacity factor than single technologies<br>High modularity (energy expansion opportunity)<br>Reduced direct pollution (local and global level) | High qualified maintenance<br>Technical and management local skills<br>High degree of social organization |

the power generation is installed close to the load and there are no transmission and distribution costs and management issues. Nevertheless, the specific cost of energy for these solutions can be higher than using microgrid systems due to the lack of economies of scale (partially overcome in Community Based systems).

Beside the social aspects related with the local community to be evaluated and managed for each specific case [62], the selection of the appropriate layout system depends mainly on the number and dispersion of the households, the geographic characteristics of the location (i.e. complexity of local terrain, insolation, etc.), the types of load required (i.e. per capita electricity power and energy demand), and local level development (i.e. local social organization, technical and management local skills, etc.) [16, 21, 26, 54, 57, 63–65], as shown in Table 4.6.

Some differences can be observed in the systems based on these categories such as efficiency (e.g. small/large components' technology, storage component, etc.), energy management (e.g. transmission and distribution management, storage system optimization, etc.), end-use devices' characteristics (e.g. Alternating Current/Direct Current devices, etc.), and financial solutions (e.g. fee-for-service, micro-credit, etc.) [49, 63, 66, 67].

As shown in Table 4.6, Home and Community-Based are mainly used for supplying small DC appliances such as lamps, radios, b/w TVs, mobile phone chargers, etc. Even though a reference to specific RETs is not reported in Table 4.6, it is important to recall that, unlike Wind Home-based Systems, most Solar Home-based Systems do not support income generating activities. They thus make Wind Home-based Systems more suitable for creating productive services and jobs at smallest scales [57].

Microgrids instead are able to provide capacity for modern household appliances, collective services, and small local businesses keep utilizing local mix of technologies based on renewable energies, battery storage, and fossil fuels. microgrids address rural communities isolated from national grids and having a certain load demand and serving a concentrated group of 15 or more households [57]. From a technical viewpoint the most challenging aspects are related to distribution and synchronizing aspect of the system.

Beside the high technical potential of microgrid Systems, relevant financial and organizational aspects have to be taken into account when the deployment of this rural electrification approach is preferred over other available alternatives. Financing, management, business models, maintenance, sustainable operations, and socio-economic conditions are indeed the main bottlenecks for its successful application. Furthermore, each community presents peculiar characteristics and interests influencing the choice of the best technical solution according to local financial, social, and environmental terms. For these reasons the microgrid electrification approach is focused on end-users, their needs and involvement, capacity building, markets, policies, financing, and allocation of responsibilities.

From the economic viewpoint, the Life-Cycle Cost (LCC) analysis is preferred to the simple capital cost for generation technologies comparison and the Levelized Cost Of Energy (LCOE) indicator is used for comparing cost effectiveness of electricity supply options. The LCOE represents the ratio between the total cost of

**Table 4.6** Criteria for appropriate layout system selection

| Criteria | Home based | Community based | Hybrid microgrid |
|---|---|---|---|
| Households number and dispersion | Single household | From 5 households, collective buildings | From 15 households |
| Geographic characteristics | Low density population areas | Medium–high density population small communities | Medium–high density population areas, small islands, conversion of diesel-based microgrids, etc. |
| Required load | 10–250 W | 500–5000 W | 5–5000 kW |
| | Mainly DC: lamps, radios, b/w TVs, mobile phone chargers, fans, small DC fridges, etc. | Mainly DC: lamps, radios, b/w TVs, mobile phone chargers, fans, small DC fridges, water supply, etc. | Mainly AC: lamps, radios, TVs, mobile phone chargers, fans, water supply, modern household appliances, public lighting, health services, etc. |
| Local level development | Low degree of social organization<br>Low finance and market development | Medium–high degree of social organization<br>Low finance and market development | High degree of social organization and local governance<br>High local technical and management skills<br>High degree finance and tariff systems |

**Table 4.7** LCOE for conventional, non-conventional and hybrid technologies (2005, ¢USD/kWh) [54]

| Levelized costs [¢USD/kWh] | | | | | |
|---|---|---|---|---|---|
| Technology | Rated output (kW) | Capital | O&M[a] | Fuel | Average |
| Diesel genset | 0.3–5000[b] | 5.01–7.31 | 5–2.5 | 54.62–4.84 | 64.63–9.25 |
| PV | 0.05–5000 | 45.59–40.36 | 16–1.21 | – | 61.59–41.57 |
| Wind | 0.3–100 | 26.18–13.55 | 8.39–6.16 | – | 34.57–19.71 |
| Pico/micro hydro | 0.3–100 | 14.24–9.54 | 0.9–1.47 | – | 15.14–6.95 |
| PV-Wind hybrid[c] | 0.3–100 | 31.40–22.02 | 10.38–8.47 | – | 41.78–30.49 |

[a] O&M includes fixed and variable components of generation operating costs
[b] Referred to base-load configuration
[c] Diesel generator is not included due to the variability of the costs based on the share of power and supplied energy from the diesel generator in this kind of systems

supplying electricity plant and the plant lifetime taking in account the related discount rate. Costs are associated with construction, operating and maintenance, fuel, and any costs involved in disassembling and decommissioning the plant. In some cases external costs and other relevant costs such as backup generator in the case of intermittent energies, operation and decommissioning of a generating plant, and environmental costs are also included. This indicator is regularly used by several organizations such as IEA [68, 69], Royal Academy of Engineering study [70], CERI [71], and SunPower Corporation [72].

Branker [73] and Bhattacharyya [74] recently reviewed several methodological options for LCOE analysis of off-grid electricity supply. According to its general definition this indicator, widely used for economic comparison of different technologies, can show some limitations failing to capture any dimension beyond costs and external costs due to environmental effects and security of supply. Furthermore, comparison of technologies with different capacity factors, evaluation of fuel cost variability, cost of back-up or standby power, external costs related to fossil fuel use are not always adequately taken into account by the LCOE approach [74]. Some of these limitations, such as the environmental costs of the technologies, have been overcome in some studies related to specific contexts [17, 20, 51, 73, 75].

Data in Table 4.7 refer to the LCOE value for conventional, non-conventional, and hybrid supply options with costs of 2005. For 2010 and 2015 forecasts are reported in [54], taking into account the uncertainty related with international fuel prices and other factors.

The LCOE analysis shows that the cost of non-conventional options is generally higher than that of conventional technologies and hybrid systems for higher rated outputs, the cost of supply generally decreases as the size of plant increases (for both capital and final electricity costs), and RETs are either cost-effective (Pico/Micro Hydro) or reaching cost-effectiveness (PV systems).

In general fully renewable energy system LCOE is higher than that of a diesel generator or a hybrid solution despite the high variability related to the context of application. Indeed, the LCOE value for diesel-powered generators and RETs is strongly dependent on the fuel price and battery lifetime, respectively.

Furthermore, conservative calculations of LCC show that hybrid microgrids, based on RETs and with a diesel-powered generator for backup, are usually the most competitive technical and the least-cost long-term energy solutions among the three alternatives [26, 57].

## Conclusion

Worldwide the electrical systems are evolving to a mixture of centralized and Distributed Generation (DG) systems. In developing countries, DG mainly based on Renewable Energy plays a pivotal role when addressing the issue of access to electricity in rural areas. Here the limits of small scale systems and renewables are compensated by the benefits that provide the "first kilowatt-hour" supplied to the modern-energies-poorest consumers.

In this contexts DG operates often detached from the main national grid ("off-main-grid") and can be *decentralized* or *distributed* depending on whether a single or multiple energy source(s) and conversion technolog(ies) is (are) employed. Moreover "off-main-grid" systems can be tailored on the specific rural areas energy needs, hence being *Home Based systems, Community and Small & Medium Enterprises Based systems,* and *Centralized* or *Hybrid Microgrids*.

According with the harnessed energy source(s) and the targeted energy needs, different conversion technologies are available with specific strengths and weaknesses. Finally, the Levelized Cost Of Energy (LCOE), despite the limitations failing to capture any dimension beyond costs, is the most common parameters to compare electricity supply options.

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# Chapter 5
# Grid Connected Systems for Access to Electricity: From Microgrid to Grid Extension

**Godfrey Gladson Moshi, Alberto Berizzi and Christian Bovo**

**Abstract** All over the world, microgrids are becoming an important paradigm to supply electricity to many different categories of customers: in developed countries, where an electricity distribution grid is already in place, microgrids are seen as a way of migrating towards the so-called Smart Grids, able in particular to provide increased reliability to final users and to exploit as much as possible renewable primary sources for the electricity generation. In this framework, it is important that, in case of a significant perturbation of the main grid, the local microgrid can disconnect and continue the operation without any particular problem, so as to increase the reliability of the supply for its customers (top–bottom approach). On the contrary, in developing countries, microgrids are often the only way to provide electricity to small remote villages, as a connection to an external main grid is not available yet. In this case, the microgrid has to be operated in a standing-alone (off-grid) mode, but it should be designed in such way that, when eventually a main grid is built, the connection of the microgrid to the main grid will be possible (bottom–top approach). In this framework, it is possible to look step-by-step at the growth of the bulk (national) power system as to the aggregation of many small microgrids. The present chapter deals with the main technical issues related to the planning and the operation of microgrids, both in the presence and in the absence of an external main grid: balancing the load, control and protection systems, voltage and frequency control, normal and emergency

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operations and so on. The goal is to provide a simple and straightforward synthesis of what to take into account when decisions have to be made at a higher than technical level.

## Abbreviations

| | |
|---|---|
| AC | Alternating Current |
| CB | Circuit Breakers |
| CERTS | Consortium for Electric Reliability Technology Solutions |
| CSC | Current Source Converter |
| DC | Direct Current |
| DSM | Demand Side Management |
| DSP | Digital Signal Processor |
| DER | Distributed Energy Resource |
| DG | Distributed Generator |
| DSO | Distribution System Operator |
| DFIG | Doubly Fed Induction Generator |
| EMI | Electromagnetic Interference |
| EMS | Energy Management System |
| IPP | Independent Power Producers |
| IGBT | Insulated-Gate Bipolar Transistor |
| IGCT | Integrated Gate-Commutated Thyristor |
| ICE | Internal Combustion Engine |
| LC | Local Controller |
| LV | Low Voltage |
| MC | Matrix Converter |
| MO | Market Operator |
| MV | Medium Voltage |
| MCC | Microgrid Central Controller |
| PAM | Pulse-Amplitude Modulation |
| PMSG | Permanent Magnet Synchronous Generator |
| PCC | Point of Common Coupling |
| PoC | Point of Coupling |
| PWM | Pulse Width Modulation |
| SCR | Silicon Controlled Rectifier |
| SCIG | Squirrel Cage Induction Generator |
| SMES | Superconducting Magnetic Energy Storage |
| VSC | Voltage Source Converter |
| WRIG | Wound Rotor Induction Generator |
| WRSG | Wound Rotor Synchronous Generator |
| ZCS | Zero Current-Switching |
| ZVS | Zero Voltage-Switching |

## Microgrid and Its components

### *Microgrid Definition*

A microgrid can be defined as a group of loads connected to distributed energy resources and storage systems within clearly defined electrical boundaries that can act as a single controllable entity with respect to the main grid [1]. Another definition is given by the Consortium for Electric Reliability Technology Solutions (CERTS), which defines a microgrid as an aggregation of loads and micro-resources operating as a single system providing both power and heat [2]. In the above definitions, micro-resources include storage systems. Distributed Energy Resources (DER) refer to distributed generation plus demand-side measures.

The lack of investments in new transmission capacity to cope with the growing demand, the advances in small-size generation technologies, the need to increase penetration of renewable energy generation in existing power system have made microgrids an important candidate in the future power system. Microgrids provide a better way to fully exploit energy resources while offering more flexibility and economic benefits which would be impossible to achieve by individual Distributed Generators. According to the definitions given in Chap. 4, microgrids concepts are typically adopted for management of a set of distributed small-size generators and loads connected by a local distribution network (the case of decentralized systems with a single generator can also be considered a particularly simplified microgrid). In any case, when dealing with off-grid microgrid, i.e., microgrid not connected to an external distribution system, the main issues are related to the balance of the load and to the voltage control. When the microgrid is connected to and external distribution grid, the microgrid concept enables one to consider it as a single entity that can respond to central control signals, providing also ancillary services to the Distribution System Operator (DSO) [3, 4].

The important features that should be drawn from the above definition so as to distinguish a microgrid from a single decentralized generator are the following:

- it is able to provide power and energy reliably to a significant portion of its load demand;
- it has its own internal control and optimization scheme;
- it may or may not operate in connection with the main grid;
- it can be used as a flexible controlled entity to provide ancillary services for the main grid or the energy market;
- it has storage capacity;
- it may be connected to various voltage level depending on size and its layout, location of generators, proximity to the existing main-grid, required level of control and automation, and the network connection rules.

Three general classifications of possible microgrid architectures are presented [5]: utility microgrids, industrial/commercial microgrids, and remote microgrids, especially exploited in Developing Countries. Utility microgrids are under the control of DSO and are connected in urban networks or rural feeders. Industrial or commercial microgrids can be developed to ensure high degree of power quality and reliability for critical processes or loads in industrial and commercial centres. These microgrids are characterized by a Point of Common Coupling (PCC) that allows interaction which facilitates import or export of power from or to the external grid. However at some instances they may operate in islanded mode, i.e. completely disconnected from the main grid, for example when problems are affecting the DSO's network.

Remote microgrids are developed for remote communities and geographical islands. They are also referred to as isolated microgrid because they have no PCC to the utility grid. These represent a common option for rural electrification programmes in many Developing Countries, where grid extension is not feasible or too expensive. In some cases, remote area and islands have been powered by using a set of several larger diesel generators. Due to the increasing costs of fuel and concerns on environmental and climate issues, integration of small generation from available renewable sources and storage are considered as the most economical choice. This integration is typical of a remote microgrid.

In the following, reference will be made to Distributed Generation (DG) as a set of small-size generators connected to a set of loads within a microgrid by means of a local grid, according to the definitions give in Chap. 4.

## *Technologies for Distributed Generation*

A classification of DG technologies can be based on energy source (see Chap. 4). Another classification of DGs is based on their possibility to be dispatched, a feature which depends on the type of primary source of energy, technology and level of control implemented. The first class is dispatchable DGs, in which the produced power can be accurately controlled and dispatched in pre-programmed purchase agreements. Examples of DG which fall in this class include hydropower with basins, fuel cells, Stirling engines, and internal combustion engine-generators as well as many co-generation schemes (that can be subject to some operating constraints). For "non-dispatchable DG", the primary source of energy, often renewable, is site-specific and the energy produced cannot be controlled as it depends on the availability of the primary resource. Such DGs schemes are photovoltaic, run-off mini and micro hydro-turbines and wind turbines [6].

## *Storage Technologies*

Storage technologies are a key element for the balance of the power, which is a strict requirement of any electric system, including microgrids. Different technologies and requirements on storage can be considered for microgrid, according to its operating conditions. When a microgrid is operating in off-grid mode, the balance between generation and demand must be provided by the microgrid. Power generated from renewables is highly intermittent. Matching power generated with electricity demand of end-users makes it necessary the use of reliable, efficient and cost-effective energy storage systems. Other important applications of storage in microgrids include: improving voltage control, frequency control and stability of a microgrid, reducing outages, reducing spinning reserve requirements to meet peak power demands, reducing congestions and improving power quality and reliability for customers with high value processes or critical operations.

When the microgrid is connected to an external distribution system, the balance requirements become less strict, as the microgrid can import or export power from/to the grid. However, from the technical and economical point of view, its power management ability can still play a paramount role.

A classification of energy storage technologies in microgrids includes the following [7]:

- Mechanical (pumped hydro, flywheels, Compressed Air Energy Systems);
- Electrochemical (Secondary batteries: Lead acid/NiCd/NiMh/Li/NaS and Flow batteries: Redox flow/Hybrid flow);
- Chemical (hydrogen);
- Electrical [capacitors, supercapacitors, Superconducting Magnetic Energy Storage (SMES)];
- Thermal (Sensible, latent and thermochemical storage).

The choice of the economically viable technology for particular application depends on factors such as: required level of power and energy to be stored, power and energy density, and storage characteristics. The latter includes: life time, operation cycle, charging and discharging performance and environmental impact. For purposes of comparison, Fig. 5.1 illustrates the characteristics of various energy storage technologies and their possible application ranges, based on the duration of discharge and photovoltaic system power rating.

## *Loads*

The basic classification of electrical loads in microgrids not considering the details of their modeling is based on:

1. level of controllability: controllable (discretely or continuously) or non-controllable loads;
2. level of priority: critical or non-critical, deferrable.

The above classification is important in load modelling and implementation of algorithms for Demand Side Management (DSM) in microgrids [9, 10]. DSM

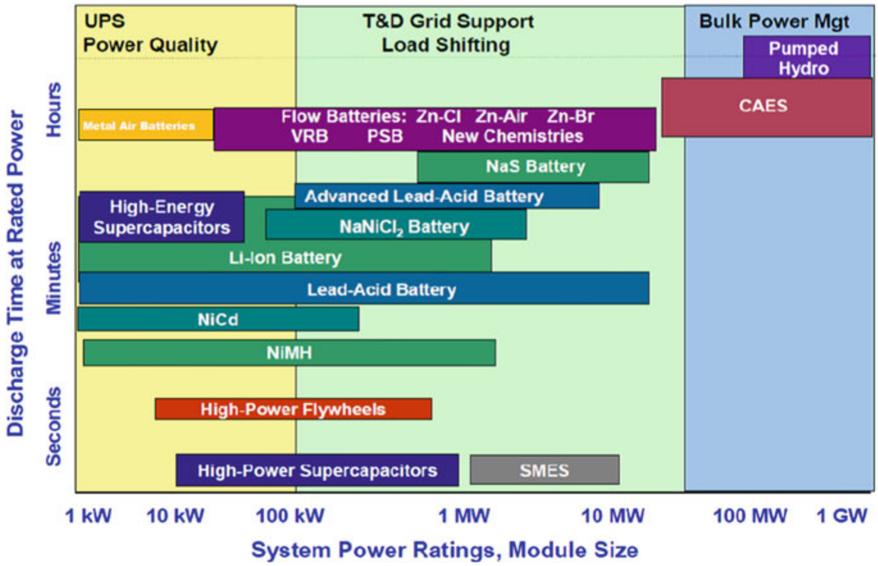


**Fig. 5.1** Energy storage technologies and their applications [8]

involves connection and disconnection of load from a microgrid so as to maintain its operation within satisfactory limits. Reconnection of loads is performed when the system recovers sufficient generation or when it is connected to the main grid. Disconnection (load shedding) is necessary when there is no sufficient generation available to supply the load within an island.

## Design of Microgrids

As mentioned, microgrids can be designed as a standalone or grid-connected systems. The standalone design is the only solution for remote areas or in Developing Countries when the community is not easily accessible by an external grid.

The main issue in designing off-grid microgrids is related to the power balance that must be guaranteed by a microgrid controller able to manage all DGs, storage resources and loads in such a way to:

- guarantee the power balance to control microgrid frequency at any time, ensuring a proper power reserve to face unexpected generation failures or load demand change;
- minimize load shedding, so enhancing reliability;
- exploit renewable sources, so reducing expensive and polluting electricity generation sources (e.g., diesel-based);
- ensure a proper voltage control.

Problems to be considered when designing a grid-connected microgrid can be managed by the functions described for off-grid microgrids, although with less strict requirements; however, new issues can be listed: protection issues such as change of short-circuit levels, reverse power flow, lack of the sustained fault current, and islanding; voltage control issues; harmonics and flicker; interconnection standards and grid codes.

The following are the main steps in the design of a microgrid:

1. identify site needs: critical facilities, distance from the existing electrical distribution system in place, if any;
2. assess resource to identify potential types of generation resources available on site;
3. demand assessment phase 1: classify loads to be served by the microgrid: AC/DC, thermal/electrical, critical/non-critical;
4. demand assessment phase 2: obtaining the demand profile of the microgrid and determine daily, monthly (seasonal) and annual peaks;
5. technological assessment to determine the optimal generation mix, suitable DGs technology and energy storage location, technology, and capacity;
6. evaluate and match the expected generation to the load to ensure that existing generation capacity meets the proposed peak load and daily operating requirements;
7. evaluate the ability of dispatchable resources to handle transient disturbances on the system while maintaining satisfactory voltage and frequency and assessing whether they can compensate for the variability of renewable resources;
8. develop control strategy: energy management system, DSM, utility interface, seamless transition, grid connected and islanded operation, communication systems, cyber and physical security, integration with existing protection and distribution automation systems;
9. determine equipment specifications and layout;
10. perform design analysis: detailed electrical model, power flow, dynamic stability, short-circuit. The analysis includes modeling and simulation of the microgrid under various scenarios to validate performance of the microgrid;
11. prepare request for proposal;
12. proceed with interconnection agreements, tendering and construction.

The design of microgrid involves optimization, modeling and simulation processes. These processes are necessary because the design presents a multi-facet problem of greater complexity. Issues such as installation cost, environmental impact, system limitations, grid connectivity, reliability, resource longevity, reuse of waste heat, capacity for intentional islanding, and other physical constraints are to be considered. The designer has to deal with a mix of both traditional and new generation equipment with diverse technologies. Also, integration of renewable technologies should fulfill all grid standards. Such integration requires advanced control for successful operation. Economic and technical detailed studies can be performed by using appropriate commercially available design tool summarized in Table 5.1, along with their main features.

**Table 5.1** Tools for economic and performance analysis in microgrids

| Tool | Total system cost | Component cost | Performance analysis |
|---|---|---|---|
| HOMER | Yes | Yes | Yes |
| DER-CAM | No | No | Yes |
| Hybrid2 | Yes | Yes | Yes |
| ESM | Yes | Yes | Yes |
| RETScreen | Yes | Yes | Yes |
| HOGA | Yes | Yes | Yes |

After the cost effective system has been identified and its components sized, other specialized power system analysis programs (PSSE/E, PSLF, PSCAD, DigSilent, etc.) can be used to assess the operability of the microgrid, in both off-grid and connected operation. They typically can carry out power flow analysis, stability computations, short-circuit analysis, among the others.

More complex systems will require a combination of simulation, design and optimization software such as MATLAB/SIMULINK®, GAMS® and AMPL®.

## Configurations of Grid-Connected Microgrid

Figure 5.2 shows a microgrid connected to the main grid at the medium voltage (MV) distribution network level.

The bus of electric network where the microgrid is connected to the main grid is called Point of Common Coupling (PCC). This point is very important, because it determines the grid equivalent impedance as seen by DGs in the microgrid and it is the main location to monitor the dynamic behaviour of a grid connected microgrid. From the PCC, the microgrid can be considered by the main grid as a single

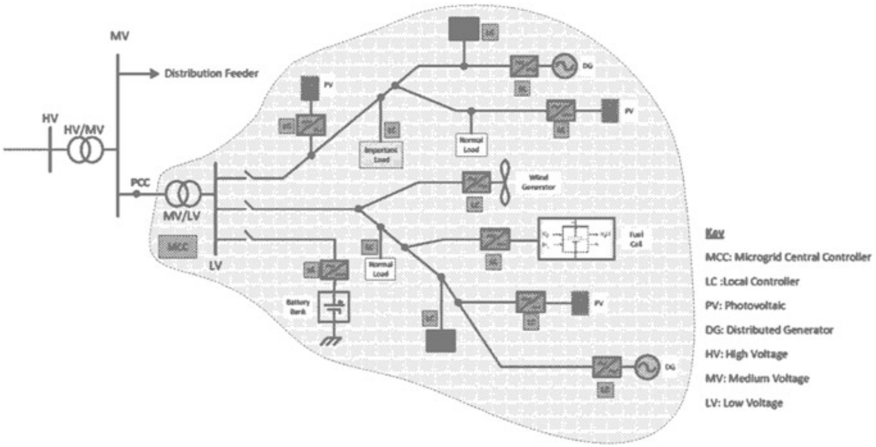


**Fig. 5.2** Grid connected microgrid

controllable unit [11]. At this point, the microgrid must fulfil all interfacing requirements as defined in existing standards.

Most of the connections are realized in distribution networks at medium voltage (MV) and low voltage (LV) level. The voltage level at which the microgrid can be connected to the distribution network largely depends on its size, its layout, the location of generators, its parameters, the degree of control of each dispatchable load and DG, and the proximity and distribution of load. However, different countries specify network connection rules for MV and LV level depending on the regulation and operational technology adopted by the DSO.

## *Reasons to Connect to the Main Grid*

One of the main reasons for connecting a microgrid to the main grid is to guarantee a good reliability level of electricity supply for the loads supplied by the microgrid: actually, in case of perturbations on the DSO's grid, the microgrid can be disconnected and continue its operation in off-grid mode, thus preventing microgrid loads to be affected by that perturbation. If the microgrid reliability is higher than the external grid reliability, that is particularly true in developing countries, the overall reliability for loads increases. This is why standards require that microgrid has ability, during main grid disturbance, to isolate itself from the main grid seamlessly, with little or not at all load shedding within the microgrid. When the main grid returns to normal operation mode, the microgrid should automatically and seamlessly synchronize and reconnect itself to the main grid. When fulfilling these features, a grid connected microgrid can guarantee high level of power availably and reliability required by the customers. Connection to the main grid can improve stability and power availability only if the main grid is a strong source to the microgrid.

Grid connection enables also purchasing of power from the main grid when electricity costs are low as well as selling electricity to the market, when it is possible and/or electricity price is high enough. Grid-connected microgrids form an active power system with a bidirectional flow of power. That is, when there is a surplus of generation in the microgrid, surplus power is injected into the main grid. However, in the case of low generation or high load, the difference between power demand and generation is withdrawn from the main grid. Therefore, grid connection offers opportunity for both DSO and independent power producers (IPP) to participate in liberalized electric market [12]. Another economic reason to consider connecting a microgrid to the main grid is the possibility of reducing the sizing of storage and DGs in the design stage. Grid connection can alleviate the need for energy storage in the microgrid which will substantially reduce the investment costs, as the grid itself can be considered, when connected, as "infinite storage".

The proximity of microgrid to the load centers reduces both losses and congestion in transmission and distribution network. A grid-connected microgrid presents a sustainable solution to meet the growing demand without substantially changing the existing transmission and distribution network or deferring the needed investments. Upgrading the existing transmission and distribution systems is expensive and time consuming process. Furthermore, locating the DGs close to loads enhances the voltage profile in distribution network, providing further control variables.

Connection of microgrids to the main grid offers high degree of operational flexibility while guaranteeing the demand. The flexibility is achieved by using power electronics switches with bidirectional current flow capability in the grid interconnection devices. This is why we referred to the grid-connected microgrid as "active power system" in contrast with the conventional distribution networks which were passive networks [13]. To explore this flexibility, various advanced optimization algorithms have been employed to operate grid-connected microgrid with different objectives and constraints. Typical objectives are: maximize generation from renewable energy resources, minimize the cost of energy to the local consumers and reduce emissions [14, 15].

In particular, for developed countries, the reasons for connection could be: reduce dependency on conventional power resources, reduce emissions and environmental impact, liberalize the electricity market, improve the quality and reliability of power, increase system security by distributing the energy plants instead of concentrating them in few locations (making them easy targets for terrorist attacks), meet the growing demand while reducing transmission costs and losses, and increase generation from RES which is a typical policy issue [16, 17].

Developing countries consider microgrids for rural electrification of remote communities. The design simplicity and cost efficiency weighs more than the benefits of having an expensive but sophisticated control system. It is recommended that the planning of isolated microgrids should anticipate future grid connection [18]. Various cases exist where the development of economic activities has facilitated grid extension to these remote areas. In this case, it is more economical to connect eventually the microgrid to the main grid in order to lower the cost of energy and increase reliability of the supply.

## *Interconnection Switch*

A microgrid can be connected to the utility grid through an interconnection switch which can be implemented using one of the following methods:

1. MV/LV Circuit Breakers (CB),
2. Static power electronic switches:
   - Silicon Controlled Rectifier (SCR) based static switches, and
   - Insulated-Gate Bipolar Transistor (IGBT) or Integrated Gate-Commutated Thyristor (IGCT) based static switches.
3. Power electronic interfacing converters.

The first method uses power CB to physically disconnect the microgrid from the grid. It is relatively simple and cheap but has slow response to achieve complete disconnection (3–6 cycles). The slow response can result in missing the timing requirements to allow loads transition between sources [19]. However, this is the predominant device being installed to date.

The second method uses SCRs in antiparallel configuration to allow bidirectional power flow. This method is much more expensive and complex. However, it offers much faster switching response (0.5–1 cycle). To attain fast switching and more control flexibility, IGBT/IGCT-based static switches can be adopted. IGBT-based switches can respond with an operation time in the 100 μs time range. Moreover, they can clamp the instantaneous currents and turn-off in a very short timeframe. Higher interconnection voltage levels can be achieved by using gate turn-off thyristors or IGCTs in place of the IGBTs. However, neither of these two configurations can offer the control of real and reactive power. In this case, power electronics devices serve for switching purposes only. The typical circuit configurations for first and second interconnect switch technologies for the microgrids are shown in Fig. 5.3 [20]. Practical implementation combines various power and switching functions into a single system with a Digital Signal Processor (DSP) [13, 21].

A third method for connecting a microgrid to the utility grid is by using power electronic interfacing converters. The state of the art on this method involves the use of a back-to-back converter. The back-to-back converter is made up of two conventional pulse-width modulated (PWM) VSC-converters with their DC sides connected through a common centre DC-link capacitor. Bidirectional power flow and the control of real and reactive power transfer between the utility and microgrid is achieved by controlling both VSC-converters [22, 23]. Figure 5.4 shows the power circuit for back-to-back converter and its configuration for connecting a microgrid to the utility grid.

The use of heavy and bulky DC-link capacitor in back-to-back converter presents some drawbacks such as increased costs and reduced converter overall lifetime. Another drawback of the back-to-back converter is the high switching losses associated with the use of hard switching and natural commutation [24]. These disadvantages are the reasons for the on-going research on possible application of other converters for microgrid interconnection switch. Possible candidates under consideration are: multilevel converters, tandem converters, matrix converters and resonant converters. A brief description of each of these converters is provided in [25–30].

Both the second and third methods use static switches which introduces devices conduction losses. Still, these methods may require additional CBs and bypass switches to achieve full galvanic isolation for safety and maintenance reasons. Depending on the switch technology, momentary interruptions may occur during transfer from grid connected to islanded mode. High-speed switches are used to allow fast system transition and ensure high reliability. This requires measuring the voltage on both sides of the switch to allow synchronization of the island and the utility.

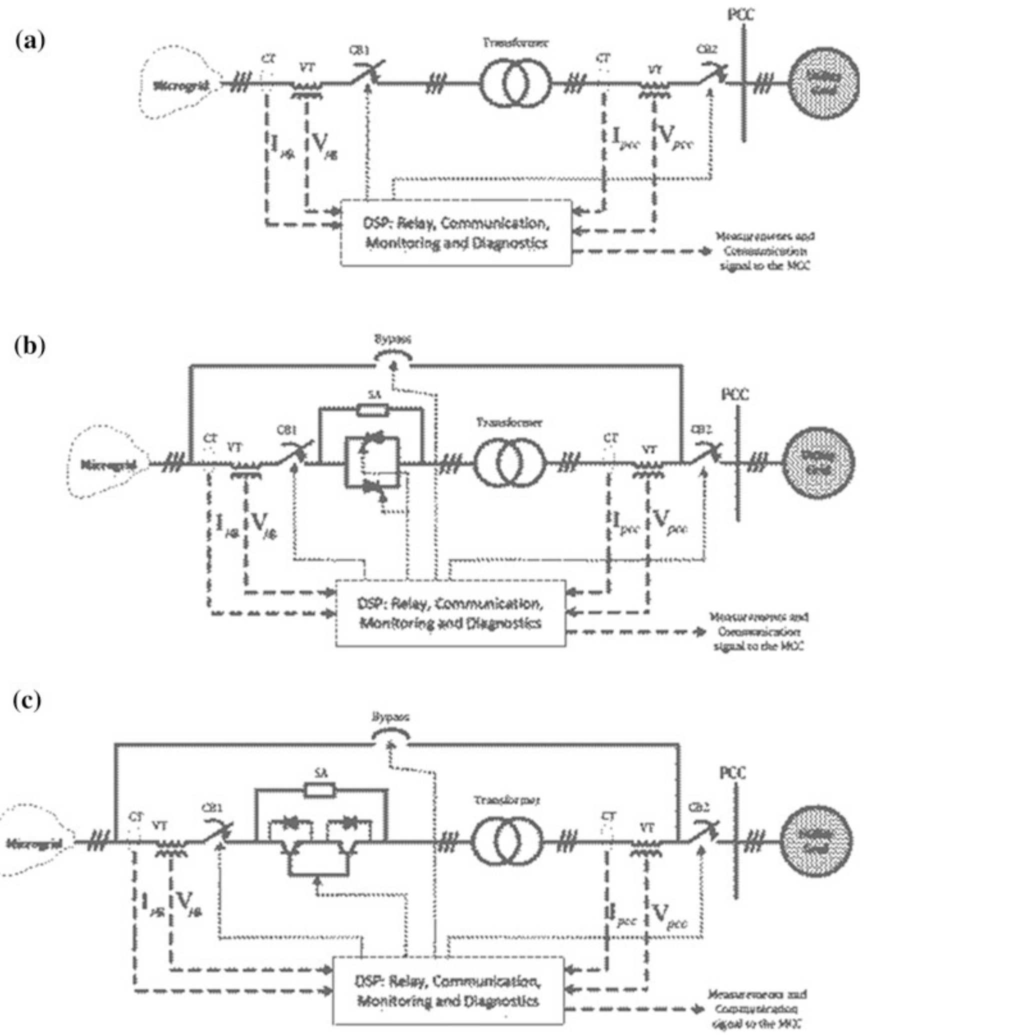


**Fig. 5.3** Microgrid interconnect switch. **a** CBs technology, **b** SCRs technology, and **c** IGBTs technology

Selection of the switching technology for connecting the microgrid to the utility grid depends on: type of microgrid, characteristics of microgrid components, voltage level at the PCC, main grid (strong or weak) and interconnection requirement as specified by standards. These factors are important in establishing the requirements of the CB, or power electronic static switches which will be used to implement the connection to the main grid. Similar case applies to the selection

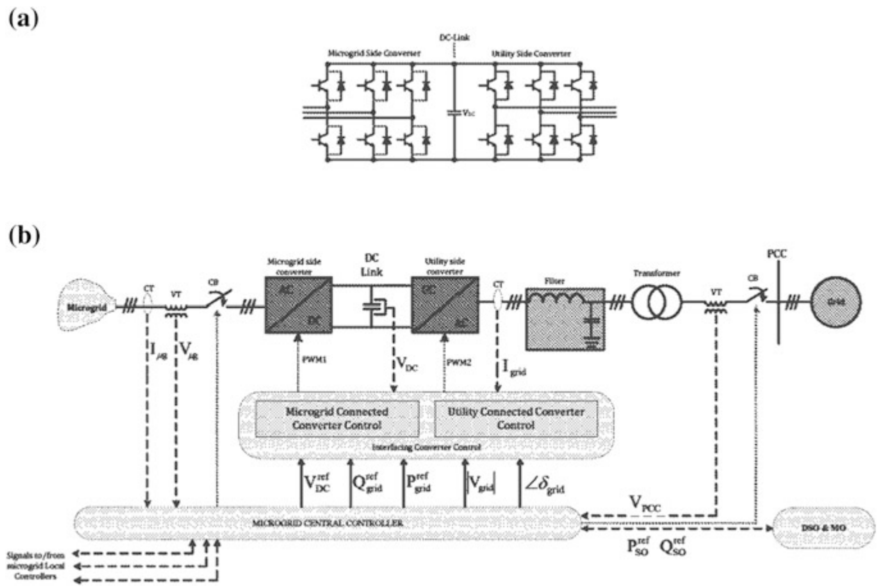


**Fig. 5.4** Back-to-back converter **a** power circuit **b** configuration for connecting a microgrid to the utility grid

of the back-to-back converter whose size depends on the maximum power transfer between the microgrid and the utility grid.

## *Standards for Connecting Microgrid to the Main Grid*

The IEEE 1547.4 [31] and IEC 61850-7-420 [32] are the main standards that specify various aspects of connecting microgrids to the main grid. The first includes requirements for design, operation, and integration of island systems with electric power systems. Among other issues, this standard was specifically developed to cover intentional islanding in microgrids which are connected to the electric distribution systems. The second defines information models to be used in the exchange of information with DER, which comprise dispersed generation storage devices. The extension to the general IEC 61850 was issued to solve the interoperability problems in power utility automation.

As already anticipated, grid connected microgrids can operate in four states: normal operation in parallel to the main grid, transition-to-island, island operation, and reconnection to the main grid. The microgrid control must be able to recognize that intentional or unintentional island state has occurred and operating disconnected from main grid. Islanding refers to a condition in which a microgrid disconnected from the main-grid and is energized only by its own distributed energy sources. An intentional islanding can result from intentional events for which the time and duration of the planned island are agreed upon by DSO and microgrid operator.

Islanding process involves two main phases:

1. transition from grid connected to island operation;
2. operation isolated from the grid (islanded mode).

Standards require that, during the transition from grid connected to island operation, voltage disturbances are quickly damped and protection systems on both microgrid and main grid sides remain unaffected.

In islanded mode, as well as in off-grid systems, the control system in the microgrid must maintain voltage and frequency for the entire islanded system. In this mode, the microgrid must generate sufficient real and reactive power as required by the loads in each phase [31]. To balance the load and generation within the islanded microgrid, various techniques (e.g., load-following, load management, and load shedding) can be used. Load following refers to the ability of the DG to be dispatched in a manner which follows short-term changes in the load. This capability depends on the DG's ramp rate and dispatch flexibility. Demand side management can be described as any actions taken on consumers' side to optimize energy consumption. It can be implemented in the following ways: peak clipping, valley filling and load shifting. Load shedding is a process in which a certain amount of load is instantly removed from the microgrid to keep it in operation with the remaining portion of load. Load shedding is the ultimate solution when all available controls are unable to maintain the operational security of the microgrid following a disturbance or contingency.

Another important issue in islanded microgrid is maintenance of sufficient reserve margin and storage management. The amount of the reserve margin depends on the load factor, the magnitude of the total load, and of each load, the load pattern, reliability requirements of the load, and the availability of DGs.

Reconnection must be done when the voltage, frequency, and phase angle between the main grid and microgrid are within acceptable limits. In this case it is very important to know which kind of switch is installed at PCC. The ability of the switch to provide a range of interconnection speeds allows flexibility to match application requirements. Depending on the switch technology, various reconnection speeds and levels of automation can be met. For example, Table 5.2 presents synchronization parameters as specified in [33]. However, it is possible to find slight variation of these limits due to regulatory requirements and requirement of DSO in different countries.

Standards specify three ways to reconnect the islanded microgrid back to the main grid: active synchronization, passive synchronization and open transition transfer [31].

In the active synchronization, a control mechanism is used to match the voltage signal on both sides of the PCC immediately before closing the interconnection switch between the microgrid and the main grid. Implementation of this approach

**Table 5.2** Synchronization parameter limits between microgrid and distribution system

| Aggregate rating of DG units (kVA) | Frequency difference ($\Delta f$, Hz) | Voltage difference ($\Delta V$, %) | Phase angle difference ($\Delta\Phi$,°) |
|---|---|---|---|
| 0–500 | 0.3 | 10 | 20 |
| >500–1500 | 0.2 | 5 | 15 |
| >1500–1000 | 0.1 | 3 | 10 |

requires measuring amplitude, frequency and phase angle of the voltage on both sides of the PCC and communications channel in order to exchange information between the micro-grid and the main grid. On the other hand, passive synchronization monitors the voltage at both sides of the PCC and allows reconnection if the synchronization requirements for voltage, frequency, and phase angle are within a certain range to ensure minimum disturbances. In this method the controller does not match the synchronization parameters. Likewise, passive synchronization requires sensing and communications, leading to the same potential reliability concerns encountered in the active synchronization method. However, this method may be slower than active synchronization. The third synchronisation approach, open transition, involves interruption of the loads served by microgrid. The load and DGs are de-energized before reconnection to the main grid. The loads are reconnected back after the microgrid is connected to the main grid.

The following are typical standard microgrid requirements:

- in the grid connected state, the microgrid, considered as a single controllable unit, must not actively regulate the voltage at the PCC;
- the grounding approach chosen for the microgrid interconnection must not create over-voltages that exceed the ratings of the equipment connected to the main grid or must not affect ground fault protection coordination in the main grid;
- the DGs in the microgrid must be able to parallel with the main grid without causing voltage fluctuations at the PCC greater than specified percentage of the prevailing voltage level of the distribution network at the PCC;
- microgrid shall not create flicker for other customers on the utility system; comprehensive standards for assessing flicker levels on utility system are provided in [34];
- the microgrid must not energize the main grid when the main grid is not energized, particularly when a fault occured in the distribution network to which a microgrid is connected has not been cleared;
- the DGs, which are interfaced in a microgrid by power electronic converters, must not inject into the microgrid a DC current component greater than a specified percentage of their full rated output current;
- harmonic current injection from the microgrid into the main grid measured at the PCC must not exceed certain levels both in total and for given harmonic order ranges;

- the interconnection system must meet applicable surge and Electromagnetic Interference (EMI) standards.

The above requirements vary from country to country and depend on the way a particular standard is adopted to suit the existing power system. For example, the IEEE 1547.4 standard limits voltage fluctuation at PCC to ±5 %. Also it is specified that a microgrid must "not inject DC current greater than 0.5 % of the full rated output current" at the PCC. These requirements may vary depending on the stability and protection system of the distribution network.

Realization of both the microgrid and its management system require a comprehensive look into all standards issues addressed in this section. Interaction between the main grid and microgrid with its components should follow communication standards for interoperability such as those addressed in [32]. Together with the local regulations, one should consider aspects such as islanding, energy management, operation mode transitions, control strategies, restoration after disturbances, protection, safety considerations, maintenance, testing, monitoring, information exchange, and power quality [35–37].

## *Interfacing Technologies*

Interfacing technology is a twofold issue: first, interfacing of DG to the microgrid itself and second, interfacing of the microgrid to the main grid. We have discussed the second aspect of interfacing in the previous section. Technologies employed to interface DG to the microgrid are summarized in Table 5.3. In this section, we

**Table 5.3** DGs interfacing technologies

| Type of DR device (prime mover or primary energy source type) | Power generation | Typical grid interface method |
|---|---|---|
| Internal combustion engines | Synchronous generators | Direct/transformer |
| Combustion turbines | Synchronous generators | Direct/transformer |
| Microturbines | Inverters or induction generators | DC-AC inverter/back-to-back (AC-DC-AC) converter |
| Mini/micro hydro | Synchronous or induction generators | Direct/transformer/back-to-back (AC-DC-AC) converter |
| Fuel cells | Chemical reaction | DC-AC inverter |
| Wind turbines (wind) | Synchronous or induction generators | Back-to-back (AC-DC-AC) converter |
| Photovoltaic (solar) | Photovoltaic | DC-AC inverter |
| Battery, ultra-capacitor, high speed flywheel, or superconducting magnetic energy storage (SMES) devices | Electrochemical, electrical, mechanical or thermal storage | DC-AC inverter |

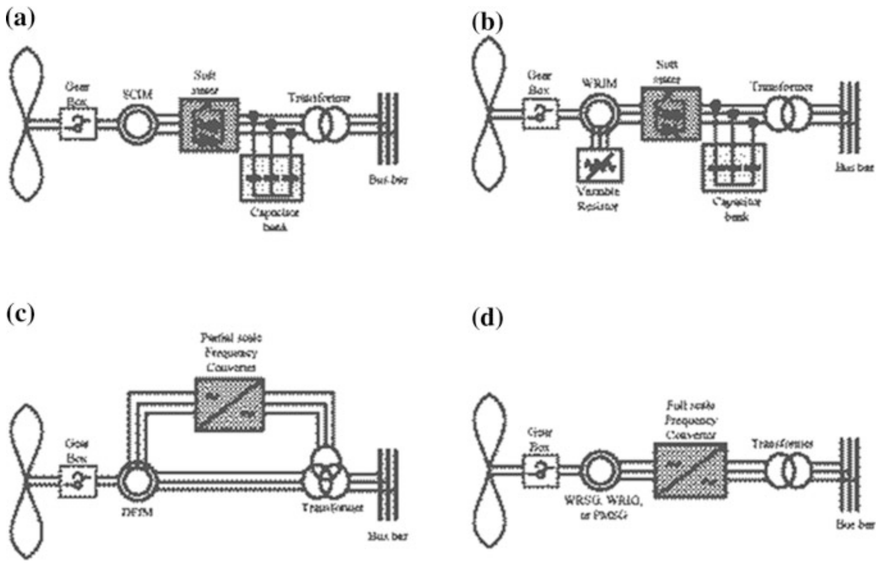


**Fig. 5.5** Common wind turbine types: **a** Constant-speed wind turbine (*Type A*), **b** Limited variable speed (*Type B*), **c** Variable-speed wind turbine with doubly fed induction generator (*Type C*), and **d** Direct-drive variable-speed wind turbine with multi-pole synchronous generator (*Type D*)

focus on the interfacing of RES-based DGs: namely, wind and PV, since other technologies are well documented in many references.

Typical configurations for interfacing renewable based DGs into the microgrid are presented in the following. Figure 5.5 shows the configurations of wind energy conversion systems [38, 39].

Characteristics for the four typical wind energy technologies are summarized in Table 5.4 [40–42].

The state-of-art configurations of a PV generation systems into the microgrid are shown in Fig. 5.6 [43, 44].

The multistring structure is the preferred architecture for microgrids, because it combines the advantages of centralized and string PV converter technologies. It offers several advantages: ability to use low rating devices, low specific costs of PV converter, minimum costs of PV system installation, high MPPT efficiency, voltage step-up and maximum power point tracking that can both be achieved by the DC/DC converter that is connected to each string, reduced power losses and modular extendibility. Relying on a central DC/AC inverter, this solution is characterised by lower reliability and scaling-up of the system. In order to realise high efficiency, flexible control, high reliability and excellent scalability, a modular system configuration shown in Fig. 5.7 is proposed in [44].

Interfacing of DGs to the microgrid must ensure safe and reliable operation, proper voltage regulation, frequency control, and power quality conditions on the

**Table 5.4** Characteristics of typical Wind Conversion Energy Systems

| Characteristics | Type A WCES | Type B WCES | Type C WCES | Type D WCES |
|---|---|---|---|---|
| See Fig. 5.5 | (**a**) | (**b**) | (**c**) | (**d**) |
| Generator type | SCIG | WRIG | DFIG | WRSG, WRIG, or PMSG |
| Speed control | Fixed speed (1–2 %) | Depends on the size of the variable rotor resistance. Power electronics can be applied to control the magnitude of the WRIG rotor current. Typically, the speed range is 0–10 % above synchronous speed | Variable speed approximately 40 % up and down speed variation | Full variable speed |
| Frequency control | No | No | Yes, partially | Yes, fully |
| Active power control | Very limited, the output fluctuates as wind speed varies. Use Pitch or stall control | Limited, use pitch or stall control (also via rotor speed control) or power electronics to control rotor current | Use pitch or stall control, variable-speed generator and power electronic converter | Use pitch or stall control, variable-speed generator and power electronic converter |
| Reactive power control | No | No | Yes | Yes |
| Reactive power compensation | Use capacitor banks or static compensation devices: SVC or STATCOM | Use capacitor banks or static compensation devices: SVC or STATCOM | Use partial scale frequency converter, normally back-to-back IGBT power converter | Use full-scale frequency converter, normally back-to-back IGBT power converter |
| Voltage ride-through (VRT) capabilities | Some of them have limited VRT capability and may require a central reactive power compensation | Yes, but limited | Yes | Yes |
| Reactive power during VRT | Cannot be provided | Cannot be provided. May need extra devices power factor correction capacitors | Not always extra device needed (a crowbar) | Can fully provide it through power converter |

*Note SCIG* Squirrel cage induction generator, *WRIG* wound rotor induction generator, *DFIG* doubly fed induction generator, *WRSG* wound rotor synchronous generator, *PMSG* permanent magnet synchronous generator

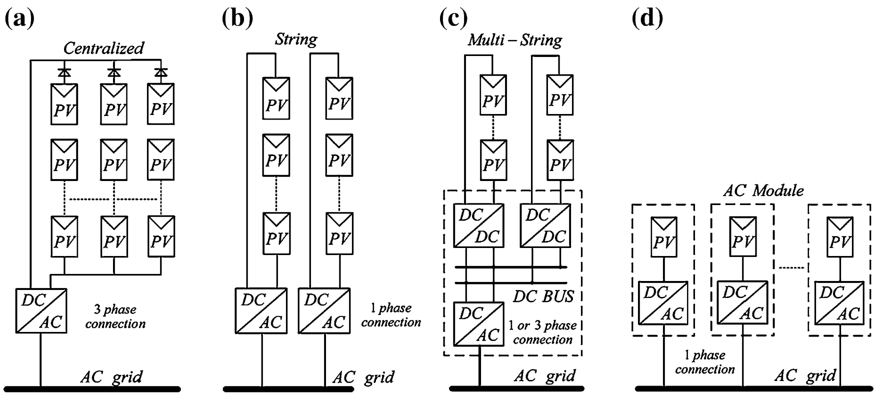


**Fig. 5.6** Overview of the configuration of PV generation system. **a** Centralized technology. **b** String technology. **c** Multistring technology. **d** AC module technology

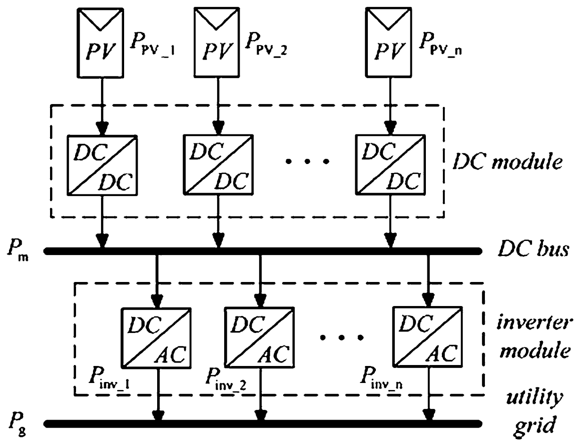


**Fig. 5.7** Multistring configuration with modular grid-connected DC/AC converters

microgrid. These DGs must be able to operate in all possible operation modes of a microgrid. Examples of common microgrid operation modes include [45]:

- parallel operation with a strong utility system;
- parallel operation with a weak utility system connection;
- operation as the only source on islanded or standalone microgrid;
- operation as one of many dispersed sources on islanded or standalone microgrid;
- operation on a dynamically changing microgrid states: transition from grid-connection to island and vice versa.

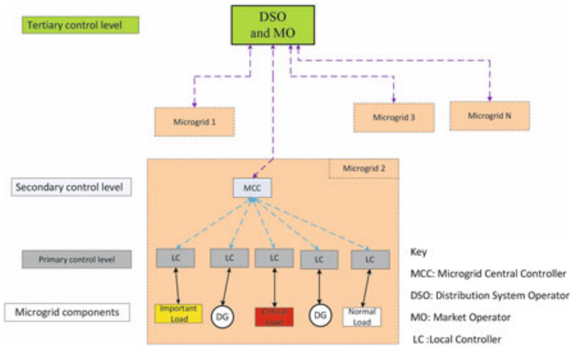


**Fig. 5.8** Centralized energy management architecture for microgrids

## *Management and Control for Grid-Connected Microgrid*

The management and control of microgrid is achieved by using an intelligent supervisory control system which ensures proper operation in all operational modes. Standards require a robust control responsible for smooth transferring of the microgrid from grid-connected to island operation. Common control strategies include centralized and decentralized control strategy. The choice depends on the ownership and regulatory policies applied to a specific microgrid. So far, the Centralized Energy Management System (EMS) is the most widely adopted approach (Fig. 5.8).

The centralized control system for microgrid can adopt hierarchical-type three-level management and control [46, 47]:

1. Distribution System Operator (DSO) and Market Operator (MO);
2. Microgrid Central Controller (MCC);
3. Local Controllers (LC).

In the grid connected mode, the DSO and MO determine the operational and market requirement for the distribution network in which more than one microgrid might be in operation. In this mode, the MCC performs optimization based on reliability, economics of local generation versus grid supply and demand, so as to continuously determine appropriate set points for the individual generators, storage elements, and loads in the microgrid. These set points are transferred to the LCs which control the operation of DGs, storage devices and dispatchable loads. The LCs interact with the MCC to exchange current local operational constraints and conditions. Depending on the technology, the LCs may have a certain level of intelligence to enable some control operations to take effect independently of the MCC. The following control functions are incorporated within the LCs:

- active and reactive power control;
- voltage control;
- charging and discharging of storage devices;
- load sharing through P-f control.

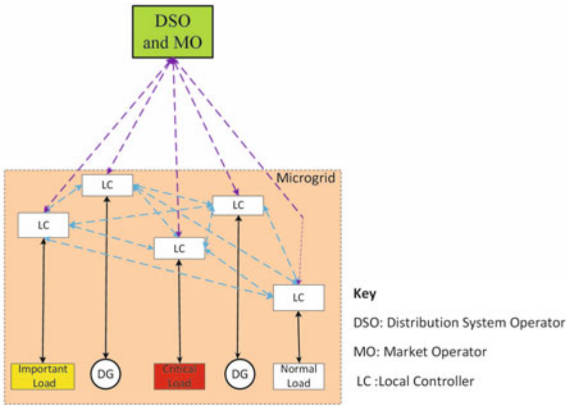


**Fig. 5.9** Decentralized energy management architecture for microgrids

These functions enable each DG in the microgrid to adopt new operating conditions based on the operational mode of the microgrid. For example, in the transition from the grid connected to islanding operation each DG must simultaneously modify its load share according to the amount sent out by the MCC. The above control functions are implemented through power electronic inverters, the dominating interfacing converters for renewable based DGs.

In the islanded mode, the MCC optimizes the set points for generators, storage devices, and loads based on balance requirement between load and generation. Often, renewable energy-based DGs will be operated at maximum power point to maximize their generation. Dispatchable DGs, which are capable of producing controlled real and reactive power on demand, are assigned the task of regulating the voltage and frequency. With this reference, the LCs of each DG perform frequency-droop and voltage-droop control to enable sharing of real and reactive power components among all DGs, whenever possible depending on the primary source and on the technology.

Decentralized EMS adopts a strategy in which a microgrid component is controlled by its own LC. This LC derives its control decision after communicating to the nearby LCs instead of being governed by the MCC (Fig. 5.9). The neighbouring LCs communicate and reach a consensus on optimal set points of the parameter under consideration before effecting the control action [48]. In this scheme, LCs have the intelligence to make operational decisions without the central master controller. Decentralized EMS avoids single point failures and guarantees stable operation, system re-configuration and replication following availability of primary sources of energy.

## Droop Control

Figure 5.10 shows a single phase equivalent circuit of the inverter based DG unit connected to an AC bus in the microgrid. We refer to this bus as point of coupling

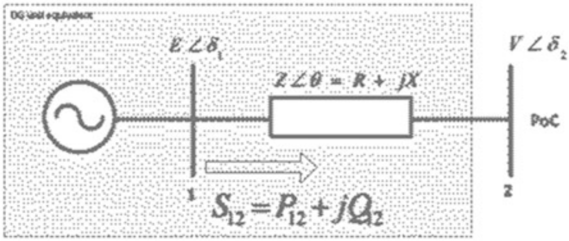


**Fig. 5.10** DG unit connected to the common ac bus in the microgrid

(PoC) of that DG. This should not be confused with the PCC, the common bus in which the whole microgrid, considered as a single controllable unit, is connected to the main grid.

It is well known [49] that, under usually valid assumptions:

$$\delta \cong \frac{XP_R}{EV} \tag{5.1}$$

$$E - V \cong \frac{XQ_R}{V} \tag{5.2}$$

where $E$ is the amplitude of the interfacing inverter output voltage, $V$ is the common bus voltage, $\delta = \delta_1 - \delta_2$ is the power angle, and $X$ is the reactance of the output impedance.

Under such assumptions, it is clear that the power angle mainly depends on the active power, whereas the voltage difference mainly depends on the reactive power. Therefore, the power angle $\delta$ or the frequency, proportional to its derivative, can be used to control the active power $P_R$ whereas the inverter voltage E can be used to control reactive power $Q_R$ [50]. To achieve the overall system equilibrium, the DGs are controlled based on the produced active and reactive power. Using this approach, droop control is implemented based on [51]:

$$f - f_o = -k_{fP}(P - P_o) \tag{5.3}$$

$$V - V_o = -k_{vQ}(Q - Q_o) \tag{5.4}$$

where $P$ and $Q$ are the inverter active and reactive power outputs, $k_{fP}$ and $k_{vQ}$ are the f-P and V-Q droop slopes (positive quantities), $f_o$ and $V_o$ are the rated values of the frequency and voltage, $P_o$ and $Q_o$ are the set points for the active and reactive power respectively. These characteristics are shown in Fig. 5.11. The DG will be forced to generate P and Q based on the adopted droop values of $k_{fP}$ and $k_{vQ}$. The droop coefficient $k_{fP}$ can be calculated using the required values of minimum and maximum frequency and the rated real power output of the DG. Similarly, $k_{vQ}$ can be calculated using the minimum and maximum voltage levels and the DG rated reactive power output.

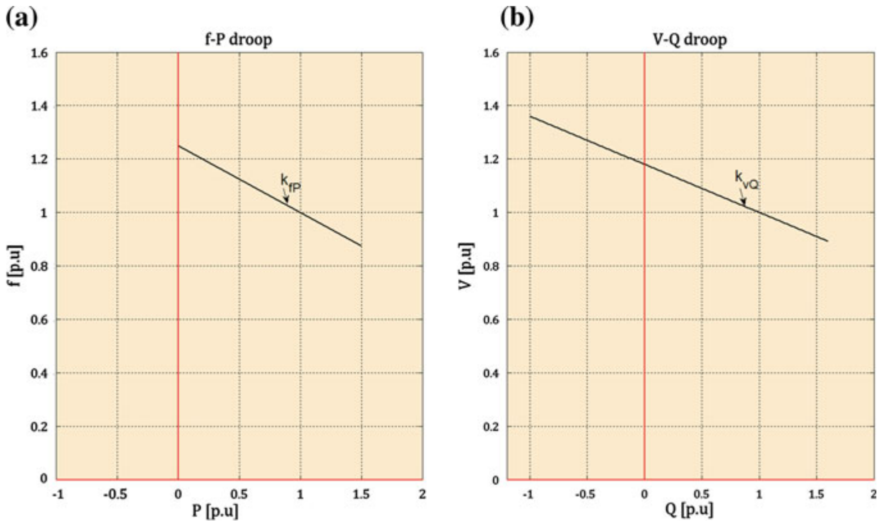


**Fig. 5.11** Inverter interfaced DG droop characteristics: **a** f-P droop, **b** V-Q droop

This method allows each DG to take up share of the total load according to its frequency droop characteristics. By utilizing the system frequency as a communication link between the LCs, communication signals are no more needed [52].

Often, microgrids contain low-voltage distribution lines which are mainly resistive. Due to the high R/X ratio of these networks, the real and reactive powers are less decoupled. In this case, the previous assumption of two separate conventional droop controls, for the real and reactive power is not valid anymore. On the contrary, X may be neglected instead of R and the droop regulation defined by Eqs. 5.3 and 5.4 is no longer effective, since adjusting the active power P influences the voltage amplitude while adjusting the reactive power Q influences the frequency. In the general case, both X and R have to be considered to regulate the voltage and the frequency droop optimally.

Improvements on droop control method consider the resistive nature of LV line and the fact that the output impedance of the inverter depends also on its control strategy. A control scheme that improves the steady-state and transient response of parallel connected inverters without using communication signals is presented in [53]. Also, it is worth to consider the comparison between frequency and angle droop control method. Angle droop control enables DGs to share real power in proportion to their rating without a significant drop in the system steady-state frequency. Frequency variation with the frequency droop control is significantly higher than that with the angle droop control [54].

## Protection Issues for Microgrids

It is necessary for the microgrid protection system to be able to distinguish and respond to both main grid and microgrid faults. For the main grid faults, rapid isolation of the microgrid from the main grid is required, in order to protect its loads. In case of the fault in the microgrid, protections should isolate the smallest possible section of the radial feeder to eliminate the fault in the microgrid and maintain continuity of supply to the section unaffected by the fault. Technical challenges presented by these new requirements for the microgrid protection include [55, 56]:

- changes in the magnitude and direction of short-circuit currents;
- reduction of fault detection sensitivity;
- undesired tripping of protection due to faults on adjacent feeders;
- unnecessary tripping of utility breaker;
- fault ride through capabilities;
- coordination setting and management;
- fault detection in islanded operation (with low short circuit power);
- automatic re-closure issues;
- topological changes in microgrid network;
- intermittence in the generation.

Some of the above issues are considered in the following.

A strong main grid can provide sufficient fault current to feed a fault in the microgrid. However, in islanded operation the fault current is drawn from the DGs. Often, microgrid DGs are not able to provide a sufficient level of short-circuit current in the islanded operating mode. The fault current level which can be drawn from the DG depends on its type, size and location.

Selection of protection technique depends very much on the microgrid architecture. Various techniques have been proposed to address microgrid protection challenges. Adaptive microgrid protections use advanced communication systems, real-time measurements and data from off-line short-circuit analysis, to adapt the relay settings to the microgrid state (topology, generation and load) [55]. Voltage based techniques mainly use voltage measurements, Park's transformation, positive sequence components, in order to provide an adequate protection system in microgrids in every operating condition. Differential protection techniques, in which comparison between measurements in different parts of the microgrid together with network zoning approach, have been reported to detect single line-to-ground fault in microgrid. Other techniques include: distance protection schemes, modified overcurrent protections and artificial intelligence-based protection system. Apart from the specific requirement of these methods, most of them require a certain level of communication either centrally operated or decentralized. The communication system must be fast to enable proper coordination in the protection system. It is necessary to ensure that failure in one communication link does not lead to failure of any other links. Therefore, security of the communication channels must be given a top priority. Often, a backup protection system which does not rely on the communication system is included as an alternative in case of a failure in communication system.

Grounding is one of the important protection requirements in the microgrids. This guarantees personal safety and reliable operation of equipment. Generally, two points must be considered: first, neutral grounding which means the type of transformer or generator neutral connection to earth; second, protection grounding which means the type of equipment frame connection to earth. LV neutral grounding is broadly classified into three types: TT, IT and TN. The TN-C-S and TT are the recommended choice for microgrid grounding [57]. In any case, the neutral grounding system for a microgrid must ensure effective fault protection, insulation integrity and safety under both islanded and grid-connected operation. Examples of issues that may need to be solved in the design of microgrid grounding system are [58]:

1. how to provide an effective neutral grounding for the MV system in a stand-alone microgrid when the MV/LV distribution transformer is D/Y connected;
2. how to provide an effective neutral grounding for the LV distribution network system in the islanded microgrid especially when both sides of the MV/LV distribution transformer are Y-grounded connection;
3. how to maintain compatibility between grounding of the MV system within the microgrid and that of the utility feeder supplying the microgrid;
4. assess if the grounding system for the microgrid complies with the grounding requirements of the existing DER installations.

The grounding scheme of the microgrid interconnection shall not disrupt the coordination of the ground fault protection on the distribution network. Technically, the location of a DG in the microgrid with respect to the PCC determines its contribution on the fault current. This location has direct influence on the performance of protection system [36]. The hosting capacity of the feeder to which the microgrid is connected determines penetration level that can be accommodated without upgrading it due to equipment thermal ratings [59].

## Microgrids Economics

To assess the economic feasibility of grid-connected microgrids, one issue is to compare costs for the isolated and connected solutions. Moreover, one can consider the case of an isolated microgrid which is going to be connected in the future. In case the future connection is planned, the initial design must in any case fulfil the standards required to connect to the main grid. Whether to go for grid connected or standalone microgrid will depend on many factors such as: accessibility, load to be supplied, microgrid ownership, availability of incentives for renewable generation, benefits and risks associated with the connection, location of microgrid, and the way in which a microgrid evolved/will evolve.

Standalone microgrids are preferred when accessibility of the area to be electrified is very difficult. This applies for the case of mountainous regions and remote villages. Apart from accessibility and climate change benefits, the decision whether to adopt grid connected or standalone microgrid is also driven by economic feasibility and load factors. Demand for electricity is less in rural areas than in the urban. For the grid-connected microgrids, any surplus power can be injected into to the main grid. Therefore low load factors have no significant effect on grid connected microgrids, since the main grid acts as an infinite storage unit facilitating continuous operation of the system while eliminating additional costs on storage batteries (e.g. in case of wind and solar PV). Nevertheless, the extension of the grid to some remote places becomes prohibitively expensive. Grid connected microgrids are ideal only for locations close to the main grid or for fast developing areas. In addition to the initial cost of the microgrid, cost for interface of the system with main grid must be incurred.

It is important to acquire a thorough understanding of a number of power system issues before attempting to realize the most cost-effective connection of a microgrid to the main grid. These include: network connection rules and regulatory requirements, connection charges, required level of automation at distribution level, technology to be employed, size of expected microgrid components and required ancillary services to be offered by the microgrid. Some of the ancillary services that can be provided by the microgrid include:

- reactive power and voltage control;
- frequency response and supply of reserves;
- regulation and load following;
- black start.

To fully obtain economic benefits of a microgrid, it is important to quantify costs of these ancillary services. This is a challenging problem since these services deal with real-time energy balance between DGs and loads [60]. To provide these services, a reliable and high speed communication system is required. These communication infrastructures may substantially increase the investment and operation costs.

Before presenting some economic aspects of grid-connected microgrid, we discuss two ways in which microgrid may evolve: top–bottom and bottom-up microgrid evolution.

In the bottom-up approach, a microgrid starts as a standalone system designed to supply electricity to local customers. These microgrids should be designed in a modular fashion, so that they can be reconfigured and expanded easily according to the size, needs, and available sources in the remote area. This feature is necessary for successful realization of the bottom-up microgrid evolution. It is necessary to design the microgrid local distribution network with higher anticipation of future connections to either another nearby microgrid or to the main grid. This is especially true due to un-even distribution of renewable and non-renewable resources within regions, countries (and continents). Therefore, connection will be necessary so that generation from different sources will complement each other.

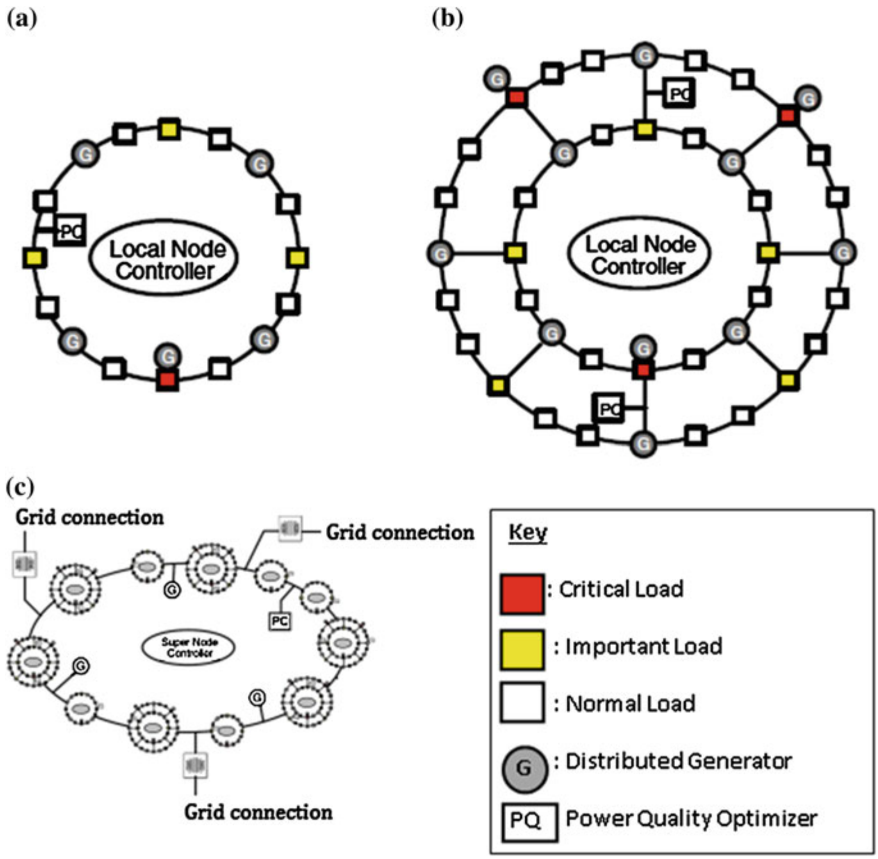


**Fig. 5.12** Formation of **a** single-ring local node, **b** double-ring local node, **c** super node [18]

The design of microgrid local distribution network should be properly done with this concept in mind. Initially, the distribution network may be a simple radial network design to supply several houses in rural area. To increase reliability, or based on the growth of the demand, system expansion might be required in future. The designer must be able to foresee this and make proper design decisions to offer the possibility of expanding the distribution network in a radial, ring or meshed network architecture. In this framework, the concepts of single-ring, double-ring, local node and super node formation as illustrated in Fig. 5.12 [18], are to be considered.

The top–bottom microgrids evolution is typical of developed countries and will dominate future power systems due to the following reasons:

- they are the best alternative to network expansion required to follow the growth of distribution loads;
- they can help reducing network congestion and transmission losses;

- they allow diversifying the generation centres to improve security and reliability of supply;
- they allow increasing generation from locally available renewable energy resources.

In according to this approach, the DGs connected to the microgrid will be operated in a way that potentially maximizes their economic advantages. For example, instead of switching off the local DGs during an emergency in the upstream network, they can form an island and continue to supply at least some critical local loads. This economic benefit cannot be easily assessed. In this case grid-connected microgrid will be realized with possible different owners of DGs. However, one would have to incur costs for centralised control system which will be managing the microgrid as one unit, in case of emergence conditions.

## *Main Grid Extension Versus Microgrids*

Comparison between optimum microgrid costs and expansion costs of extending the main grid can be used to determine the economic feasibility of the bottom-up approach of building a microgrid. The distance from the existing grid and load factor of the area to be electrified are the main factors in assessing the feasibility of grid extension. Other factors to be considered for grid extension are the cost and feasibility of installation, operation and maintenance. As the distance from the existing grid increases, the cost of grid connection rises considerably. This rise has been reported by various authors and the rate of rise is dependent on economic and

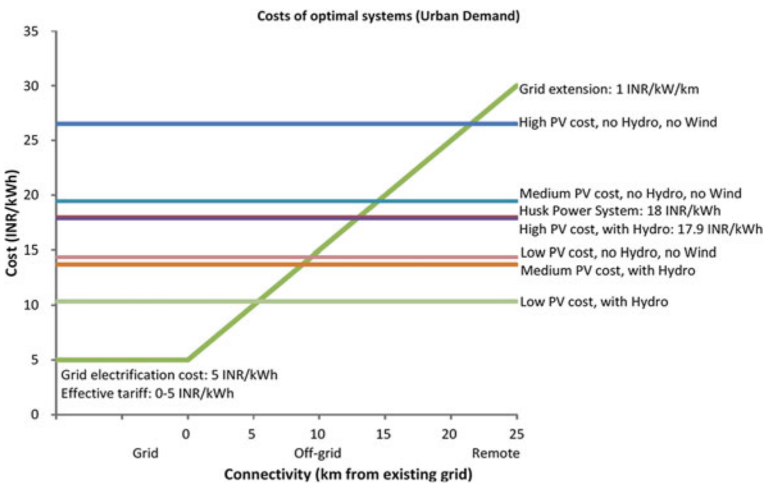


**Fig. 5.13** Cost comparison microgrid systems (with diesel) with grid extension [61]

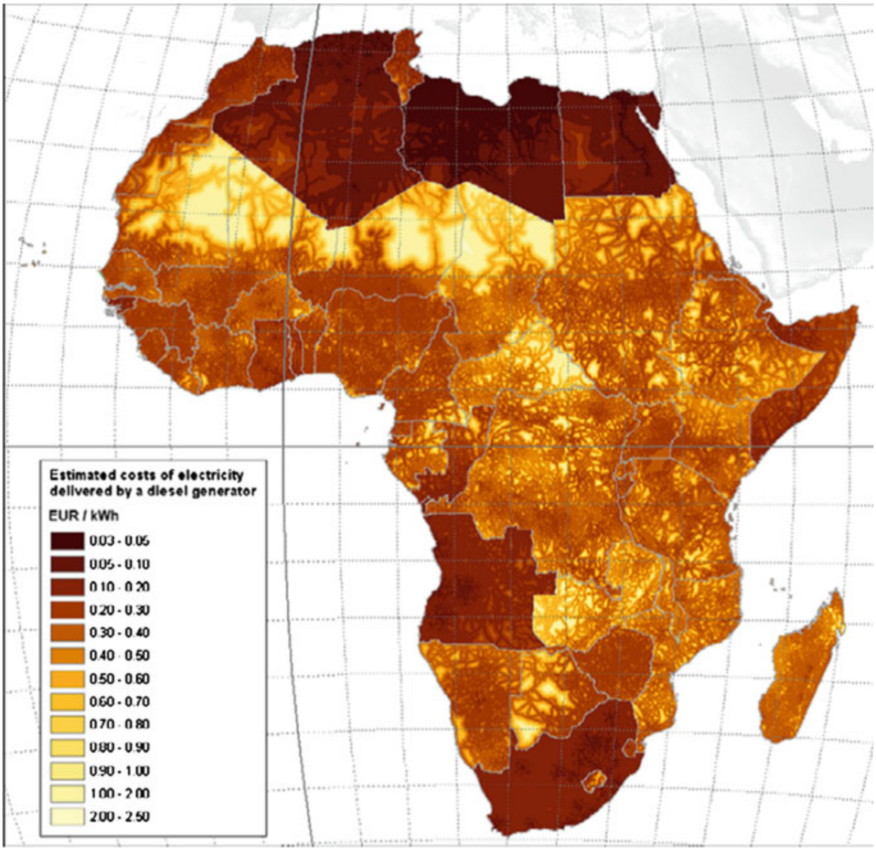


**Fig. 5.14** Estimated costs of electricity (€/kWh) delivered by a diesel generator using the diesel price for each country and taking into account the cost of diesel transportation [63]

technological factor. Figure 5.13 shows a case reported in a study which compared different electrification options in India [61].

Figure 5.13 was obtained by comparing microgrid optimal cost with the cost of grid extension. In this case, HOMER was used to calculate the microgrid optimal costs and adopted the cost of extending the grid based on the approximation given by [62]. The cost of a distribution transformer is included in the grid extension cost. In this specific case, grid extension offers the cheapest solution when the distance to the existing grid is less than 5 km. The break-even grid distances for different technologies fall somewhere between 5 and 20 km.

The break-even grid distance will vary depending on potential availability of renewable energy sources, whether small hydropower is available in the microgrid, price of diesel, market penetration for PV and wind technologies, load density and size of microgrid. Also, incentives to the use of some particular primary energy sources and of some fuels, in some cases, can bring to completely different conclusions. For example, Fig. 5.14 shows the map of electricity costs per kWh delivered by a diesel generator in Africa [63]. Variation of electricity costs, from 0.30 € (dark brown) to 2.4 € (light yellow), shows how different results may be obtained when comparing the cost of grid extension to stand-alone microgrid with diesel DGs.

Other factors such as quality, reliability and security of electricity and energy offered by grid extension should be compared to those offered by microgrid. Networking of various DGs in a microgrid allows fewer generators to be used and still achieve standard reliability criteria. Often, multiple DGs will be running on different types of fuel allowing diversification of the supply chain. However, to achieve a certain level of energy security provided by a particular microgrid architecture entails additional costs in DGs, storage or distribution system.

## Conclusion

Grid-connected microgrids present a flexible, reliable and economical way to integrate renewable and non-renewable decentralized energy resources into the existing power system. Connecting a microgrid to the main grid offers advantages such as reduced transmission and distribution congestion, costs and losses; reduced dependency on fossil fuels, emissions, and environmental impact; improved quality, reliability and security of power; economic gain by selling surplus power to the main grid, enabling the end users to participate in the energy market through demand side management, reduced design costs and provision of ancillary services to the existing power system. The key feature of a grid connected microgrid is its ability to present itself as a single controllable system to the main grid. The design of microgrids is required to meet operational and interconnection standards which enable the connection to the existing or future main grid. Therefore, it is necessary to adopt a design approach which focuses on modularity in order to enable future connection to other microgrid or to the main grid. Currently, standalone microgrids are the best choice to electrify remote areas which are inaccessible due to complicated terrains or long distance from the existing grid. Whether to go for grid extension or standalone microgrid will depend on the break-even distance obtained by comparing optimal microgrid costs to those of grid extension. It is important to acquire a thorough understanding of a number of power system issues before attempting to realize the most cost effective connection of a microgrid to the main grid. Nevertheless, the bottom-up and top–bottom microgrid evolution suggests that grid connected microgrids will populate the future MV and LV distribution systems.

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# Chapter 6
# Technologies for Power Generation in Rural Contexts

**Jacopo Barbieri and Emilio Simonet**

**Abstract** Overcoming poverty requires self-sustained economic growth. Energy, and particularly electricity, is essential for setting up small businesses which serve the local market. Building enterprises and creating new jobs are the only sustainable means of lifting people out of poverty. In this context, energy is an instrumental right to achieve the MDGs. And particularly, according to the 2011 World Energy Outlook [1], Renewable Energy Technologies (RETs) must play a prominent role in the challenge of implementing and developing sustainable energy markets. Energy supply that is only sufficient for lighting and cooking at household level (i.e. basic energy needs) and social services (health, education, etc.) is a step in the right direction. However, a stable power supply, which can be used for economic activities, provides opportunities for productive uses of energy and income generation, and therefore, lead to the creation of sustainable (energy) markets. Hence, enhancing education, reducing isolation, implementing safety measures, improving healthcare, preventing natural disasters, fostering productivity are only some of the benefits brought by the access to electricity in rural areas. Four major Renewable Energy Technologies, and most diffused storage systems will be described along this chapter. A brief description of resources assessment methodologies, an overview of main components and layouts, and some considerations about capital costs, Levelized Cost of Energy (LCOE), and impact are given for each RET. Moreover, hybrid systems' main layouts and configurations are also described.

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## Solar Photovoltaic Systems

Solar energy is the most abundant of all the renewable energy resources. Solar photovoltaic (SPV) generators utilize semiconductor-based materials (solar cells) which directly convert solar energy (solar radiation) into electricity.

### *Resources Assessment*

Solar radiation is universally available at any location, generally with higher values closer to the Equator, but the value of radiation at the ground level significantly varies from place to place due to geographic and climatic conditions. SPV generation is also influenced by seasonal variations: during the warmer months the insulation is higher than in cold months. Similarly, insulation is usually higher during the dry season than during the rainy season.

Nevertheless, nowadays a number of studies and databases are available in order to obtain a first estimation of the annual plant producibility for a selected location. Two examples of free database follow.

Photovoltaic Geographical Information System (PVGIS) provides a map-based inventory of solar energy resource and assessment of the electricity generation from photovoltaic systems in Europe, Africa, and South-West Asia. It is dedicated specifically to the context of distributed generation or stand-alone generation in remote areas [2–4].

IRENA's Global Atlas provides resource maps and tools for evaluating the technical potential of both solar and wind energy. The Global Atlas integrates a number of aspects, from resources to potential, and includes accompanying information such as socio-economic data [5, 6].

When no data are available, ground measurements of solar radiation can be made using solar radiometers. In this case it is worth noting that temperature fluctuations, wind, rain, and other factors seriously affect the measurements. For more detailed information see, for example, Weather Modeling and Forecasting of PV Systems Operation [7].

### *Technology Overview*

Solar photovoltaic (SPV) generators convert the energy from the sun thanks to solar cells. Solar cells are made with semiconductor-based materials. Most common material is monocrystalline or polycrystalline silicon. A number of solar cells are gathered together to form a solar panel. Typical power for each solar panel is in a range from 80 to 200 W, depending on size and technology, while the conversion efficiency of each panel is generally in the range 15–18 % when silicon cells are used [8]. Two or more panels can be combined in order to achieve the desired output capacity. This fact gives SPV a high degree of modularity and scalability: the technology is suitable for a wide range of different applications, from small lanterns up to mini-grid systems.

Since values of solar radiation at the ground level generally are higher in tropical areas, SPV systems tend to have higher performance in most developing countries than in North America or Europe. In North America, the insolation varies from 1,400 to 2,300 kWh/m$^2$, whereas in Tanzania values are in the range of 2,500 kWh/m$^2$ [9]. High reliability, long lifetime, the absence of moving parts, and its use of sun as a free fuel make PVS virtually free to use during its entire lifetime.

In addition to the solar panels, SPV systems typically consist of the following components:

- Batteries and charge controller for energy storage.
- Inverter.
- Wires/cables and other hardware for electric connections.

Depending on the size, the application, and other criteria, SPV systems can be classified according to the three main categories defined in Chap. 4 [10]:

- SPV home-based systems
  - Pico SPV systems;
  - Classical solar home systems.
- SPV community-based systems.
- Micro-grid SPV systems.

Solar home-based systems are stand-alone SPV systems built for a particular end use, for example lighting or water pumping.

Pico PVSs are defined as small solar home systems with a power output of 1–10 W, mainly used for lighting, and thus able to replace sources such as kerosene lamps and candles. Devices are powered by a small solar panel and use a battery which can be integrated in the device itself (Fig. 6.1) [11].

Classical solar home systems consist of a SPV module, a charge regulator, lead-acid deep-cycle battery, and optionally an inverter (Fig. 6.2). Generally these systems cover a power output of up to some hundred Watts. Since SPV generate DC power, DC loads like DC energy saving lamps, radios, and special DC fridges make optional the presence of the inverter when the system is designed for basic needs. The configuration without an inverter makes solar home systems very energy efficient without any conversion losses. In this case, the charge controller is the core of home-based systems, since it controls the energy inflow and outflow into and from the battery bank, ensuring optimal charging and discharging and avoiding damages [12, 13].

Community based systems are larger stand-alone PV systems that provide energy to community services such as health centres, schools, factories. In this case generally an inverter is needed, and the charge controller is embedded in this device (Fig. 6.3). With a typical range from some hundred to some thousand Watts

Fig. 6.1 Pico SPV system [10]

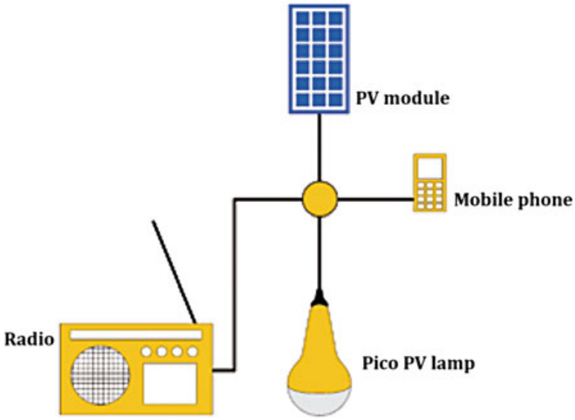
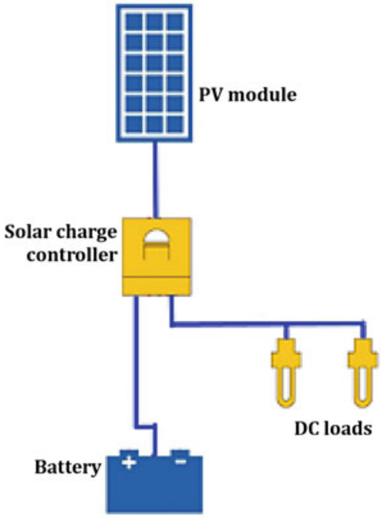



Fig. 6.2 Solar home system [10]




output power, community systems usually integrate 12 or 24 V batteries, even if bigger systems work with higher voltage (48 V) [10].

Also solar battery-charging stations are a typical application of PV for communities: the station is set up at a central place in a village, and is provided with a battery bank charged from an array of SPV modules. A DC–DC converter is used to charge batteries of individual solar lanterns or other devices [14, 15].

Finally, SPV mini-grids can provide electricity to a number of households and community services. In this case solar panels arrays are assembled in the range of some hundreds of kWp, and a distribution network provides the electricity to the connected loads.

The complexity of the system is higher. Essential elements of the systems are [13]:

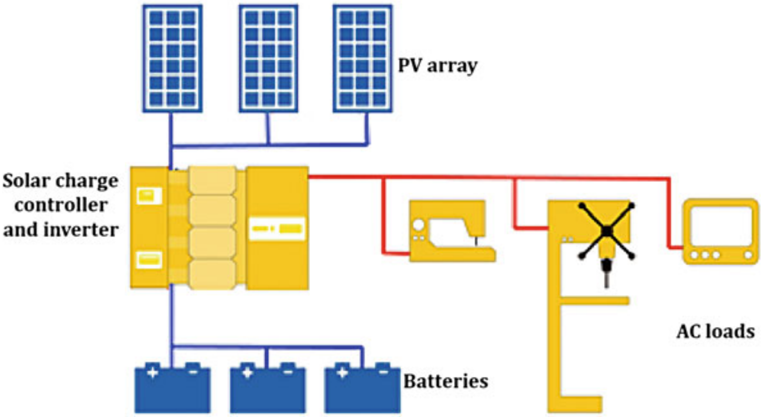



**Fig. 6.3** Community based system [10]

**Table 6.1** Comparison of different SPV systems

| System | Production voltage | Presence of inverter | Loads |
|---|---|---|---|
| Home-based Pico SPV | 12 V DC | No | Lamps, radio, mobile charger |
| Home-based Classical | 12–24 V DC | Optional | Light, TV, fridge, PC, mobile charger |
| Community-based SPV | 12–24–48 V DC | Optional | Light, cooler, water pump, hardware for artisanal work, ... |
| SPV mini-grid | 24–48 V DC | Yes | Light, cooler, water pump, hardware for artisanal work, ... |

- PV array(s).
- Battery banks for electricity storage.
- Power conditioning unit (PCU) consisting of junction boxes, charge controllers, inverters, distribution boards and necessary wiring/cabling.
- Power distribution network (PDN) consisting of poles, conductors, insulators, wiring/cabling.

Table 6.1 gives an overview of the different types of SPV systems.

## *Economics and Environmental Impact in a Glance*

Regarding costs associated to this technology, currently the price of a PV module is around 2.5 $/Wp in the most developed markets, with prices in emerging markets like India below 1 $/Wp. When considering micro-grid systems, about 50–60 % of the total cost is due to the solar PV array, while battery bank accounts for about 10–15 % and power conditioning unit for 25–35 % [12, 16].

The Levelized Cost of Energy (LCOE), according to ESMAP [17], IRENA [18], and REN21 [19] is in the range 0.26–0.75 \$/kWh. Average cost for a 300 W device is 0.56 \$/kWh, while for a 25 kW plant 0.51 \$/kWh.

Life cycle energy requirements of silicon-based SPV range from 2,699 to 5,253 $MJ/m^2$, and the Energy Pay-Back Time (EPBT) varies in the range 1.5–2.7 years.

Greenhouse gas (GHG) emissions are in the range 23–45 g $CO_2$-eq./kWh, which is about an order of magnitude smaller than that of fossil-based electricity [20]. For comparison, GHG emissions from a diesel generator are more than 700 g $CO_2$-eq./kWh [21].

***Solar PV for Repeater Station in India*** [22]

The need of a reliable power source to provide uninterrupted charge for the batteries and the frequent interruptions of grid power makes SPV the most cost-effective solution for powering remote telecommunication systems in most of the cases. Usually, repeater stations rely on fossil fuel (i.e. diesel generators), so SPV represents an optimum solution to reduce operational costs and pollution.

In this case study, a small SPV system ($\approx$3.5 kWp) provides uninterrupted optimal charging during daylight hours.

Smart control logic automatically triggers grid supply, then diesel genset if there is no grid power, when battery charge drops below critical level. Control logic also monitors room temperature and can switch on air-conditioner if temperature rises (powered by grid or diesel genset).

The system can be designed in such a way there is an energy surplus. In that case, the hybrid system could provide power to other customers in the nearby (e.g.: households) and thus the operator of the telecommunication station would become an energy service provider.

## Small Wind Systems

A wind power generator converts the kinetic energy of the wind into electric power through rotor blades connected to a generator. For stand-alone applications, small wind (SW) turbines, typically up to 50–100 kW, are used with average efficiency around 35 % [8]. There is a variety of technologies in the small wind turbine market. However, for installation in isolated rural communities in developing countries, it is important to rely on well proven and mature technologies to ensure optimum performance during the project lifetime. As an alternative, the construction of artisanal turbines using local materials and manpower provides lower costs and the active participation of local people [23–26].

### *Resources Assessment*

Wind power is extremely site specific. The energy produced by a turbine over a year depends critically on the average wind speed at the site. Wind speed is highly influenced by topography and obstacles, so turbines are normally located along ridges and hilltops to minimize the influence that obstacles can have on the wind profile. Clearly, wind power also changes during the day and can be significantly different during different seasons. For these reasons, data on local wind resources throughout the year is necessary to select most suitable places for wind turbines installation. In general, it should be considered that wind speeds in the range of 4–5 m/s are the minimum to make a system self-sustainable from an economic point of view [9].

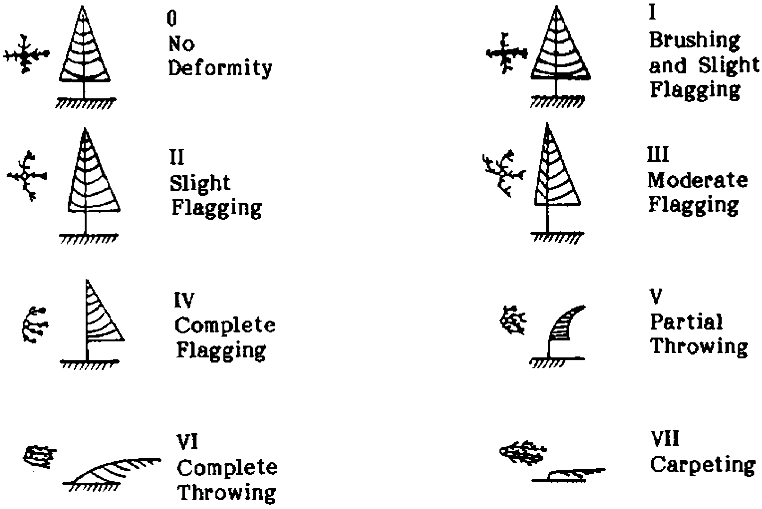
Most effective and accurate wind speed data for a specific site can be obtained by installing meteorological towers equipped with anemometers and wind vanes that measure the wind's speed and direction respectively. When this kind of data cannot be obtained because of technical or economic reasons, it is possible to use secondary data from nearby measuring stations created for other purposes, such as meteorological stations or airport installations, together with appropriate calculation models [13, 27]. A number of models exist, and the proper ones should be selected according to available information and site characteristics [28].

When no data is available, an empirical method is based on the observation of the trees: Fig. 6.4 shows that their deformation level will serve as a good indicator of the wind speeds in the area, according to the Griggs-Putnam Index of Deformity [29].

A further possibility is given by online databases, such as the previously mentioned IRENA's Global Atlas for solar and wind. Unlike the case of SPV, however, online databases can offer only very general information, since, as it has been said, the average wind speed is highly dependent on the specific characteristics of a chosen area. Moreover, wind resource maps evaluate wind conditions typically at 50 m height. This is useful for traditional wind turbines (with a size of some hundred of kW or more), while SW turbines installation requires data at less than 30 m height [13].

### *Technology Overview*

Wind turbines can be classified in two macro-categories according to their design: horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT). HAWT are the most used, due to their higher efficiency, even if VAWT are also suitable in particular for small size applications. HAWT turbines can be upwind or downwind type. In the first case, the most common, wind first invests the rotor, and then the hub, the generator and the orientation mechanism (tail). The opposite is true for downwind turbines, hence the blade orientation mechanism (if present) acts before the rotor (Fig. 6.5) [30].




| Index | I | II | III | IV | V | VI | VII |
|---|---|---|---|---|---|---|---|
| Speed [m/s] | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | 10 |

**Fig. 6.4** Griggs-Putnam index of deformity. Modified from [29]

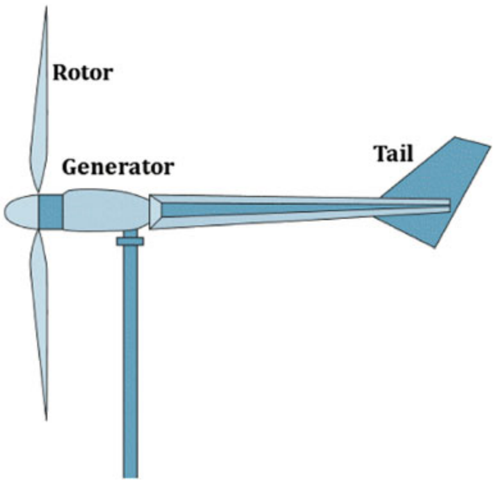



**Fig. 6.5** Small wind turbine [10]

The three-blades design is prevalent, since it minimizes vibrations and noise. Most SW turbines have a direct drive, permanent magnet rotor generator: this configuration is the simplest possible since gearbox is not needed. This kind of generator produces alternate current. The turbines are generally placed on a pole, preferably higher than 15 m to keep them out of ground turbulence. Tilt-up poles or towers are the best solution for turbines up to some kW since they are easy to install and offer good accessibility for maintenance [10].

SW systems can be subdivided into three categories according to the criteria expressed in Chap. 4:

- SW home-based systems.
- SW community-based systems.
- Micro-grid SW systems.

The layout of SW home-based systems is similar to the one of classical SPV home systems, and is suitable to supply energy for household requirements (lighting, mobile charging, radio, TV, etc.). Typically, pico- or micro-wind turbines up to about 1.5 kW are used for this application. In addition to the turbine, the simplest DC system requires a bridge rectifier (i.e. an electronic device that converts alternate current in direct current), a charge regulator and batteries for energy storage. The turbine can be mounted roof-top or on a pole. When AC loads are present, the bridge rectifier is replaced by a power conditioning unit in order to deliver proper voltage and frequency.

SW community-based systems are characterized by the use of SW turbines in the range 1.5–15 kW. When average wind speed in the location is adequate, they are ideal for dwellings, schools, hospitals, telecom towers, water-pumps, etc. SW community-based systems can be used also for battery charging, whit a layout very similar to SPV battery-charging stations.

Small and medium size turbines are used in micro-grid systems, with a typical power range of 15–100 kW. Also in this case, the layout of the system is similar to the one described for SPV systems. Clearly, depending on the context, it is possible to connect to the mini-grid one or more turbines. However, it is worth noting that there are few examples of mini-grid systems supplied only by wind turbines. More frequently, mini-grid systems using SW turbines are hybrid systems in which the wind turbine is coupled with a diesel generator, a SPV system, etc. (for further information refer to the Hybrid systems Paragraph).

### *Economics and Environmental Impact in a Glance*

The price of a wind turbine strongly depends on the size, material and construction process. Costs of SW systems in general include the cost of the turbine and also the cost of all the other required components: tower or pale, battery storage, power conditioning unit, wiring, and installation. Typical overall costs are in the range of about $3,000–6,000 per kW [31, 32]. As per maintenance operations, the turbine requires occasional cleaning and lubrication, while batteries, guy wires, nuts and bolts, etc. require periodic inspection. Clearly, maintenance costs depend on the cost of local spares and service [13].

LCOE according to ESMAP [17], IRENA [32], and REN21 [19] varies in the range 0.15–0.40 $/kWh depending on the installation size, being 0.35 $/kWh the average cost for a 300 W plant and 0.20 $/kWh the average cost for a 100 kW plant.

Life Cycle Analysis (LCA) of wind systems state GHG emissions values in the range 4.6–55.4 g $CO_2$-eq./kWh. The range variation is due to economies of scale: small wind turbines of 1 kW require about three times more energy per unit power than large wind turbines of 1 MW [21].

***Small Wind Turbine for Telecommunications in Madagascar*** [10]

In Madagascar, a 5 kW SWT was installed next to a telecommunication tower located in a remote site which is especially difficult to reach, making the transport of diesel and the maintenance of the diesel generator unaffordable.

The system is comprised of a 5 kW wind turbine and a battery bank. The wind turbine's voltage directly charges the battery. The pole of the turbine is 18 m high and has been locally manufactured. The battery bank supplies the electronics of the antenna which needs about 1 kW power. The site is characterized by an average wind speed of 7 m/s, and the expected average daily electricity production is 32 kWh.

Considering the total installation costs of the wind turbine and the battery bank at around $24,000, return on investment is expected within 2 years.

## Small Hydropower Systems

Hydropower plants transform the kinetic energy of a water flow into mechanical energy using a hydraulic turbine. Mechanic energy can be used to directly drive machineries, or is converted in electric power using an electricity generator. There is no unique definition of small hydropower (SHP), but in the context of rural areas it generally includes pico-, micro- and mini-hydro, with maximum generating capacities up to about 5 MW [33]. Unlike other renewable-based technologies, the electricity production is continuous, without interruption as long as the water is flowing.

### *Resources Assessment*

Hydro resources are extremely site-specific: the right combination of flow and fall is required to meet a certain electric load. Since a river flow can vary greatly during the seasons, a single measurement of instantaneous flow in a watercourse is of little use: gathering detailed information is required to estimate energy production potential. Moreover, also the evaluation of the best site is required.

For some areas general data about water resources assessment can be obtained by Infohydro, a database provided by the World Meteorological Organisation [34]. The Food and Agriculture Organization provides the software Local climate Estimator, containing a database of rainfall patterns through which is possible to compute an approximate hydrograph [35].

However, in most cases data for the site of interest are not available, or a more accurate estimation is necessary. For these reasons, a direct evaluation is required. To measure the flow several methods exist. A brief description of the two most common methods is given here below.

- Velocity-area method: this method is suitable for medium size rivers. The evaluation of the stream is obtained by measuring the cross sectional area of the river and the mean velocity of the water.
- Weir method: for small rivers, a temporary weir can be built. This is a low obstacle across the stream to be gauged with a notch through which all the water may be channeled. Water flow measurement is obtained by a measurement of the difference in level between the upstream water surface and the bottom of the notch.

Once the measurements have been made, data can be organized in a Flow Duration Curve, i.e. a curve showing for a particular site the proportion of time during which the discharge there equals or exceeds a defined value. The curve can be used to size the turbine over the available water flow.

In addition to the flow, also the estimation of the waterfall is required. Field measurements of gross head are usually carried out using instruments such as theodolites, laser levels, or GPS [36].

## *Technology Overview*

SHP is the most mature renewable technology: a huge number of plants have been installed in the last 30 years all over the world. Best geographical areas are characterized by the presence of perennial rivers and a hilly or mountainous terrain. Unlike other renewable technologies, hydro plants generally require some infrastructure work, since a canalization system is necessary to send the flow to the turbine, and the construction of a building provides protection to the generator from damage. On the other hand, SHP are characterized by a conversion efficiency up to 90 % and require low maintenance operations [9].

A typical SHP includes the following elements (Fig. 6.6):

- Weir, intake and channel.
- Forebay tank.
- Penstock.
- Turbine.

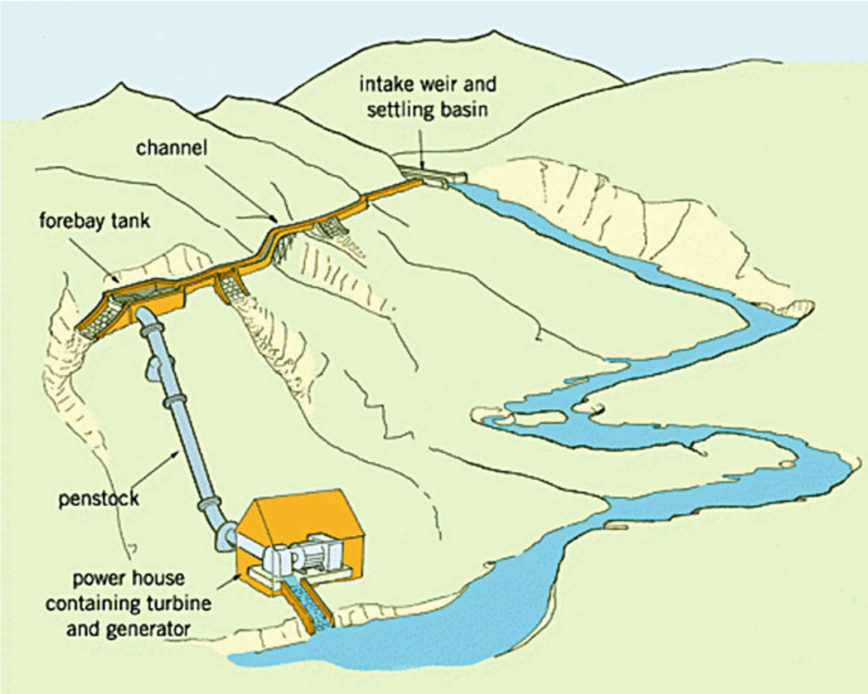



**Fig. 6.6** Small hydro plant scheme [33]

- Generator.
- Electronic controllers and converters.

The turbine is the core element, the type depending on the flow and head pressure: turbines are generally classified as high-head, medium-head, and low-head. For high and medium head SHP applications, most used turbines are Pelton, Turgo and Banki, while Kaplan or Francis turbines are suitable for low heads [13, 37].

In the case of medium or low heads, an interesting solution is the use of pumps as turbines. This solution has as its main advantages a lower cost and a greater availability of mechanical and electrical equipments. On the other hand, pumps are not optimized for functioning as turbines, therefore the conversion efficiency is lower [38–40].

The application of the criteria set out in Chap. 4 leads to the following classification:

- SHP home based systems.
- SHP community based systems.
- Micro-grid SHP systems.

Home-based systems are pico-hydroelectric installations with electric power up to about 2–3 kW. This kind of system is easy to install, and can incorporate all the electro-mechanical elements into a single device. A head of 5–6 m can be sufficient for 1 kW output power. For this reason, pico-hydro installations generally don't need channels and penstock. The generator is permanent magnets type. Electricity production is continuous, hence storage is optional. Also the use of voltage and load regulation is not mandatory, but is strongly recommended in order to avoid problems to the electric loads. Most simple regulators are mechanical (automatically driven valves which adjusts the flow to meet variations in power demand) or electronic (excess electrical power is switched in and out of a ballast load by a controller) [41].

Community-based systems are used to supply the same services described for SPV and wind community systems. In this case, micro-hydro plants can be used, with generating power from some kilowatt up to about 20 kW. Most systems are run-of-river type, this meaning that no water storage is needed. On the other hand, channels and penstock are in general used.

Finally, micro- and mini-hydro plants are used for micro-grid systems with electrical power from a few tens of kilowatt up to 5 MW. Larger infrastructure works are required in this case: according to the site configuration, bigger plants could require a basin and/or a small dam, and the construction of an electricity distribution network is necessary. The generator is typically synchronous, given that it is no longer possible to use simpler systems when such power generation capacities are provided. Moreover, for turbines above 20 kW a proper regulator should be installed in order to guarantee the optimal functioning of the system [8].

### *Economics and Environmental Impact in a Glance*

Hydro plant costs highly depend on the site characteristics, and in particular on the terrain and accessibility. For micro- and mini- systems, being equal other parameters, also the distance between the power house and the loads can have a significant influence on overall capital costs. Hence, optimization models should generally take into consideration all these parameters [42]. Of course, the use of local materials, local labor, and pumps as turbines reduces the expenditure. In general, the investment per kW varies in the wide range $500–5,600, being higher the costs of small plants and lower those of larger size plants [43–47]. Operational costs are low since plant reliability is high and the technology has been developed for many years [41].

LCOE varies in the range 0.01–0.40 $/kWh [17, 19, 48]. Typical average LCOE for a 300 W plant is 0.15 $/kWh, while the average LCOE for a 100 kW plant decreases up to 0.02 $/kWh.

GHG emissions vary greatly depending on the presence of a reservoir: run-of-river hydropower emissions are in the range 0.3–13 g $CO_2$-eq./kWh, while in the case of reservoir hydropower the range is 4.2–152 g $CO_2$-eq./kWh when potential GHG emissions from flooded land are included [21].

## Biomass Gasifier Power Systems

The term biomass is very general and refers to the biodegradable fraction of organic products and residuals from agriculture, forestry and from industrial activities that deal with organic matter. Moreover, also the organic fraction of urban waste is included.

A number of thermo-chemical processes exist to convert biomass into fuels that can run engines for power generation. Among these, one of the most suitable for low generation capacities in a rural, off-grid context, is biomass gasification, which is the process through which a solid combustible is converted into fuel gas. Biogas reactors are the other biomass-based technology suitable for such contexts, but they are used more frequently when biogas is produced for cooking purposes. Therefore biogas reactors are described in Chap. 3.

### *Resources Assessment*

Biomass resources assessment is a very complex issue that should be addressed from time to time depending on the specific context. Clearly, a comprehensive discussion is beyond the scope of this chapter, since it should include a full analysis of the biomass production chain. Moreover, biomass benefits cannot be accounted only for energy production purposes, since they include also food and other issues such as medicines. Therefore, benefits other than energy should always be considered when evaluating the construction of an electric power plant.

Table 6.2 gives an idea about different types of biomass.

Depending on the site, in general, studies about biomass resources potentials refer to large areas [49, 50]: very little or no information is available for specific sites when referring to the context of developing countries. Therefore, a specific assessment is often required. Depending on the case, this can be done through an

**Table 6.2** Examples of biomass resources [13]

| Forest residue | Agricultural residue | Agro-processing residue |
|---|---|---|
| Forest pruning | Paddy straw | Rice husk |
| Wood from plantations | Wheat straw | Cashew nut shells |
| Wood from marginal lands | Maize stalks | Oil seed shells |
| Grasses and bushes | Cotton stalks | Oil cakes |
| Wood pulp | Maize cobs | Coconut shells and fibre |
| Saw dust | Mustard stalks | Coffee and tea waste |
| Bamboo | Millet straw | Bagasse |

accurate modeling and/or data collection on the field [51, 52]. Also GIS-based remote techniques can provide appropriate information [53]. For further information about estimation techniques refer to [54].

## *Technology Overview*

During the gasification process biomass is subjected to partial combustion in the presence of a limited supply of air. The ultimate product is a combustible gas mixture known as producer gas. The combustion of biomass takes place in the gasification reactor, a closed vessel, normally cylindrical in shape. Producer gas typically contains carbon monoxide, hydrogen, nitrogen, carbon dioxide and methane. Thermal value depends upon the type of biomass used, being the typical range 3,800–6,300 kJ/Nm3 [55, 56].

Gasification of biomass takes place in four distinct stages: drying, pyrolysis, oxidation/combustion, and reduction. Gasifiers are classified into three categories on the basis of the reactor type: fixed bed, fluidised bed or entrained flow. Fixed bed gasifiers are the preferred solution for small- to medium-scale applications [57].

There are three types of fixed bed gasifiers: dawndraft, updraft, and crossdraft. In the case of downdraft gasifiers the flow of gases and solids occurs through a descending packed bed. In case of updraft gasifiers, the gases and solids have counter-current flow. In the cross draft gasifier, solid fuel moves down and the airflow moves horizontally. Generally the gas contains a high level of tar and organic condensable and requires cleaning.

In addition to the reactor, a typical system includes the following components (Fig. 6.7):

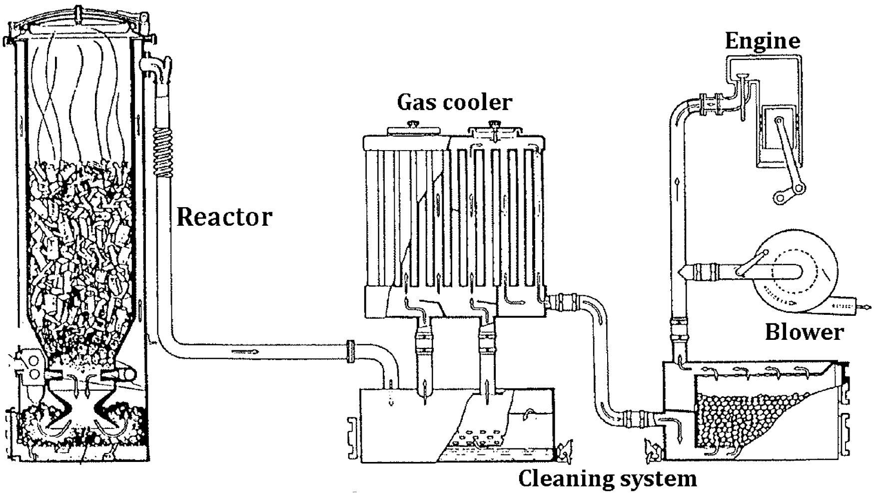



**Fig. 6.7** Layout of a small scale gasifier power generating system. Modified from [58]

- Gas cooling system.
- Cleaning system, consisting in a cyclone and/or water scrubber, and/or other systems (filters,…).
- Gas engine coupled with an alternator.
- Auxiliaries (blower, control system,…).

Due to technical reasons, biomass gasification is not suitable for home-based applications: minimum size plant is around 7–8 kW electric power [57, 59], with a power generation efficiency in the range 10–20 % [60].

On the other hand, energy for community services or villages can be successfully provided using gasifier power plants [52]. The configuration can be both classical stand-alone (directly powering a specific load), or mini-grid, the last case with an electric generation capacity up to some MW [17, 57].

## *Economics and Environmental Impact in a Glance*

Capital costs for gasifier power plants vary on a very wide range according to the size, materials, and technology (type of reactor, type of engine, etc.). The cost for small installations (10–35 kWe) ranges from 850 to 2,200 $/kWe, while the costs for medium and larger plants (50–2,000 kWe) are in the range 1,200–7,600 $/kWe [17, 57, 61–63].

LCOE varies from 0.08 $/kWh up to 0.14 $/kWh [13, 17, 19, 60].

Regarding LCA, when biomass resources are properly managed the cycle is closed with regard to the carbon content of the biomass: $CO_2$ emissions from combustion are completely compensated by the growth of new biomass. Hence, only other emissions due to fuel supply, power station construction and maintenance, and non-renewable start-up fuel are considered. This consideration leads to an estimated range from 63 up to about 70 g $CO_2$/kWh [64] (it is worth noting that in this case only $CO_2$ is taken into consideration, while for the other technologies a $CO_2$-equivalent emission range was reported).

***Husk Power Systems: Electricity from Rice Husks in Bihar's Villages (India)*** [65]

Husk Power Systems (HPS) provides electricity to around 100,000 people across 125 villages in India, using biomass gasifiers fuelled by rice husks.

Rice husk is compressed to bricks. At the end of the process some char is produced in addition to the fuel gas.

Fuel gas is cleaned by four filters, and then it is used to fuel an internal combustion engine and generate electricity. A mini-grid system transmits the electricity to the houses in a range of 3 km. HPS business model is primarily focused on villages that are off-grid. At the moment, there are 35 power plants in operation with a generation capacity in the range 32–52 kW.

A 32 kW plant needs 50 kg of fuel per hour, and power about 700 typical rural households. Customers pay in advance for electricity, and the cost is less than they might have previously paid for diesel or kerosene.

Main aspects for this case study are summarized below.

- Source of energy: rice husk. 50 kg of rice husk an hour can run a 32 kW plant. Thus 1.8 billion kg of rice husk (Bihar′s 1 year production) could produce about 2.2 GW of power
- Supply chain: husk purchased from local rice mills. One month's stock of husk ensures dry feed during the monsoon.
- Funding: initial investments come from personal funds. HPS has also received support from some international funding bodies and from Indian Ministry of New and Renewable Energy.
- Investment: total installation costs are less than $1/watt, including distribution. Running costs are about $350, including salaries, husk cost, maintenance cost.
- Return time: about 2–3 months to become operationally profitable, and 2–3 years for capital expenditure to be returned, depending on subsidies.
- End users: 11,000–12,000 connections have been taken across over 125 villages, of which 80–90 % are domestic users.
- Billing and payment: domestic users pay about $1.5 per month for a 30 W connection. Electricity is available for 6–7 h in the evening in most sites.

## Technologies Comparison

Table 6.3 aims to summarize main advantages and shortcomings of each technology described above, in order to give a general overview of the different systems.

## Storage Systems

As discussed in the previous paragraphs, storage is a key issue when renewable energy systems are used. This is particularly true when addressing stand-alone systems using unreliable sources such as wind energy or solar energy.

A number of technologies based on different principles are available for energy storage, but for small scale systems up to some MW batteries are the most

**Table 6.3** Comparison of specific requirements for different technologies. Modified from [66]

| Issue | Solar PV | Small-wind | Micro-hydro | Biomass gasifier |
|---|---|---|---|---|
| Resource availability | Only during daylight and variable according to the season | High short-term and seasonal variability | Seasonal variability | Seasonal variability |
| Resource assessment | Possibility of extrapolation of existing data concerning a neighbouring area | Extrapolation of existing data requires the use of dedicated software and a thorough assessment of the site configuration | In most cases, no existing data available; on site measurement of flow and observation of seasonal variations required | In most cases, no existing data available; specific study is often required |
| Possibility to install the system close to the energy utilization | Yes, if roof or ground available | Not always practical. In a few cases, small wind turbines can be installed directly on roofs. Consider also noise problems | Not always practical. The location is dependent on the water resource | Yes, but the discharge of combustion gases should be considered |
| Space required | The ratio surface/power installed is high for PV arrays compared to other generators | Space for setting up include the stays installation and possibility to lay down the turbine for maintenance | The infrastructure is very dependent on the geomorphology of the site | Installations are compact and require little space |
| Site restrictions | Shadowing | Roughness, obstacles, etc. | Accessibility to the water resource | – |
| Civil engineering constraint level | Low to medium, depending on the configuration of the ground, the quality of the roofs, etc. | Medium to high depending on the configuration of the ground, the consistency of the soil or the quality of the roof | Could be high depending on the slope and width of the river | Low to medium, strictly depending on the size of the installation |
| Needed operation skills | Low | Low. High for maintenance and operation | Low. High for maintenance and operation | Medium. High for maintenance and operation |
| Operation constraints | Batteries storage or hybridation needed to adapt the production to the demand | Batteries storage or hybridation needed to adapt the production to the demand | To adjust the settings of the turbine in relation to the available flow and the electricity demand | To adjust the settings depending on biomass type and quality |

(continued)

**Table 6.3** (continued)

| Issue | Solar PV | Small-wind | Micro-hydro | Biomass gasifier |
|---|---|---|---|---|
| Electrical performance | Voltage regulation needed (battery, hybridation) | Voltage and frequency regulation by an external mean | Voltage and frequency regulation by flow or demand regulation | Voltage and frequency regulation by demand regulation |
| | Storage to adapt production to demand | Storage needed to adapt production to demand | Energy conversion needed when using battery charging | |
| | Energy conversion needed if AC demand | Energy conversion needed when using wind turbines for battery charging | | |
| Safety issues | Electrical mechanical (wind effect on PV array) | Electrical moving parts Mechanical (erection/laying down the machine) | Electrical. Moving parts. Water pressure | Electrical. Moving parts. Toxic gases. High-temperature heat sources |
| Environmental impact | Visual. Ground occupation. Battery recycling (if battery storage) | Visual. Noise. Battery recycling (if battery storage) | Visual (especially due to the weir and the penstock, if any). Fauna and flora impact | Possibility of impact on forests and of harmful emissions |

**Table 6.4** Summary of battery properties. Modified from [69]

| | Deep-cycle lead-acid | Lithium-ion |
|---|---|---|
| Useful storage capacity (kW per battery) | 0.5–10 | 0.5–10 |
| Lifetime (years) | 3–10 | 10–15 |
| Roundtrip efficiency (%) | 70–90 | 85–95 |
| Capital cost ($/kWh$_{cap}$) | 150–500 | 500–1,500 |

common device. Battery storage is a mature technology, owing its success to the high energy density and modularity. As a matter of facts, a number of batteries can be connected together to obtain required voltage and capacity.

Most common type of batteries is lead–acid [9]: they offer a good energy density at a reasonable price. It is worth noting that for electric supply systems deep-cycle batteries must be used, since storage must be able to discharge large amounts of energy during a single discharging cycle. Among the different types of lead-acid deep-cycle batteries [67], the valve-regulated lead–acid (VRLA) is the one requiring lower maintenance. Lifetime is a critical issue, and depends on a number of factors. Generally, lifetime can be up to 10 years, but adverse environmental conditions (high temperatures), intensive charge/discharge cycles, or overcharging can shorten battery life.

As an alternative, also lithium-ion (Li-Ion) batteries are suitable for the applications addressed in this chapter. Compared with lead-acid batteries, Li-Ion batteries offer higher energy density and efficiency, and can handle deeper discharges with less impact on lifetime. Moreover, their lifetime is longer [68]. On the other hand, Li-Ion batteries require more accurate charge controllers and their cost is higher [8, 69]. Table 6.4 gives a summary of both lead-acid and Li-Ion batteries.

## Hybrid Systems

One of the main problems of renewable energy, and in particular of solar and wind, is the strong variability of the resources. Indeed, solar radiation is available only during the day, and both solar and wind resources vary according to the weather and seasonal conditions. For these reasons, when off-grid loads require supply continuity, large energy storage capacity could be necessary if a single technology is used, and power systems need to be oversized in order to produce an excess of electricity for storage. As a consequence, the cost of the system can considerably increase. Moreover, in some cases a single source does not provide enough energy to meet the load's requirements. In most of these cases, the implementation of hybrid systems can provide competitive advantages. As a matter of facts, hybrid systems are able to produce electricity even at times when one of the used resources is unavailable.

A typical production layout for rural areas includes the following components [70]:

- One or more technology using unreliable renewable energy sources.
- Secondary technology using reliable energy sources (typically a genset or a hydropower plant).
- Storage system.
- Inverter and charge controller.
- Other electric material (cables, wires, etc.).

A hybrid system can be used both to provide electricity to single community services, such as health centers, schools, water pumping systems, and to supply multiple loads in a micro-grid scheme. In the last case, the system is composed of three subsystems [9]:

- *Production subsystem*, consisting of the components described above.
- *Distribution subsystem*, including all the distribution equipment.
- *Demand subsystem*, including all the end-use equipment (meters, internal wiring, appliances, etc.).

## Typical Configurations

### SPV/Diesel or Wind/Diesel

SPV or small wind coupled with a diesel genset is one of the most common and simple configurations. SPV or wind provides most of the electricity, while the genset balances the production when fluctuations of renewable resources occur. In general, the presence of a fully dispatchable power system makes storage optional. Nevertheless, batteries are often included in the system: in this case batteries meet short-term fluctuations, and the diesel generator takes care of the long-term fluctuations [71, 72]. Typically, this kind of system is used for generation capacities up to 100 kW when quality power cannot be delivered by the intermittent sources alone [13].

### SPV/Small Hydro or Wind/Small Hydro

This kind of hybrid system is similar to the precedent: small-size hydropower plant is used in place of the genset. Hence, produced electricity is 100 % from renewable sources [73, 74]. On the other hand, both wind or solar energy and hydropower must be locally available in the site of interest, condition that does not occur frequently.

### PV/Wind

If the site conditions are favorable, a system combining two renewable sources such as solar and wind is more reliable than a system using a single resource [75].

Clearly, the performance of such systems strongly depends on local weather variations, and an accurate assessment of both solar and wind resources during the year is mandatory. The system requires battery storage, inverter and charge regulator [76]:

- if electricity demand is lower than wind turbine production, the excess electricity form wind turbine and PV is stored;
- if load demand is higher, the PV array cover the excess load;
- if load demand is higher than the power supplied from both renewable systems, additional energy is taken from the storage.

Wind-PV hybrid systems are used when required power is up to 50 kW [77].

### Other Configurations

Other configurations are possible when more than two technologies are coupled together in a complex hybrid system. The greater differentiation of energy resources ensures greater availability and reliability of the system. Clearly, also the optimization and management of the system is more complex. Some examples of these systems are summarized in Table 6.5.

## *Connection Schemes*

Each power generation unit must be connected to the electric grid. Different connecting topologies exist. AC bus line, DC bus line, or mixed bus line are the most frequently used in remote areas [10, 84].

- *AC bus line*: all generating units are connected to an AC bus line for power transmission. PV arrays need a DC/AC converter, while technologies generating alternate current (hydro, wind, biomass gasifier, genset) are allowed for direct coupling, even if a voltage and/or frequency regulator may be necessary, especially for wind. If the system has a storage, a bidirectional master inverter controls the energy supply for the AC loads and the batteries (Fig. 6.8).

**Table 6.5** Examples of other hybrid layouts

| Typology | Technology mix | Source |
|---|---|---|
| Two unreliable sources plus hydro or diesel or biomass gasifier | PV/Wind/Hydro | [78, 79] |
| | PV/Wind/Diesel | [80] |
| | PV/Wind/Biomass | [81] |
| One or more unreliable sources plus hydro and diesel | PV/Hydro/Diesel | [82] |
| | PV/Wind/Hydro/Diesel | [83] |

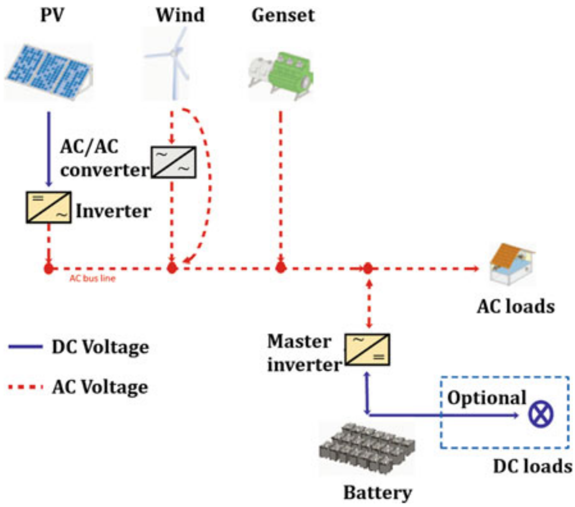



**Fig. 6.8** AC bus line hybrid system. Modified from [9]

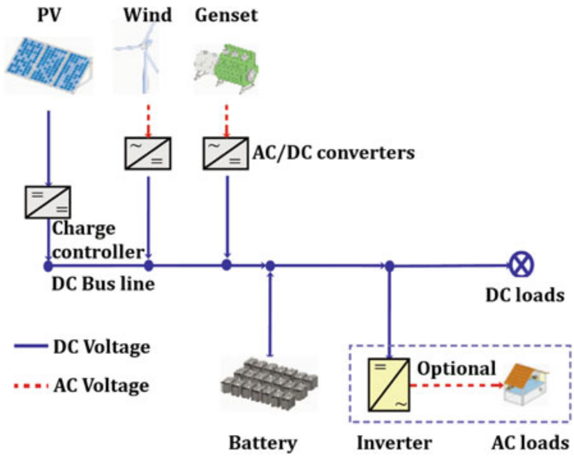



**Fig. 6.9** DC bus line hybrid system. Modified from [9]

- *DC bus line*: in this case all the technologies generating alternate current need AC/DC converter, while PV is allowed for direct connection. DC loads and batteries are directly coupled to the DC bus line. Batteries are controlled by a charge controller. AC loads can be powered by an inverter (Fig. 6.9).
- *Mixed bus line*: DC and AC generating units are connected to the DC or AC line. A master bi-directional inverter controls the entire system (Fig. 6.10).

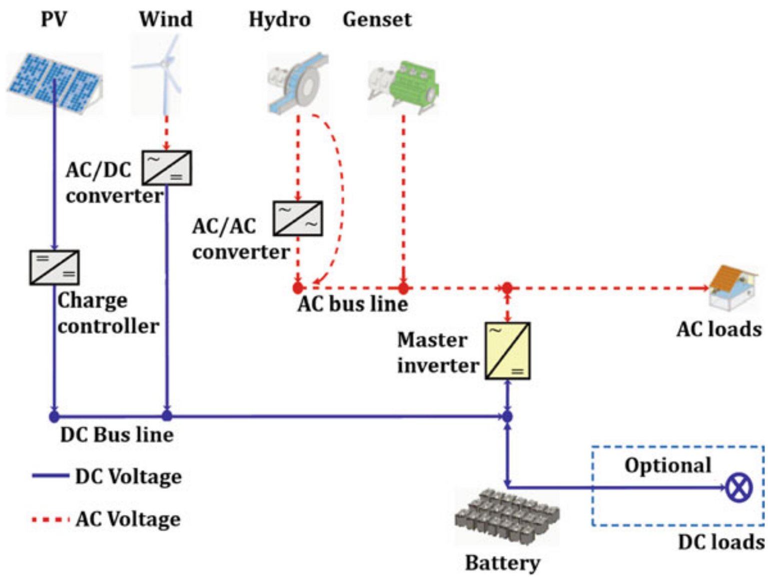



**Fig. 6.10** AC/DC bus line hybrid system. Modified from [9]

***Solar Energy Solutions for Tripolia Hospital*** [65, 85]

A good example of the potentially of solar power systems is the Tripolia Hospital, in the town of Bihar (India) Tripolia is a charitable private hospital run by the Sisters of Mercy of the Holy Cross. At present, the hospital has an innovative solar installation consisting of three different technologies:

- Concentrated solar power (CSP);
- Solar thermal water heaters;
- Solar photovoltaic (SPV).

As in many places in India, Bihar suffers of frequent power cuts. Since the hospital requires a great amount of energy for its normal operation (mainly in form of electricity and hot water), the managers decided to increase their energy self-sufficiency of the facilities, especially because the lack of energy might have a great impact in the health and wellbeing of the patients. Now, the hospital relies on its own methods of energy generation for up to 250 patients as well as an additional 200 staff and students that live on the campus.

The most impressive part of the solar system are four giant mirrored parabolas installed on the hospital roof, each with a collection surface of 8 m$^2$ Through a simple motor, the dishes can track the movement of the sun automatically. Thanks to the concentration of the sun power, just one square metre of reflective dish surface can generate 500 W of power. Main purpose of this CSP system is the sterilization of medical instruments and powering the laundry facilities. The system operates as follows: By concentrating all the sunlight that falls on each 8 $m^2$ mirror dish to a point, the heat of the sun is transferred to the water in a header pipe, creating steam. The pressure of the steam builds rapidly since each dish can transfer up to 4 kWh of power to the water. Once the pressure reaches 5 bar, the steam shoots into the autoclave, where medical instruments have been previously loaded into. It only takes 15 min for normal instruments to be properly sterile. Operational instruments take a little longer, but in 30 min are ready too. For most of the months of the year, the CSP system is self-sufficient to create steam for all laundry and sterilization needs; just during the monsoon days, when solar resource is not usually enough to cover all energy needs, the hospital pays for electricity from the main grid to generate the steam. However, since the electricity grid is not reliable, diesel powered generators have been also installed as a back-up for those periods.

Along with the CSP system, Tripolia also has a solar PV system and low temperature thermal solar system. The solar PV system powers entirely the streetlights on the campus walkways as well as four computers, an office, and the lights and fans of 14 bedrooms. On the other hand, the solar thermal system, connected to five water heaters, provides hot water for those 14 bedrooms.

This case study not only reflects the potentially of distributed solar power systems to increase self-sufficiency in areas where reliability of the national grid is very low but also demonstrates as well planned projects can be cost-effective in the long term when implementing adequate cost-benefit analysis. Indeed, the combined solar appliances mentioned above are saving the hospital an estimated 40 % on their electricity bills, ensuring the sustainability of the model in the long-run.

## Conclusions

Nowadays, guaranteeing energy access in remote areas is a challenging issue of increasing evidence, necessary to meet the Millennium Development Goals. In particular, fundamental objectives such as improving healthcare and education cannot be achieved without basic energy supply. In this Chapter, the focus has been on electricity supply to be obtained using Renewable Energy Technologies, whose role is considered prominent in the challenge of implementing electricity services according to the sustainable development principles. In this framework, the main aspects of solar PV, small wind, small hydropower, and biomass gasifiers have been analyzed, taking into account the main issues that are related to the specific context of rural areas in developing countries. Storage systems have been introduced and most diffused configurations and schemes of hybrid systems have been described, referring to field studies available in the literature. The case studies in the boxes complete the analysis by giving some concrete examples of application of the different technologies.

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# Chapter 7
# End Use Application: The Case of Solar Thermal Systems

**Mario Motta and Marcello Aprile**

**Abstract** The contribution of solar thermal systems in meeting the global energy demand is, differently to what it is often perceived, among the highest compared to traditional renewable energies (such as biomass and hydropower). It is slightly lower in terms of capacity (282.6 $GW_{el}$) and energy produced (581.1 $TWh_{el}$/y) than wind. Moreover, it is about double of the contribution of PV and about one order of magnitude larger than geothermal and CSP (concentrated solar power). The simplest and most widespread application of solar thermal systems is the production of domestic hot water (DHW). The solar heat can also be used for active heating and cooling of buildings, although the portion of the covered load is limited by the fact that the availability of solar radiation during the heating season is in general the lowest on an annual basis. Solar combi systems (for the combined production of DHW and heating) are widespread in some local markets (mainly European). Other solar thermal technology uses, less diffuse, with a high future application potential are: production of industrial process heat, solar district heating plants, solar cooling. The descriptions given of solar collectors in this section are also valid for these cases of application. However, these uses are beyond the scope of this text. More information about technological peculiarities and sizing criteria of the aforementioned systems can be found in the literature [1–4].

## Technologies

The estimated total capacity of solar thermal collectors in operation worldwide by the end of 2012 is 268.1 GWth, equivalent to 383.0 million square meters of collector area. This corresponds to an annual collector yield of 225.0 $TWh_{th}$, which

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is corresponding to savings of 24.0 million tons of oil and 73.7 million tons of $CO_2$ respectively [5].
The largest part of the total capacity in operation is present in China (64.9 %) and Europe (16.7 %); North America, Australia and New Zealand accounts together for 9.2 %. Therefore, the rest of the solar thermal capacity in operation, which includes most of the developing countries, accounts for less than 10 % as follows: Asia excluding China (4.1 %); Latin America (2.7 %); the MENA countries (Israel, Jordan, Lebanon, Morocco and Tunisia) 2.0 %; some Sub-Sahara African countries 0.4 % (namely Mozambique, Namibia, South Africa and Zimbabwe).

Solar thermal systems implement a generator of thermal energy consisting of a collector field. The field is formed through the hydraulic connection of collectors (if more than one is in use) that convert the direct and diffuse components of the solar radiation into thermal energy. The heat generated in the collector is continuously removed through a heat carrier fluid (heat transfer medium) flowing in the piping internal to the collector. The fluid is then routed through the hydraulic circuit of the field, in most cases toward a tank where thermal energy is stored. The main component of solar thermal system is indeed the collector field. Its task is to convert the solar radiation into usable heat. Besides that other key components such as the thermal storage unit are considered. In addition, a back-up heat source can be present. In this section, the main solar collector types and their specifications are presented and discussed. To deepen knowledge on these matters, the reader must refer to specific textbooks [4].

The central part in each solar collector is the absorber. Here, the short-wave (solar) radiation is converted into heat; part of this heat is transferred to the heat transfer fluid and another part is lost to the environment.

The absorber material has to present a high absorption capacity within the spectrum of solar radiation (0.3–3 μm) and a low absorption and thus emission capacity in the thermal radiation wave spectrum (that corresponds to the operating temperatures of the absorber). The absorber also has to enable a good heat transfer to the heat carrier and must be temperature-resistant. Mainly metal is used to build absorbers. In the simplest case, it is painted with black color on the face exposed to the sun (maximum absorber temperature approx. 130 °C). More advanced absorbers have a "selective coating" and can reach temperatures of up to 200 °C without vacuum insulation, and even higher with vacuum insulation. A large majority of the market available collectors presents a transparent cover, which separates the absorber from the environment. The cover has as well the role to transmit as much incident solar radiation as possible.

More collectors, depending on the plant size, are connected together to constitute a field. The heat transfer fluid, which flows through the collectors of the field (usually water or a mixture of this and an antifreeze fluid), by way of a hydraulic circuit is directed to the thermal storage. In most solar systems, this is done through an heat exchanger (solar or primary heat exchanger).

In a steady state, the incident radiation on the collector surface is equal to the sum of useful heat and several different loss terms, as explained through the energy balance of the absorber of a solar thermal:

$$A_A G = Q_{\text{use}} + Q_{\text{loss,opt}} + Q_{\text{loss,convective}} + Q_{\text{loss,conductive}} + Q_{\text{loss,radiative}}$$

where: $A_A$ is the absorber area [$m^2$]; G is the incident global solar irradiance on the collector aperture [$W/m^2$]; $Q_{\text{use}}$ is the useful heating power of the collector [W]; $Q_{\text{loss, opt}}$ are the optical collector losses [W] which include all losses that are due to reflection and absorption in the transparent cover; $Q_{\text{loss, convective}}$ [W] are natural convection losses which occurs in the gap between the absorber and the transparent cover; $Q_{\text{loss, conductive}}$ are the heat conduction losses [W] in the gap between the absorber and the cover as well as through the back insulation and through the frame edges; $Q_{\text{loss, radiative}}$ denotes radiative losses [W] (mainly in the infrared spectral range).

The various losses contribute differently to the steady state energy balance, depending on the operating temperature of the collector and thus the temperature of the absorber. Different measures to reduce these losses can be taken in order to maximize the useful heat output from the solar collector. Selection of the most effective measures depends on the desired operating temperature of the collector and the climatic conditions (solar irradiance, wind speed, ambient temperature) in which the collector shall operate. The performance of the collector under different operating conditions is described by the collector efficiency curve.

## *The Collector Efficiency*

The collector efficiency $\eta$ is defined as the ratio between the thermal energy produced (collector output) and the incoming radiation, which impinges on the transparent surface (if a cover is used) of the collector (irradiation). It is usually expressed in percentage terms. The efficiency is influenced by the collector construction characteristics and particularly from its optical and thermal properties.

Optical losses describe the portion of the radiation that reaches the collector and cannot be absorbed onto the absorber. They depend on the geometrical characteristics of the collector, on the transparency of the cover (transmittance$'$) and the ability to absorb the radiation of the absorber surface (absorbance). They are described by the factor $\eta_{0;}$ namely optical efficiency (or factor). The thermal losses depend on: the temperature difference between the absorber (collector's part at the highest temperature) and the outside air; the type of construction (including the insulation level). In cases of practical application, it can be useful to employ a simplified formulation of the collector efficiency as function of the mentioned operation's boundary conditions. For example, if all non-linear losses are approximated by a quadratic expression, the following equation can be employed:

$$\eta = \frac{Q_{\text{use}}}{A_A G} = \eta_o - c_1 \frac{\Delta T}{G} - c_2 G \left(\frac{\Delta T}{G}\right)^2$$

where $\Delta T = T_{av} - T_a$, with $T_{av}$ is the average temperature of the heat transfer fluid through the collector; and $T_a$ is the ambient air temperature (or surrounding); $c_1$ denotes the linear heat loss coefficient [W/m$^2$K]; $c_2$ is the quadratic heat loss coefficient [W/m$^2$K$^2$]; G is the global radiation reaching the collector cover (hemispherical solar irradiance) [W/m$^2$]. The example given, using a formula of the collector efficiency as a function of the average temperature of the heat transfer fluid, follows the approach of the European standard EN 12975-2:2006. In the technical sheets of market available solar collectors the three aforementioned parameters ($\eta_0$, $c_1$, $c_2$) are given, as result of experimental tests defined in the standard. The three coefficients characterize the operation of each individual collector. An example of the efficiency curve of a collector is given in Fig. 7.1, in which the optical and thermal components of the overall collector losses are shown.

From the efficiency curve one can see that the thermal energy losses increase with the increase of the temperature difference between the collector (heat transfer fluid flowing through it, Tav) and the surrounding environment (Ta), and with the decrease of the solar radiation. The collector optical efficiency, i.e., the collector efficiency when the aforementioned temperature difference is zero, represents a measure of the amount of incident solar radiation that cannot be collected by the

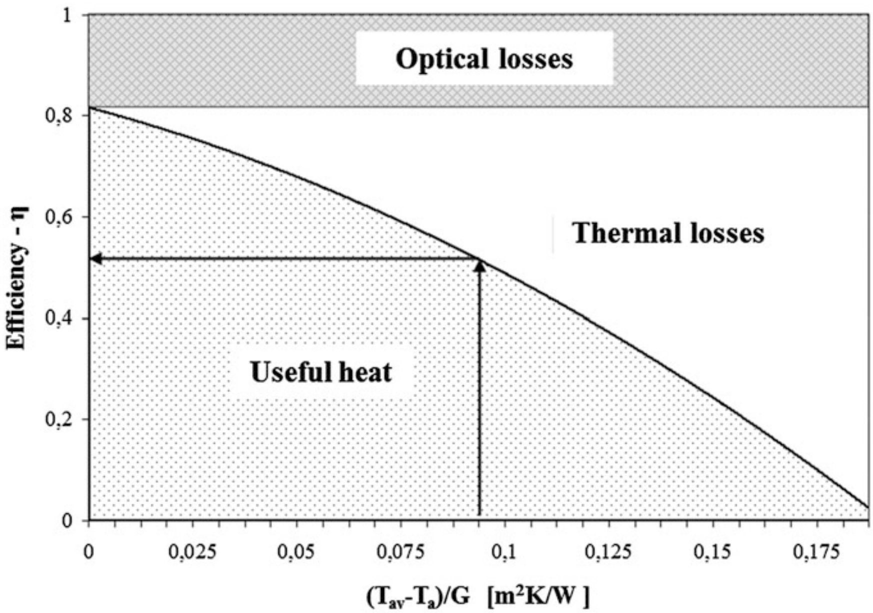


**Fig. 7.1** Example of efficiency curve (useful heat, thermal and optical losses)

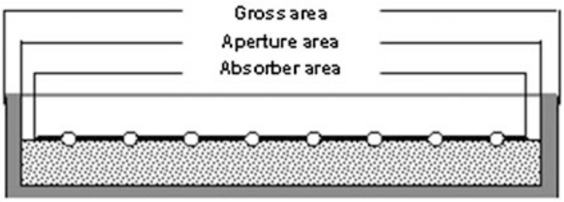


**Fig. 7.2** Definitions for collector area

solar collector because of unavoidable reflection and imperfect radiation absorption. To perform the calculation of the efficiency of the collector under conditions in which the angle of incidence of the radiation is different from that of the test conditions, the IAM—incidence angle modifier—has to be assessed for the collector considered. The latter definition and calculation methods are given in the European standard EN 12975 part 2.

Attention must be paid to the definition of the collector area, as compared to the certified performance tests carried out on the collector. The areas used in the standard can be: total area, aperture area and absorber area (Fig. 7.2). These can differ significantly, especially for certain types of collectors (e.g. evacuated tubes). For the definitions of the different areas, see EN ISO 9488.

In Fig. 7.3, examples of efficiency curves related to various types of collectors are shown. It is known that the unglazed collectors used for heating of outdoor swimming pools have higher optical efficiency than glazed collectors. However,

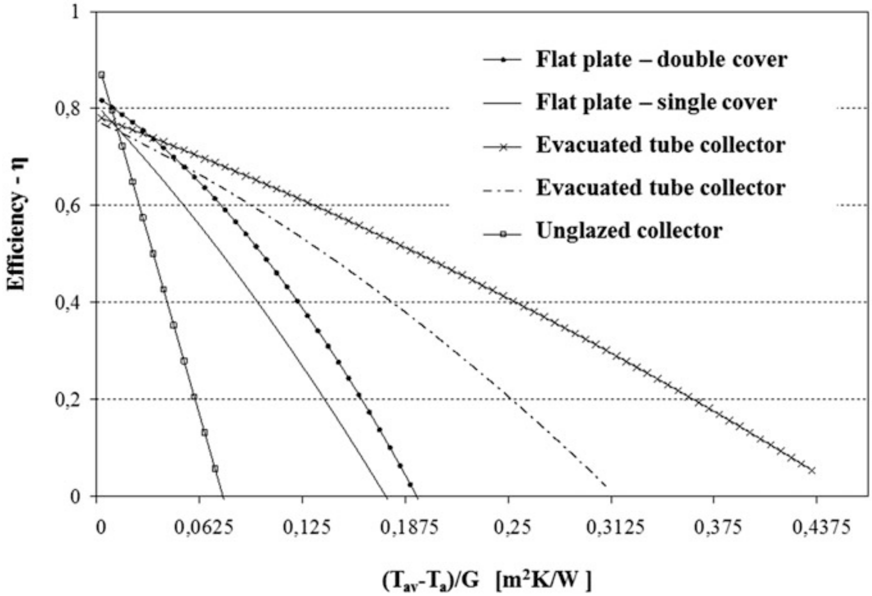


**Fig. 7.3** Efficiency curves related to various types of collectors

their thermal losses, due to the lack of insulation, grow quickly with the increase of the fluid temperature. Flat-plate collectors show better thermal performance than unglazed collectors, thanks to the suppression of external convection losses. Therefore, the level of temperature of heat production where the efficiency is zero is higher than in unglazed collectors. Similarly, as shown in Fig. 7.3, double cover collectors are more suitable for higher production temperatures than single cover components. Evacuated tubes are better performing, especially for high fluid temperatures or low solar radiation levels.

## *Types of Collectors*

There are different types of solar thermal collectors that can be classified with respect to the ability to produce thermal energy at different temperature levels, the cost, the performance and suitability for different applications. In Table 7.1 schemes representing the different typologies of solar thermal collectors are given.

The breakdown of the cumulated worldwide capacity in operation in 2011 by collector type is: 27.9 % glazed flat-plate collectors, 62.3 % evacuated tube collectors, 9.2 % unglazed water collectors and 0.7 % glazed and unglazed air collectors. The large advantage of the evacuated tube collectors is almost completely due to the predominance of the Chinese market of the others. China is the largest producer and widest market worldwide of evacuated tube collectors. Following a short description of the main collector typologies is given.

### Unglazed Collectors

They are the simplest collectors on the market. Unglazed collectors do not present a transparent top cover, neither casing or insulation layer. They are constituted only by the absorber (mainly polymeric) and have losses of thermal energy much higher than those of a glazed collector (under the same operation and climatic boundary conditions). Therefore, they can be used only for low temperature applications—i.e. thermal energy request at max 20−30 °C. They are able to operate only when the difference between the latter and the external environmental temperature is reduced (losses by conduction and convection are low). They are

**Table 7.1** Schemes representing the different typologies of solar thermal collectors

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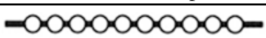
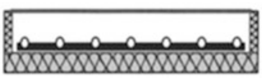
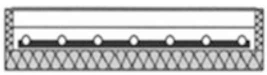
|---|---|---|---|---|
| a. |  | | | Unglazed collectors |
| b. |  | c. |  | Glazed flat plate collectors |
| d. |  | e. |  | Evacuated collectors |

used almost exclusively for heating swimming pool water (in rare cases for pre-heating of DHW). The main unglazed collectors markets are North America and Brazil.

### Glazed Collectors Plans

It is the most popular product in Europe. They have, almost exclusively, constituted by a metallic absorber, a glass cover, structural case and insulation. The absorber consists either of several metal fins or a single absorber plate. One of the most critical issues affecting the performance of flat-plate collectors is the coupling of the tubes, where the heat transfer fluid circulates, to the absorber. Different types of manufacturing technology, such as laser or ultrasonic welding processes, are used for this purpose. The optical characteristics of the absorber are the most important parameter for the thermal performance of the collector. The frame normally is made of aluminum, plastic or stainless steel. The collector is thermally insulated on the back and sides, a transparent cover (or more than one) closes the box on the top (Table 7.1). The connection pipes, inlet and return, of the fluid are fixed on the box.

These collectors are built in modules ranging from 1 to 12.5 $m^2$. The tendency is to manufacture larger modules, particularly for applications with large overall areas. Depending on the application, the solar collectors are installed on a simple supporting structure to provide optimum tilt and orientation, but they may also be integrated into inclined building roofs.

### Evacuated Tube Collectors

Among the main causes of heat loss in a solar thermal collector, there are phenomena that promote natural convection heat transfer between the absorber and the glass cover. To reduce or eliminate this phenomenon, vacuum is created in the volume between the absorber and the cover.

An evacuated tube collector always consists of single tubes which are connected to a header pipe. Each single tube is evacuated in order to reduce heat losses. The tubular geometry is necessary in order to withstand the pressure difference between the atmospheric pressure and the internal vacuum (typically a few Pascal). Evacuated tube collectors can be grouped into two main categories:

- Direct flow: tubes with flow of the heat transfer fluid through the absorber;
- Heat pipe: a strip of selective absorber is in thermal contact with the heat pipe. The latter at one side is in thermal contact with the heat carrier fluid.

The pressures required to reduce the most important phenomena of dispersion (convective) should be less than $10^{-2}$ bar. Below this threshold, the conductive heat transfer becomes negligible too. Most collectors are evacuated to pressures of about $10^{-5}$ bar. The losses by radiation are kept low, through the use of surface treatments selective absorber (high solar absorptance but low emissivity), as in the case of flat collectors.

### Other Collectors: Air Collectors

Among the different technological solutions which could be relevant to the application of solar thermal systems in developing countries, solar air collectors are the most relevant. They are particularly suitable in cases where warm or hot air is needed. The main operating principles are similar as for solar collectors with liquid heat transfer fluid. In these collectors the heat transfer fluid (air) is circulated through an electric fan. In Europe, the market for solar air collectors represents only 1–2 % of the solar liquid collector market. This is mainly due to the difficulty to apply them for the main solar thermal end user, the DHW production.

Typical applications for solar air collectors are heating of residential and non-residential buildings. They turn to be suitable for industrial processes where large flow rates of heated air are required. As example fruits, herbs or coffee drying in Latin America have been experienced.

As far as solar-driven air-conditioning is concerned, they can be coupled with desiccant cooling technology.

Solar air-collectors have the advantage to not suffer of freezing problems during winter or overheating problems in summer. They are rather simple and cheap components. On the other hand, they can be hardly applied to end users where the demand is not well in phase with the solar radiation availability. The latter derives from the difficulty to build storage systems which can be coupled with solar air collector fields.

## Typical Types of Plant

Worldwide, more than three quarters of all solar thermal systems installed are thermosiphon systems and the rest are pumped solar heating systems. The Chinese market which as aforementioned influenced the overall world figures most. It is dominated by thermosiphon systems for DHW preparation equipped with evacuated tubes. In general, these systems are more common in warm climates such as in Africa, South and East Asia, South America, southern Europe and the Middle East and North Africa region. In these regions thermosiphon systems are more often equipped with flat plate collectors.

The calculated number of water-based solar thermal systems in operation was around 67 million by the end of 2011. And 85 % of them were used for DHW preparation in single family houses; and 10 % were used by larger domestic hot water consumers, such as multifamily houses, hotels, hospitals, schools, etc. Around 4 % of the worldwide installed capacity supplied heat for both domestic hot water and space heating (solar combi-systems). The remaining systems amounted for about 1 %, equivalent to almost 3 million square meters of solar thermal collectors. They delivered heat to district heating networks, industrial processes or thermally driven solar air-conditioning or cooling applications.

In a global context, the share of large solar DHW applications is increasing (still about 20 % of the new installed capacity in 2011). While the share of the domestic hot water applications for single family houses decreases slightly (short below 80 % of newly installed capacity in 2011).

Nevertheless, the high rollout of single family house solar water heaters (SWH) will continue to play an important role in the renewable energy policy roadmaps of developing countries. An example is provided by the South Africa's one million SWH programme [6], with associated electricity savings of 34 $TWh_{el}$.

A diversification of the market by types of applications can hardly be detected in a worldwide context, but in several well-established markets in Europe the market penetration of solar combi-systems, solar supported district heating networks, industrial applications and solar cooling systems is increasing. Among the top 10 European markets in terms of newly installed glazed collectors in the year 2011, Germany, Spain, Italy and Austria have the most diversified solar thermal applications. They include systems for hot water preparation, systems for space heating of single- and multifamily houses and hotels, large-scale systems for district heating as well as a growing number of systems for air conditioning, cooling and industrial applications. In other markets, specialization in the field of certain applications became obvious: for example in Denmark almost two thirds of the newly installed capacities in the year 2011 were large-scale solar thermal systems with an average system size of 7,500 $m^2$ attached to district heating networks.

## *Natural Convection Solar Systems*

In Australia and in some Mediterranean countries (e.g. Israel, Greece, Cyprus, Turkey), as in many other more remote parts of the world, systems that do not require the operation of a pump are largely adopted. In these systems, the circulation of the fluid inside the collector is due to the temperature difference between the absorber and the tank. The latter causes a difference in fluid density that activates circulation by natural convection (e.g. density differences for water: 20 °C is 998 $kg/m^3$ and 80 °C only 972 $kg/m^3$). These systems present the tank located on the top of the collector and are suitable for small plants (normally for the production of domestic hot water). They are self-regulating, where the pressure drops due to the motion of the fluid in the circuit balance the forces due to convection. At least in the most basic forms, they are systems that operate without the need for a control unit or the installation of sensors. The natural convection systems are prefabricated and require a small effort for installation, especially on flat roofs. Once set on the roof, they only require connecting the inlet and return pipes. They do not require electricity for the operation of pumps nor a control unit.

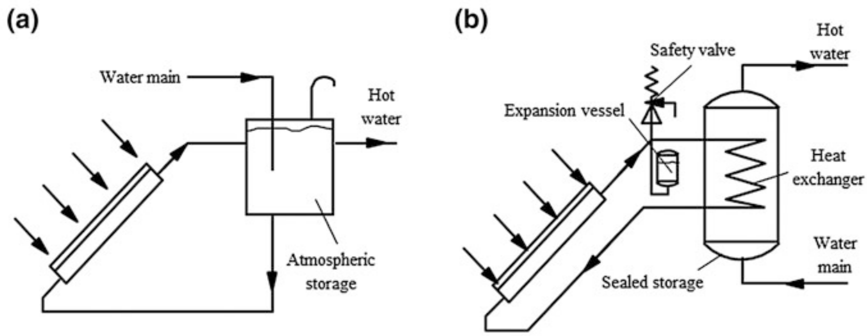



**Fig. 7.4** Simplified schemes of natural convection systems. **a** Natural convection (*open circuit*). **b** Natural convection (*closed circuit*)

The easier but less common typology is the open circuit, formed by collector that supplies an atmospheric storage (see Fig. 7.4a). In these systems, domestic hot water passes directly through the collector. Thus, the heat transfer medium cannot implement antifreeze protection, limiting the diffusion of such systems in places where water freezing does not occur. Moreover, the collector tubes require corrosion protection measures.

Another scheme of natural convection system for DHW production is the closed circuit, presented in Fig. 7.4b. As a preventive measure against freezing and corrosion, a closed-loop system is used, in which a heat transfer fluid flows between the collector and a heat exchanger connected to the sanitary hot water tank. The circuit is maintained in overpressure with respect to the external environment and has an expansion vessel and a safety valve. In climates where water freezing can occur, an antifreeze/heat transfer fluid shall be used. In this situation, the water pipes exposed to the external environment should be protected by appropriate measures (usually electric heaters with thermostat). The tank normally consists of a cylindrical heat exchanger. The domestic hot water is kept in the innermost section of the tank, whereas the heat transfer fluid connected to the collector flows around the external surface of the internal cylinder. Most of the plants built in the Mediterranean region adopt this scheme. They are made with a metal casing that contains the collector and supports the tank (both horizontal and vertical configurations are possible).

## *Forced Circulation Systems*

Most of the systems sold in Europe employ a pump and work with a heat transfer fluid consisting of water and an antifreeze component (propylene glycol often). In these plants, there is a clear separation between the circulating fluid in the primary circuit (antifreeze mixture) and the secondary circuit (water contained in the tank).

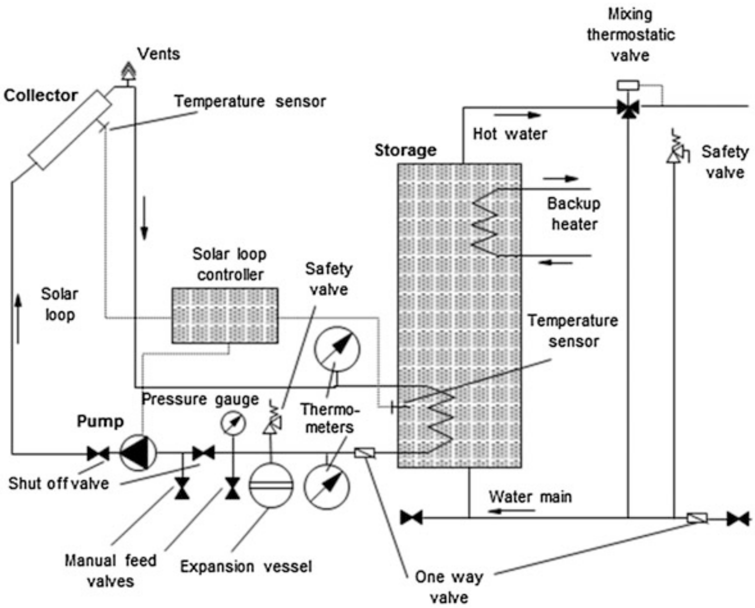



**Fig. 7.5** Simplified schemes of forced circulation systems

The thermal connection among the two circuits is ensured through a heat exchanger. In some countries the primary circuit, could contains only water.

In systems with forced circulation (see Fig. 7.5), a control unit will operate the pump of the primary circuit when the temperature at the exit of the collector array will be a few degrees higher than the temperature at the bottom of the tank, which is normally the lowest in the system. In this way, the heat transfer fluid from the collector field will be used to supply thermal energy to the fluid in the secondary circuit as well as in the tank. The collector is normally installed on the roof of the building, whereas the tank is normally placed in the basement. In the technical room of these systems the expansion vessel, manual vent valve, shut-off valves (before and after the pump assembly), manual feed valves and safety valve will be present. To avoid thermal losses due to undesirable phenomena of circulation inside the tubes (caused by the cooling of the fluid contained in the collector when the pump is switched off), one way valves are installed on the return branch from the collector field. For the control system at least two temperature sensors are required: on the output branch of the collector field and in the lower part of the tank. The differential controller uses a dead band (hysteresis) to avoid frequent on-off cycles.

### Forced Circulation Systems for DHW Production

These forced circulation systems are essentially based on a closed circuit. In this way, it is not necessary to have a tank for each collector and the storage can be installed at a distance from the collector, typically in the basement of the building. This will be beneficial for the reduction of the heat loss from the tank. Another advantage is the possibility to enhance the overall integration of the solar thermal system in the building aesthetics.

Most plants of this kind serve small capacity households. These plants have on average a solar collector field of 10 $m^2$ and a storage tank with a maximum volume of 400 L. The tank is usually equipped with two integrated spiral heat exchangers: a primary heat exchanger in the lower part of the tank, connected to the solar collector filed, and a secondary heat exchanger in the higher part of the tank, connected to the auxiliary generator. The same scheme can be used also for larger systems (e.g., multifamily dwellings, hostels, hospitals) with surfaces between 10 and 50 $m^2$ of the collector field. If DHW is used directly as storage medium, the overall storage volume can be divided in two series connected tanks: the pre-heating tank, connected to the solar field, and the auxiliary tank, partially supplied by auxiliary heater. Normally, external plate heat exchangers are employed instead of integrated ones. Moreover, in order to avoid the risks associated with the accumulation of DHW (i.e. Legionella proliferation), a large storage buffer tank can be used instead of large DHW tanks. The water in the buffer tank constitutes a closed circuit. Domestic hot water can be produced instantly through a dedicated heat exchanger or accumulated in a small DHW storage. More details on the control and operation of such systems can be found in the specialized literature [4].

## *Other Applications: Solar Cooling*

Space cooling via solar thermal collectors, better known as solar cooling, has drawn the attention of solar system's manufacturers. It allows optimizing the use of solar thermal energy for domestic hot water, whose contribution is among other things limited by the problem of summer overproduction. Therefore, it allows shifting part of the cooling loads from the electricity to the thermal domain, thus reducing the load on power grids.

The technology of solar cooling exploits the thermal energy to activate thermodynamic cycles similar to those of a gas refrigerator, which produce chilled water. It can be used for building air-conditioning or for refrigeration in industrial processes.

The solar cooling systems can be classified according to the typology of thermal driven cooling technology in: open cycles and closed cycles. In closed cycles chilled water is produced, which can be used for air-cooling or direct distribution of refrigerated water. The closed cycles are based on adsorption or absorption technologies, which use absorbent materials in liquid form (the first) and solid (the latter). In both cases, often can be used conventional solar thermal collectors, being sufficient an operating temperature between 65 and 95 °C. In the past, one limitation to this technology has been the lack of small size appliances (with capacities of less than 20 kW). Today, the industry has remedied this shortcoming by producing appliances with capacities as low as 5 kW. One of the peculiarities of these systems is the need, for most of the systems, of heat rejection systems. One of the peculiarities of these systems is the need, for most of the systems, of heat rejection systems. The latter are often considered the weak point (high maintenance and water consumption) of these solar cooling plants. Research on thermally driven machines capable to work with the same temperature level of driving heat and with dry heat rejection are currently undergoing.

Open cycles are used in air handling units implementing desiccant-evaporative cooling (DEC) systems. They cool the air directly through a process of dehumidification and evaporation, without the use of intermediate fluid; therefore, they can only be installed in buildings where a suitable duct system and air distribution (or more in general in applications where dehumidified air is needed—e.g. industrial processes) is provided. The temperatures required for the operation ranges between 55 and 90 °C and are therefore compatible, also in this case, with the majority of conventional solar technologies.

For what the industrial refrigeration concerns, some pilot projects and studies have been carried out in the last decade. In particular the application of dry cooled technologies has been investigated and the results published in [7, 8].

Technical details, design information and examples of application of these systems are out of the scope of this publication. Nevertheless, the reader can refer to specialized publications such as [1].

## Methods of Preliminary Design and Sizing

The main objective of the design and sizing of a solar thermal plant is to achieve a certain value of solar fraction (FSOL), defined as the ratio between the thermal energy supplied by the solar system and the energy needs of users in the span of twelve months. The size of the aperture area of a solar thermal system depends on the desired solar fraction. In general high solar fractions (the thresholds are strongly dependent on the application) are not advisable from an economic point of view. A good economy can be obtained by designing the system for complete coverage of requirements in the summer months, when there is a greater availability of solar energy. In the other months the plant will cover fractions of decreasing demand directly related to the worsening of the weather conditions.

### *Design of Solar Thermal Systems*

Design methods for solar thermal systems provide estimates of the annual thermal performance by taking into consideration both system boundary conditions (e.g. solar radiation, heating load) and main design parameters (e.g. collector area, storage volume). In general, the useful output of solar thermal plants is estimated by using hourly based energy simulations. However, simple design methods have been developed for standard solar thermal applications, like domestic hot water production and active heating in buildings where the minimum temperature of energy delivery is about 20 °C. The F-chart [9] is one of such methods. Based on the results of a large number of detailed simulations, the F-chart method provides a means for estimating the solar fraction for three standard system configurations, liquid and air systems for space and hot water heating and systems for hot water only. The monthly solar fraction ($f_i$) is correlated in terms of two easily calculated dimensionless variables, the monthly collector energy loss to heating load ratio (X) and the monthly solar energy gain to heating load ratio (Y):

$$f_i = aY + bX + cY^2 + dX^2 + eY^3$$

where the coefficients *a, b, c, d, e* are specific for each type of system configuration. The main design parameter is the collector area, which affects both X and Y. Besides collector area, the value of X depends on collector loss coefficient and monthly average ambient temperature, whereas the value of Y depends on collector optical efficiency and monthly average radiation incident on the collector surface. Additional factors shall be applied in order to account for collector-heat exchanger efficiency and storage volume. The interested reader can found more details on this method specialized textbooks [10] and EN standards [11].

## Conclusions

Solar thermal systems contribute significantly to the global renewable energy production. In this chapter, the main solar collector technologies have been presented. We focused on the most widespread application of solar thermal systems, i.e. the production of domestic hot water, whereas other less common applications (combi, solar cooling) have been briefly introduced. The market of solar water heaters is dominated by small systems for single family houses. The simplest type of plant is the natural convection system, which is self-regulating, prefabricated and easy to install, although its operation requires the storage to be placed on top of the collector. A better building integration can be achieved through forced circulation systems, in which a pump is used in the solar circuit and the storage can be installed indoor, usually in the basement of the building. Forced circulation systems are the preferred choice in large building such as multifamily dwellings, hostels and hospitals.

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# Part III
# Energy and Economy

The cost of energy represents a heavy financial burden for low-income people in developing countries. For the poor, the unit of energy obtained from candles or kerosene is much more expensive than electricity. While energy technologies represent one of the first elements to be considered for energy access, the different energy scenarios, the structure of the demand and the market, the financial mechanisms, and the business models must also be taken into consideration in designing strategies for the provision of modern energy services.

Chapter 8 focuses on energy as a driver of sustainable economic growth that can generate opportunities for the population to increase the quality of life. It reviews the demand structure within the low-income segment, from households to SMSs, and highlights the potential that access to energy brings about for income-generating activities, job creation, and development of untapped energy markets. The chapter examines also the business models used in providing different energy services to respond to household requirements as well as for electricity delivery and highlights the main drivers and barriers.

In Chap. 9, an overview of the financial mechanisms to support access to energy is given: the status of the investment is described from the World Bank perspective. A blend of public and private sectors financing, venture capital attraction, and availability of both project development and implementation financing are required to scale-up energy access expansion in developing countries. Energy access is today mainly financed by national governments, multilateral organizations, bilateral official development assistance, and the private sector. In this chapter, the need for further and more structured investments where the role of the private sector is increasingly central is discussed and justified.

Finally, Chap. 10 draws attention to the social dimension and to the participation of local communities in the design of innovative business models. The concept of business model is discussed within the context of inclusive sustainable development. The four elements characterizing business models for energy access are presented and discussed. Three case studies are analyzed and some success factors are identified: inclusive partnership approach with local players and communities, appropriate mix of finance models, establishment of local companies, cooperatives, or organizations, and integrated use of multiple energy sources and products.

# Chapter 8
# Energy and Sustainable Economic Development

**Stefano Bologna**

**Abstract** Access to clean, affordable and reliable energy is a fundamental driver of economic growth, environmental sustainability and social development. The correlation between energy and socio-economic progress is widely recognized. Energy interacts with people and their activities in several ways as it is needed for basic survival but also for improving productivity by the mechanization of agriculture and manufacturing and thus enabling income generation through improved agricultural and enterprise development. Nevertheless, the poor spend more time and effort obtaining energy than others and spend a substantial amount of their household income on energy just for basic human survival (cooking, drinking, keeping warm). The interaction between energy production, supply and uses with the environment has also to be carefully considered: the strategies that developing countries are going to choose for their energy mix can make a great difference for their domestic and sustainable growth, as well as for the impact on the global environment and on the global development in the long run.

## Energy as a Driver of Growth

"Energy is the lifeblood of the modern economy and development has been historically linked to the widespread availability of affordable energy. No country in modern times has substantially reduced poverty without an increase in its use of commercial energy or a shift to more efficient energy sources that provide higher quality energy services" [1].

By gaining access to energy services communities substantially improve their lives, particularly as they have more time, their health is improved and opportunities for income generating activities increase [2].

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The importance of energy for the poor goes far beyond their relatively modest requirements. In reality, household energy consumption in developing countries represents a much bigger proportion of total energy demand than in industrialized nations. As an example, 45 % of India total primary energy consumption takes place at the household level. The cost of energy also represents a heavy financial burden on the greater part of low-income people in developing countries. The energy unit obtained from candles or kerosene is much more expensive than electricity from the grid. Since the efficiency of kerosene lamps is very low, light cost as much as $3 per KWh, while the cost of solar lighting is about $2.2 per KWh. A 2008 World Bank study estimated that lighting from renewable energy sources results in $5–$16 per month in savings for poor household in developing countries. By considering these data, it is evident that the overall economics of renewable is becoming increasingly favourable.

The poor also spend a substantial amount of their household income on energy just for basic human survival (cooking, drinking, keeping warm). In Kenya low-income households spend more than 20 % of their total income on energy. In Brazil, low income households spend 10–20 % of their income on energy while higher income households, which rely entirely on electricity, usually spend 3–5 % of their income [3]. That explains the disproportionate impact that rising international prices of oil have on the poor population and highlights the direct correlation between macro and micro level energy security in developing countries. For example, a household survey conducted in Northern India estimated that, due to the increase of petroleum product prices, 39 % of households largely stopped using liquefied petroleum gas or kerosene for cooking [4].

The interaction between energy production, supply and uses with the environment is to be considered as an increasingly critical factor. The choices which developing countries make today for their energy mix will make a big difference for the global environment in the medium to long-term. Consumption of energy in developing countries is sharply increasing also as a consequence of population growth. As many developing and emerging economies are becoming important economic actors with increasingly significant responsibility in shaping the global environment, particularly climate change, the global impact of the decisions on energy is of critical importance [4]. Developing and emerging economies have the opportunity to choose a green path by integrating renewable energy technologies into their energy mix at an earlier stage of their growth rather than building unsustainable energy infrastructures. The earlier they make this choice the better their chances to improve livelihood and reduce their impact on the environment.

## *Income Generation*

Although adequate access to modern energy services is per se an objective that brings along immediate benefits, its full potential to trigger sustainable development can only be attained if it is used for income generation and not as an end in itself [5].

It is interesting to note that while the path out of poverty requires the availability and access to adequate, reliable and affordable energy services, poverty itself remains one of the main barriers to access energy. The result is that energy access is a crucial input for income-generating activities and, at the same time, generating income from energy access is also a key challenge in ensuring the sustainability of energy supply systems. Maximising the linkage between energy access and income generation is therefore crucial for poor people.

A wide range of energy services are required by Small and Medium size Enterprises (SMEs) and some of them may require energy in different forms such as electricity, heat and mechanical power at different stages of production and processing. The amount of energy required also varies according to the type of processing and the size of the enterprise. In any case, there are common requirements that energy supplied to enterprises must have such as reliability, adequacy or quality to meet the needs of the enterprise, and affordability as a reasonable proportion of the running costs.

One of the most critical limiting factors, widely recognized by African entrepreneurs is the insufficient and unreliable supply of electric power. Manufacturing industries in Africa experience on average 56 days per year of power outages, with peaks at national level of 140 days. As a result, firms lose 6 % of sales revenues in the informal sector. Where the utilization of expensive back-up generators is limited, losses can be as high as 20 %. This economic cost has been estimated as 4 % of GDP in Tanzania, 5.5 % in Uganda and 6.5 % in Malawi [6]. These deficiencies in the power sector threaten Africa's long term economic growth and competitiveness.

SMEs in developing countries satisfy most of their energy requirements through electricity and heat derived from fossil fuels. In view of the rapidly rising cost of these fuels, enhanced use of renewable energy technologies would not only improve the local environment, but also increase the productivity and competitiveness of the SMEs and offsets unreliable energy supplies from national grids [7].

Lack of access to adequate energy services is not hindering only existing business by lowering its outputs and limiting its growth, but it greatly reduces the opportunities for local value addition generated by productive activities that would enable poor people to earn an income. Energy access can provide the expansion and enhancement of productive activities by improving existing earning activities, creating new earning opportunities and reducing opportunity costs linked to the provision of energy.

The provision of access to energy services in its own brings about opportunities for entrepreneurial activities and business development. The provision of fuel, conversion equipment and appliances offers opportunities ranging from production through distribution, sales and maintenance which are present throughout each value chain and extend to by-products and wastes.

Moving from imported to locally produced energy services and equipment such as bio fuels, improved stoves, solar panels and lanterns can have a positive effect on the growth of the local economy. However, cost, quality and the existence of proper distribution and servicing capacities, is important to determine the profitability and the success of the business.

In addition to the opportunities for new productive activities, there are less-readily quantifiable short and long-term impacts deriving from the opportunity costs associated to the lack of access to energy that are recognized as having a relevant impact on earning potential. They include time spent on education or income generating activities, greater productivity that results from better quality or more reliable lighting, better health resulting from eliminating noxious gases associated with inefficient cooking stoves [8].

## *Job Creation*

Compared to the traditional concentrated and capital intensive production and distribution energy systems, the deployment of renewable energy systems to provide access to modern energy services has the potential to create a larger amount of new jobs per unit of energy delivered throughout the entire value chain.

The IAEA estimates that achieving universal energy access by 2030 will require 952 TWh of electricity generated per year, of which 400 TWh will come from mini-grids and 172 TWh from isolated systems [9]. If this transition is to happen, a large number of new jobs would be created in the decentralized energy sector. While sufficient data exist on the green jobs that can be created by moving towards a low carbon economy, little information has been gathered on the number of jobs that access to energy may generate. The increase in energy access is linked to the increase in economic growth which, influenced by other factors such as productivity, increases the availability of jobs. However, the relationship is complex and employment growth is not always a direct consequence. In practice the correlation between energy access and the availability of jobs depends mostly on the growth of the enterprise and the employment intensity of that growth [10].

The supply of energy itself represents an important employment sector. Indeed, there is a great potential for employment in processing renewable energy inputs like biomass, in producing, selling, installing and servicing both the devices that transform renewable energy sources into usable energy (solar panels and lanterns, wind turbines, biogas digesters, cook stoves) and the equipment and appliances that turn energy into the desired services (heat, light, refrigeration, mechanical power). Some current employment figures confirm the significant potential. India, for example, estimates that its off-grid solar photovoltaic sector employs 72,000 people and its biogas sector 85,000. China’s biogas industry has employed 90,000 workers from 2006 to 2010 and its solar water heating sector may involve 800,000 people. Smaller countries too have started creating new jobs in off-grid renewable energy systems. Bangladesh has an estimated 60,000 people involved in the solar heating system sector. IRENA predicts that almost 4 million direct jobs in off-grid renewable electricity generation could be created by 2030 if the Energy Access for All Scenario is fulfilled [8].

When elements such as job creation, reduction of fossil fuels consumption and other environmental considerations are targeted by governments aiming at medium to long-term economic benefits the impact on the life of people and the country sustainable economic growth can be significant. Brazil for example has decided to take this approach by investing on the production of ethanol. This lead the country to be the world most advanced country in this sector. Due to the labour intensity nature of alcohol production in Brazil, 700,000 jobs were created with additional three to four times this amount in indirect jobs. The cost in creating one job in the ethanol industry is around twenty times less than a job in the chemical industry [5].

## A New Market

The International Finance Corporation and the World Resources Institute estimate that the 4 billion people living on less than $8 per day spend $433 billion per year on poor-quality energy solutions to meet their requirements [11]. This is a considerable and largely unexploited market and shows that there is a huge and growing potential for companies to supply clean, affordable and reliable energy services to the low income households.

Energy closely follows food and housing as the biggest expense for low income households, which spend an average 9 % of their overall expenditure on energy. Households with an annual income of up to $500 spend on average $148 per year on energy, while those earning between $1,000 and $1,500 per year spend about $360 per year. These amounts are comparatively small, but in total they represent a market of significant size [12]. In some countries, the poor comprise the largest share of the energy market. It accounts for 90 % of spending on non-commercial energy in countries such as Nigeria and Indonesia and more than 50 % in countries such as Brazil, India and Uganda.

The poverty penalty is a phenomenon occurring in developing countries that refers to the higher cost shouldered by the poor, when compared to the wealthier, in purchasing the same product or service. A study by Micro-Energy International showed that 1 kWh costs $2.30 in Bangladesh compared to about $0.30 in Western Europe. The cost of lighting can also be much higher. In the year 2000 in Guatemala 1 kWh of light cost $0.80 from the grid, $5.87 from kerosene and $13.00 from candles [12]. People in these contexts are certainly prepared to pay for clean, reliable energy services produced from renewable sources. An analysis carried out by the IFC shows that more than 90 % of households, which have no access to smokeless lighting and cooking systems can afford better products and services. In fact, they already spend more on conventional energy than on cleaner and more modern energy [13].

While the socio-economic rationale, the increasingly lower cost of renewable technologies and the market potential are evident, the economic reason in support of private investment in energy access has not always been obvious. Apart from the challenges linked to addressing low-income markets, due consideration should be given to the distortion created by omitting the cost of externalities and the effect of subsidies. In fact, an overarching barrier that affects both developed and developing countries in shifting from fossil fuels and adopting renewable energy technologies is the failure of energy pricing to account for externalities, or for the environmental and social cost of conventional energy production. This has suppressed renewable energies for decades by making fossil fuels appear cheaper than they really are [14]. If the true cost of production, distribution as well as the costs linked to the use of any source of energy are taken into account, including externalities, investments on renewable energy technologies become more financially attractive. The energy game is biased in favour of fossil fuels because we omit the environmental and health costs of burning coal, oil, and natural gas from their prices. Unfortunately, conventional energy sources are given even greater market advantage over renewable energy technologies as most governments, including developing countries, provide substantial subsidies to fossil fuels. Conservative estimates by the Global Subsidies Initiative and the International Energy Agency (IEA) indicate that governments spent globally in excess of $620 billion to subsidize fossil fuel energy in 2011. Of these, about $100 billion were spent for production and $523 billion for consumption [15]. A recent study by the Overseas Development Institute gives a clear idea of the magnitude of the distortion considering that, "within developing countries, subsidies to consumers for fossil fuels in 2011 are 75 times higher than the average annual approved climate finance from 2010 to 2012. Five countries (China, Egypt, India, Indonesia and Mexico) appear in both the list of top 12 recipients of climate finance and the list of top 12 providers of fossil fuel subsidies to domestic consumers" [16].

The above figures become even more significant when they are compared to the estimates of the investment required to provide universal access to energy. According to the International Energy Agency, the investment required to attain universal energy access by 2030 is $36 billion per year of which $33 billion for electrification and $3 billion for clean cooking [9]. Comparing this investment requirements to the $433 billion per year spent on energy by the poor reveals the significant market potential for energy services based on renewable energy. Indeed, markets in developing countries are rapidly expanding. Renewable energy technologies in China and India are growing at a sustained pace. Brazil produces most of the world's ethanol derived from sugar and has built new power plants based on biomass and wind energy. Renewable energy markets are developing at fast pace in countries such as Argentina, Costa Rica, Egypt, Indonesia, Kenya, Tanzania, Thailand, Tunisia, and Uruguay.

## Business Models for Energy Access

As energy from renewable sources is becoming increasingly economically attractive, governments in developing countries are studying the potential of private companies to provide energy services to the poor. However, most of the business-driven energy projects aiming at providing energy access to the people at the bottom of the pyramid have yet to gain significant scale [12]. The landscape of players is diverse, ranging from multinational companies and large utilities to small and medium sized renewable energy companies, to social enterprises from developing countries or spin-offs from design centers and universities.

There are two main areas that broadly define the market where improved energy access generates business opportunities:

- Household devices and systems. These include solar lamps, solar thermal systems and improved biomass cook stoves. They are a first step up towards the satisfaction of basic energy needs and are often the most cost-effective option for household dispersed in rural areas as well as for those living in urban slums to gain access to basic energy services such as lighting and clean cooking.
- Electricity delivery systems, which include grid extension and distributed off-grid systems.

While the first can be a viable option for locations nearby existing grids that can dependably provide extra power supply, the second comprise stand-alone and community-level mini-grid systems that can be fed by hydro or diesel electric generators but progressively more making use of other energy sources such as biomass, solar, and wind. Considering the costs required to deliver energy to many rural communities from centralized systems, distributed energy systems are often a more suitable and economic solution in providing access to energy. The International Energy Agency estimates that to gain access to electricity, 70 % of rural populations will require distributed solutions [9]. This Chapter focuses on the delivery models used for decentralized production and particularly community-based mini-grids, as there is evidence to show that these can be the cheaper forms of electrification (on a per unit basis, calculated over the system's lifetime).

## *Contextual Drivers and Barriers*

Business models are determined by a combination of technology, finance and management and are influenced by a variety of contextual factors such as economic policies and laws, trading and quality standards, financial services like credit and guarantee schemes and incentives such as feed-in tariffs and tax relief schemes. Energy delivery systems deal with common and specific technical, financial, organization and ownership issues by adopting innovative ways to address the challenges of providing affordable and reliable energy services, overcoming market barriers and market failures, and increasing the profitability and up scaling of sustainable energy systems in low-income energy markets [17].

### Social and Economic Constraints

A relevant part of the challenges lies at the social level, which encompasses local cultural preferences, awareness of technologies, availability of skills, local leadership and social organization. It is not easy to convince new customers that a product or service is worth buying if they never heard of renewable energy. Indeed, the socio-cultural context influences the people's recognition of the benefits of modern energy services and therefore their willingness to pay, their awareness of technology options, their capacity to adopt and maintain new technologies and the way they use the energy [18].

User acceptance is thus critical and women engagement often proves a key element to facilitate the adoption of new technology. Moreover, ensuring that the services provided are regularly paid can be a problem when customers have no access to bank accounts and have limited cash flow. Low-income markets can certainly support commercially viable businesses, but financing solutions that are based on end-users' ability and willingness to pay must be sought and income generation activities and creation of flexible payment schedules must be promoted as part of the business model.

From the economic stand point, renewable energy systems usually involve high initial investment and low running cost. One of the key social challenges to address is the so called "economics of poverty". Impoverished people tend to choose the lowest upfront investment and shy away from higher investments that pay off over time. This is partly due to limited cash and lack of micro-financing, but also has a strong "cultural habit" to focus on the near future.

### Partnering and Local Presence

Local presence and expertise should be ensured through innovative partnerships that entail hybrid business models where social enterprises could play an important role. The localization of the appropriate technology with local production or, at least, assembly can speed up the uptake of the commercial sustainability. Moreover, the provision of reliable customer support services when skills and competence are lacking is also a challenge. Capacity building through training and access to information is thus essential to ensure installation and after sale services.

One of the most important factors for firms and organizations supplying energy devices is to secure efficient and reliable distribution channels. Distribution is certainly an important factor both for appliances and power when the users are scattered in remote locations. "Partnering strategically with companies that have already established strong distribution channels is one way of getting products to market more quickly" [13].

In addition, market information is often scarce, physical infrastructure such as roads are often poor and legal frameworks and enforcement mechanisms are underdeveloped and unreliable. Linking with mobile network operators could provide significant synergies, since the products are complementary as cellular phones need to be charged and they need similar supply chains for their distribution. In working together with non-traditional partners like non-governmental organizations and microfinance institutions is important to develop supply and distribution channels and marketing. Firms and organizations engaged in the provision of equipment and appliances should also ensure sufficient working capital to enable retailers to have an adequate stock of products.

### Technical Solutions and Financial Aspects

The technology choice is also important as it influences all other factors. Although the economic situation of rural areas often pushes for technology choices made on a short term least-cost basis, quality has a strong influence on the system's lifetime. Any compromise made on the quality of system components will impair the attainment of the real long term lowest generation costs. In order to increase efficiency gains and cost savings, priority should be given to sizing the system appropriately and to energy efficiency. In fact, regardless of the choices, energy efficiency is very important since it can dramatically influence the energy load, and therefore the amount of power generation required. This will impact on investment costs and the financial viability of the project. In fact, for most countries supply and demand side management should constitute the first energy policy.

Financial and operation issues are critical to the long-term sustainability of mini-grids. Questions such as operations and maintenance, role of the private sector, tariffs and subsidies, and capacity building and training are essential considerions when developing rural electrification programs. This is particularly true with the use of hybrid mini-grids. Today, off-grid systems based on renewable energy sources are already mature and cost-effective solutions for rural electrification. Their attractiveness will increase even more as technologies progress and cost decrease in the years to come.

### Business Models for Household Needs

Notwithstanding the increasing number of products and appliances which successfully entered the market, the household level is still a difficult market segment. This is primarily due to the low margins and the need for often fairly complex partnerships and distribution channels. Another challenge is represented by the difficult access to finance experienced by both suppliers and customers. In developing business models for the household market it is necessary to deal with a several aspects along the value chain relating to design, manufacturing, marketing and distribution, finance, and after-sales service [17].

In addressing the household level, firms and other energy service providers should primarily aim at affordability in all aspects. Firms serving the bottom of the pyramid always require sufficient volume to compensate for typically low margins. Affordability is critical for both household and decentralized systems and across all business models. This can be achieved through innovative design for products and services, innovative business models and provision finance for consumers [17]. Successful business models for the low income energy market are based on long-term commitment with a focus on the return on investment rather than on profit margin. Based on the experiences accumulated in several projects, there is a unanimous consensus among development stakeholders that, whatever the technology chosen, the distribution of free of charge systems should be absolutely avoided. It is essential that customers commit from the very beginning in order to appreciate the value of the system [18].

### Business Models for Electricity Delivery Systems

There are different business models which have been experimented in delivering of decentralized energy though off-grid systems. These are driven by various actors such as local governments trying to foster economic activity, communities looking for improved access to energy, and entrepreneurs looking for establish profitable businesses in the energy sector. These models have different features and advantages. Government models typically reach a broader range of consumers. Community-driven models will often have a stronger local support. Private sector led models often emphasize the financial viability.

The definition and classification of business models in relation to the operational aspects of the delivery system is complex due to variety of roles that the different actors can play in relation to ownership, financial mechanisms, flows of goods, services and money. The majority of innovations in business models for energy access are based on partnerships for the development, production, distribution and maintenance of energy systems and services in which local entrepreneurs, social enterprises and non-traditional commercial partners such as non-governmental organizations and community groups are involved.

The development of sustainable energy delivery systems can follow several business models according to local social and economic conditions. Community based service models are organised around cooperatives or NGOs and are mainly used for mini-grid systems in remote areas that are not attractive enough to private entrepreneurs or utilities. In this case, the communities are at the same time owner and operator of the system and as such provide management and maintenance services and collect payments. In Latin America, many small rural suppliers have the legal status of cooperatives, while some of the medium-sized systems are co-owned by municipalities or prefectures that own and operate their own systems. In China ownership is frequently at the village level. In many countries, the community model is the only option in isolated areas. An advantage of this model lies on the fact that the owners and managers in a cooperative or community-based organization are also the consumers and therefore have a strong interest in the quality and reliability of the service and ensure their presence in managing it. Conversely, community based energy services often lack the technical skills to operate and manage the system and the business skills required to ensure the financial sustainability. To overcome these weaknesses substantial technical assistance is required to ensure that awareness among the users, nurturing of the business and an adequate level of technology exists. Another challenge is the higher risk of social conflicts within a community. Disputes of who has paid for what, who should benefit and at what price needs to be addressed by taking into consideration social, technical and economic issues. Also due to this, community-owned systems require a long preparation and a great deal of technical and social capacity building to be successful.

Private sector-led energy delivery systems often occur when government support raises the interest of firms, but in some cases also spontaneously. Economic considerations that prove the business sense of the venture prevail in this model to attract private companies. In fact, more and more private sector service providers enter into the rural energy market through subsidy schemes or regional concessions. System location and scale, income profiles of potential customers, as well as available subsidies determine the decision of private companies to invest. If on one hand the private model is in principle the one with the greatest potential as it usually provides electricity more efficiently, on the other hand it could also be the most difficult to set up in practice. Compared to public utilities, private firms are often more able to navigate political interference. A key challenge is how to maximise private sector participation and minimise subsidies. A private-sector model can take different forms according to the ownership of the system, the type of contracts and the type of subsidies. In the fee for service model, the private firm owns the system, ensures its operation and maintenance and provides a service to the end user. In the dealer model, the end user buys the system from the dealer and assumes all responsibility of operation and maintenance. A similar model is when the equipment is leased to the end user who can take up ownership at the end of the lease period [19].

According to the World Bank, utilities are still the major actors in providing rural electrification in developing countries. The principal advantage of this approach is that the primary responsibility lies with an experienced party with the financial resources and technical capabilities to implement and manage the project. An advantage of the public utilities in providing electrification is the capacity to focus on the needs of the sector and impose strategic and cross subsidised tariffs. In this way areas where electrification is cheap and profitable can contribute to areas in which electrification is very expensive and non profitable. The disadvantage of public monopoly is that they are often driven by political agendas and lack the understanding of specific community needs. The success of these models usually rely more on the innovative business approaches adopted by the utilities, rather than on the traditional public-oriented programs. The utility model is also raising skepticism. If utilities were to be the key to full access to energy in developing countries, electrification rates would significantly outpace population growth, which is not the case for most developing countries. On the contrary, the liberalization of the energy markets that has taken place in most developing countries has tied utilities to market-driven priorities, and running remote, low-revenue mini-grids in rural areas of developing countries is certainly not a priority for many utilities [20].

Hybrid models combine different approaches to benefit from the advantages of each of the models and to minimize deficiencies. Accordingly, they can vary substantially, by adopting different types of operate and manage contracts and combining different ownership structures (i.e., one actor owns the grid, the other the generation capacity). For example, a utility or a private company implements and owns a renewable energy system, a community-based organization manages it on a daily basis and a private company provides the technical back-up and management services. The collaboration enjoys the technical expertise and experience of the utility with the possibility to realize economies of scale in the realization of big infrastructure works (grids), the local involvement of the community-based organization, and the financial investment, technical expertise and efficiency of a private company [19].

## Conclusion

The Sustainable Energy for all initiative, launched in 2012, places huge emphasis on the role of the private sector in delivering universal energy access. However, the private sector alone often cannot reach the poor as profit margins and time frames are less attractive. Pro-poor models usually require “non-traditional” business partners such as government, non-government organizations, social enterprises and communities so as to ensure that all the interlinked elements needed to ensure the success and sustainability of the operation are considered: the economic and financial feasibility, the appropriateness of technology, the favourable policy environment, the adequate regulatory and tariff system, the buy in by the local community and the adequate support services.

Significant progress has been made to deliver modern energy services to the global poor. However, achieving universal energy access is a global change which is difficult to imagine considering that the number of people without access continues to grow. New models which go beyond what seems possible today are needed. A mix of products, delivery models and actors need to be put in place with significantly greater levels of activity than there are today [10].

To achieve this ambitious goal involves a mix of actors, public institutions, private companies and civil society forming innovative partnerships. When progressive policy makers, innovative firms and frontier financiers meet together, the resulting business models can make a substantial contribution in closing the energy access gap.

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# Chapter 9
# Financing Energy Access

**Koffi Ekouevi and Gabriela Elizondo-Azuela**

**Abstract** Modern energy services are essential to human development, productivity, competitiveness, and economic growth [1–3]. Despite gains over the last three decades, based on 2010 data, about 1.3 billion people do not have access to electricity and about 2.6 billion people still rely on traditional biomass fuels such as fuelwood, charcoal, agricultural waste, and animal dung for cooking and heating [4]. Most of the people without access to modern energy services live in Sub-Saharan Africa and South Asia. The majority of them, about eight out of ten people, live in rural areas [4]. It is projected that close to 1 billion people will lack access to electricity and 2.6 billion will continue to use traditional biomass fuels in 2030. Innovative financial mechanisms blending public and private sector resources are required to address this development challenge.

## Status of Investment in Energy Access

It is recognized that a blend of public and private sectors financing, venture capital attraction and availability of both project development and implementation financing are required to scale up energy access expansion in developing countries [5]. Energy access is mainly financed by national governments, multilateral organizations, bilateral official development assistance (ODA), and the private sector. According to the [4], in 2009, about $9.1 billion was globally invested in energy access to provide electricity access to 20 million people and to provide access to clean cooking solutions to 7 million people. The share of multilateral organizations in this investment is estimated at 34 % that of national governments

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at 30 %, followed by private sector and bilateral ODA with shares estimated respectively at 22–14 %.

It is usually difficult to have data to disentangle investment on energy access from overall investment in energy operations. Many of these operations have multiple purposes and overlapping components. In addition, in countries where electrification access levels are low, the majority of investment in the energy sector such as generation, transmission and distribution has the potential to impact electrification levels. A review was conducted by Barnes et al. [6] on World Bank energy investment portfolio over fiscal years 2000–2008 to highlight the share of energy access investments. This review revealed that investment on energy access represented about $4 billion out of a total energy investment of $20 billion of the period. Out of a total of $4 billion investment on energy access about $1.8 billion was devoted to physical investment in electricity access and investment on energy for cooking was only about $164 million.

Regional development banks such as the Asian Development Bank (ADB) and the African Development Bank (AfDB) are key institutions providing financing for energy access. An increasing trend is observed in ADB financing on energy access as promoted by the Energy for All Initiative launched in 2008 [7]. For the year 2010, about $955 million was devoted to energy access investments. The Energy for All program aims at providing energy access for 100 million people by 2015. Regarding the AfDB, its energy sector policy document recently released clearly indicates the need to further support energy access in Africa. It is reported that the volume of its investment in 2009 represents about 15 % of the total investment needed in Africa for universal access estimated at $23.8 billion per year till 2030 [8].

In addition to multilateral organizations, national governments are leading the financing of energy access in many countries. In emerging countries such as China, Brazil, India, and South Africa, large scale energy access initiatives including off-grid renewable energy programs are being implemented. These initiatives are benefitting from high level of political commitment backed with substantial public resources allocation over medium to longer terms. In the case of South Africa, for example, the 1994 Parliament approval of a plan ensuring equal access to basic services to all South Africans was an important milestone. This was followed by the South African Department of Energy's decision of 2001 to allow other entities than ESKOM the national utility, such as registered municipalities to receive national funding to finance rural electrification programs [9]. A political mandate with a reliable public funding mechanism created a good momentum for the development of off-grid renewable energy programs.

Some developing countries such as Bangladesh, Sri Lanka, Mexico, Mali, and Kenya have also developed encouraging access programs including a growing share of renewable energy technologies with a blend of public and private sector resources. In this regard, the example of Bangladesh is a spectacular one. The Rural Electrification and Renewable Energy Development Project is currently installing over 50,000 solar home systems per month. This project is supported by a $130 million zero interest International Development Association loan approved in 2009 with and additional financing of $172 million loan approved loan in 2011. An operational institutional arrangement consisting of a partnership between the Bangladesh Infrastructure Development Company (IDCOL) with about 40 non-governmental organizations including private sector companies and micro-credit agencies is fundamental to the successful performance of this project [10].

The increasing development of off-grid initiatives including the deployment of renewable energy technologies in rural areas responds to the realization that national utilities cannot by themselves through grid extension alone address the energy access expansion agenda. Off-grid energy solutions whether through individual systems or stand alone mini-grids are being adopted in situations where there are high costs of grid extension to connect communities remotely located from the grid and usually with low load density. The continuing commercial maturation of solar photovoltaic systems, small wind generators and micro hydropower have contributed over the last 10 years to deliver energy services to communities that the grid was not able to reach [11].

Large scale off-grid renewable energy programs have succeeded in addressing the intensive initial capital costs barrier through many financing instruments. Usually, a form of subsidy is applied to incentivize operators to adopt renewable energy technologies while developing electrification schemes in remote communities. The buy down of initial capital costs has facilitated the pace of deployment of renewable energy systems over the last 10 years. The subsidy mechanism applied in the case of the Bangladesh program includes financing incentives features such as long tenor loans, grants covering up to one third of the capital costs, low interest loans and about 5 year grace periods [12]. In the case of Mali, Senegal, and Uganda rural electrification funds provided up to 80 % subsidy on the initial capital costs allowing energy service companies to engage in rural electrification schemes with rural energy technologies. Other countries such as Costa Rica and the Philippines have adopted Rural Electrification Cooperatives to oversee the overall planning and implementation of off-grid electrification programs.

While there is a growing momentum on the importance of modern energy access to poverty reduction and inclusive growth, the current levels of investment on energy access are way short compared to the investment required. Bazilian et al. [13] found that financial flows related to the energy sector in developing countries are significant but still inadequate in view of the task at stake. Cook [14] noted that overall private sector has not developed electrification in rural areas on the scale envisaged with privatization and the variety of approaches pursued to increase private participation in infrastructure.

## Investment Needs for Modern Energy Services

The UN Sustainable Energy for All goals offer a platform where renewable energy technologies can be developed and play an increasing role in meeting the energy access challenge in developing countries over the coming years. The growing

**Table 9.1** Cumulative investments to facilitate access to modern energy service, in billion USD [15]

| Goal | Cost estimates (billion USD) Electricity | Cost estimates (billion USD) Cooking | Period | Source |
|---|---|---|---|---|
| Universal energy access | 700 | 56 | 2010–2030 | [16] |
| Improved access to reach MDG1 | 223 | 21 | 2010–2015 | [16] |
| Universal energy access | 35–40 per year | 39–64 | 2010–2030 | [17] |
| Universal electricity access | About 55 per year | | | [18] |
| Universal electricity access | 35 per year | | over 2008–2030 | [19] |
| Improved access to clean cooking | | 1.8 per year | to 2030 | [20] |
| Universal electricity access | 858 | 2005–2030 | 2005–2030 | [21] |
| Improved electricity access to reach the MDGs | 200 | | over 2003–2015 | [22] |
| Universal electricity access | 665 | | over 30 years | [23] |

awareness on the adverse impacts of climate change, volatile prices of fossil fuels, poverty and social inequalities are other factors that are expected to support the development of renewable energy programs in rural communities. Many attempts have been made to estimate global investment needs for modern energy services. A selected number of these estimates are summarized by Table 9.1. The range of these estimates result from a variety of methodologies and assumptions [15].

As part of the UN Sustainable Energy for All Initiative, a growing attention is on financing of universal access for all. Using their energy for all case, the IEA estimates that a total of about $1 trillion ($979 billion) would be needed to achieve the goal of universal access for all by 2030. This represents about an average of $49 billion per year from 2011 to 2030 [4]. The volume of this investment is estimated at about 3 % of the global energy related infrastructure investment. In terms of its impact on climate change, universal access is estimated to only increase CO2 emissions by 0.6 %. Investment needs are the highest for Sub-Saharan Africa where rural electrification levels are low and a high percentage of the population still rely on traditional biomass fuels for cooking and heating. About 64 % of the additional investment required will be for Sub-Saharan Africa followed by developing Asia with 36 %.

The Global Energy Assessment has identified the following pathways to improve energy access in developing countries: (i) diffusion of clean and efficient cooking appliances; (ii) extension of both high-voltage electricity grids and decentralized micro-grids; and (iii) increased financial assistance from industrialized countries to support clean energy infrastructure. Examples of policies and investments were analyzed and costs were estimated. It is estimated that to provide clean cooking about $17–$22 billion per year would be needed by Sub-Saharan Africa, South Asia, and Pacific Asia. These estimates include fuel subsidies to buy down the cost of cleaner fuels, grants or micro-lending, to help address affordability issues at the level of households [24].

These global estimates of investment needs for energy access are contributing to retain the attention of policymakers of the magnitude of the mobilization of financing resources to achieve universal energy access for all by 2030.

## An Increasing Role for Private Sector Participation

Private sector participation has been mostly directed towards the market segments where the expected revenue flow is more sustainable and less bounded to uncertainty (for example, in grid extensions, but also in mini grids or in off-grid solutions delivered to higher income consumers such as financially thriving farmers or households with the capacity to pay tariffs that allow cost recovery). Financing the delivery of universal modern energy access will require the efficient and coordinated deployment of both public and private resources across the spectrum of existing and emerging instruments and schemes.

With the growing recognition of the potential for low-income customers to become fast-growing markets for goods and services—as in the mobile industry—and the emergence of new models for serving them, rural energy markets are increasingly being recognized as potential business opportunities. Across the world, there are a number of initiatives in clean energy to serve the off grid market—solar portable lights, household biogas, solar home systems- that have managed to scale-up through leveraging private finance [12, 25, 26].

In many cases, the financing of mini-grids allows private sector financing. For example, in Laos, a successful PPP has been established to fund a hybrid mini-grid (hydro, solar PV and diesel), serving more than 100 rural households. In the project, public partners fund the capital assets, while the local energy provider finances the operating cost [27].

Notwithstanding, today there are many examples of private firms running successful and innovative mini-utilities with renewable energy. For example, enterprises such as Husk Power Systems and DESI Power, both mini-utilities using biogas, are already operating several profitable systems in India [25].

The commercial dissemination of PVs to serve household and small business electricity needs has been tested for about two decades mainly through the so-called dealer and fee-for- service models. Both models rely on concessions or exclusivity rights to serve a specific area or territory and typically rely on targeted subsidies (for example, full or partial capital cost subsidies and output based subsidies). The financing scheme in these models typically rely on a combination of public and private sources that includes capital grants from budgetary or concessional resources, equity from private sector parties or participating companies and micro-financing to allow customer participation.

With time, these schemes have been adjusted to include different types of PPPs more aligned to specific business environments. For example, the Bolivia

Program—based on medium term service contracts with output-based aid—combines the dealer model with the traditional ESCO concession scheme whereby the exclusivity term is reduced to only 2–5 years and opened to a broader menu of ownership options. Other models include leasing arrangements; for example, in Honduras and Dominican Republic Soluz is providing SHS services via direct lease or lease-to-own arrangements [12]. In these cases, rolling out micro-financing schemes has been key to the success of the model. The experience with the dissemination of PV and other devices over the last two decades has highlighted a few important lessons including the importance of after-sale activities, availability of micro financing and the creation of enabling business environments.

New venture funds have recently emerged, generally seeking energy access investments in projects that exhibit a combination of unique characteristics including strong or proven business models, experience management and technical teams as well as a degree of financial sustainability [25]. At the same time, the experience gained from first-generation market development projects in clean energy shows that, in almost all cases, significant public resources have been necessary to increase affordability, provide access to financing, and remove non-economic barriers. In some cases, even with high capital subsidies, the up-front costs of technological solutions exceed by an order of magnitude the upfront payment capacity of poor households. Access to financing adapted to the cash flow profiles of poor households will therefore be a key enabler for scaling up clean energy markets [26].

## Conclusions

Promisingly, innovative multi-stakeholder business models are continuously emerging to provide customized and financially sustainable services based on renewable energy across the spectrum of rural energy needs. Yet, even with a strong focus on market development and PPPs, the financing of universal energy access ultimately depends on how strategically- and efficiently-available public and concessional resources—as well as carbon financing—are used to attract private investment. The solution seems to lie predominantly on two aspects: creating the business environment conditions to attract private sector participation (robust legal and regulatory frameworks, contract design and other) and engineering financing schemes that take into consideration and address the range of risks that affect all involved stakeholders.

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# Chapter 10
# Integrating the Social Dimension into New Business Models for Energy Access

**Irene Bengo and Marika Arena**

**Abstract** In the last decades, the issue of energy access has attracted increasing attention from both academic and practitioners and the debate has gone beyond purely technical issues, raising the interest of the public opinion and private citizens. Particular attention has been given to the question: how private and public organizations can ensure energy access to everybody? From this perspective, this Chapter aims to analyze and discuss three cases of social proactive organizations in the energy sector in order to highlight how they have succeeded in combining social values with environmental and financial sustainability. New business models aiming at reaching low-income communities with efficient and sustainable energy systems should take into account all social aspects linked to the energy supply chain from production, distribution to final use and ensure the active participation of local communities. This ensures that energy access initiatives lead to effective results in terms of industrial and manufacturing activities but also contribute to improve health, education and livelihoods.

## Beyond the Technical Dimension

Within the global debate on access to energy for all it is more and more recognized that the role of technologies, though central, may not be the only focus.

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From this perspective, current business models have shown some drawbacks and limitations. On the one hand, the recent economic crisis has underlined the critical weaknesses of the current economic system in answering to the interdependency principles and social problems of global development [1]. In addition, for-profit organizations have been increasingly recognizing that, to survive and succeed, they cannot focus only on short-term profits, but they need also to consider their contribution to environmental and social sustainability. They have started to gradually acknowledge the existence of a potential synergy between "sustainability, social responsibility" and "profitability" whereby the improvement of environmental and social performances can become a potential source of competitive advantage [2–4]. On the other hand, local and foreign policies, organizations and multilateral institutions have struggled to provide concrete responses to the urgency of providing access to basic services, create systems with active participation of all stakeholders, create stable employment and enable the integration of disadvantaged people [5]. At the same time, non-profit organizations and non-governmental organizations (NGOs) are increasingly aware of the relevance to ensure the financial sustainability of their projects and initiatives in order to be able to meet unsolved social problems [6].

From this perspective, the energy sector is a very sensitive field. First of all, it is characterized by contrasting opportunities and challenges in term of environmental and social impacts. From a technological standpoint, the choice of sources that can be used for energy conversion or power generation may lead, as discussed in other chapters of the book, to different levels of impact on the environmental and social development (i.e. human development, access to services, job creation). Secondly, the sector is characterized by the presence of different types of organizations engaged in the supply chain: large multinational companies, public and private utilities, small and medium enterprises, NGOs, non-profit organizations, social enterprises and community associations.

## Ensuring Social Sustainability

The origin of the concept of business model is quite recent and a unique and shared definition has not been shared at the global level yet [7, 8]. In a broad perspective, a business model describes how an organization works and creates value [9]. In particular, Osterwalder [10] defines a business model as "a conceptual tool that contains a set of elements and their relationships and allows expressing a company's logic of earning money. In order to identify the core components of a business model, Osterwalder and Pigneur [11] propose the so-called business model canvas which is defined by four perspectives (Fig. 10.1): value proposition; financial; activity and customer.

The structure presented in Fig. 10.1 has its origin in the for-profit sector whose final objective consists in the creation of economic value. In this chapter, instead, we focus on organizations that aim to pursue sustainable development through the

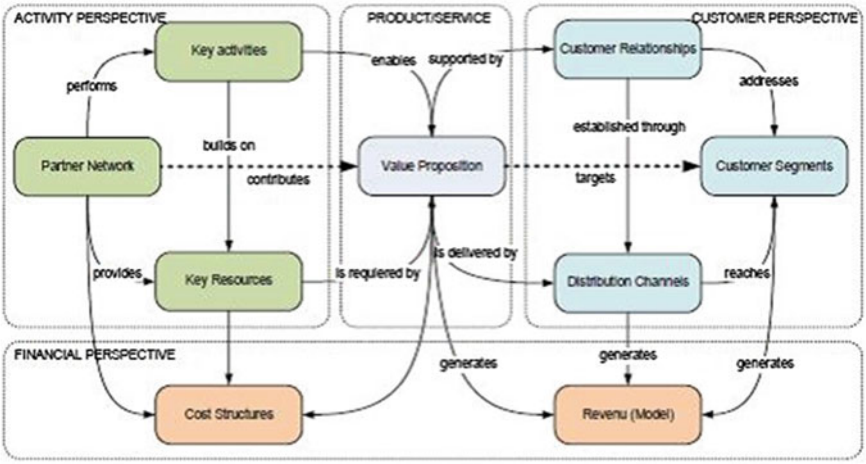


**Fig. 10.1** Business model canvas grouped into perspectives. *Source*: [12]

involvement of social actors and communities. Hence, some key differences should be taken into account. From this point of view, a model that appears particularly interesting is the so-called 'base of the pyramid (BoP)' or inclusive business model, relying on the idea of enabling the poor to participate in economic activities, involving a range of actors such public organizations, policy makers, business, social entrepreneurs, development organizations, NGOs and users. These business models are based on the "4As Framework": Availability, Affordability, Awareness and Acceptance [13] (Fig. 10.2). These principles are to be taken into account in the design and development of new business models [14].

In relation to energy access the above perspectives are described in more details. The value proposition need to describe which customer's problems should be solved by a product or service and why the offer should be more valuable than similar products by competitors. In general terms, we can identify three main types

**Fig. 10.2** The 4As Framework. *Source*: [13]

of energy access solutions [15]: national grid extension; distributed renewable energy systems; products and appliances.

The main dimensions to focus on are resources, activities and partner networking. When providing energy services as resources, activities and partner network can be strongly influenced by the coexistence and cooperation between for-profit and non-profit organizations [16]. For instance, multinational enterprises entering developing countries can collaborate with non-profit NGOs to adapt their business approaches to the characteristics of local markets. Large national and multinational enterprises frequently create linkages with local firms and social entrepreneurs such as suppliers, contractors and distributors. These collaborations also reinforce the ability of large companies to source inputs and to reach customers, while the local firms benefit from the improvement of their capacities [17]. Obviously, for-profit organizations still remains critical actors for addressing global energy challenges as they are efficient and capable in providing primary solutions, developing innovative products and services, deploying modern technologies and delivering efficient services. In addition, they have access to management and technical capabilities and financial resources. However, some significant existing models not only rely on the linkages and collaborations between large companies and local community associations, such as NGOs or social enterprises, but also include business directly managed by NGOs, community groups and local social enterprises (Fig. 10.3) [18].

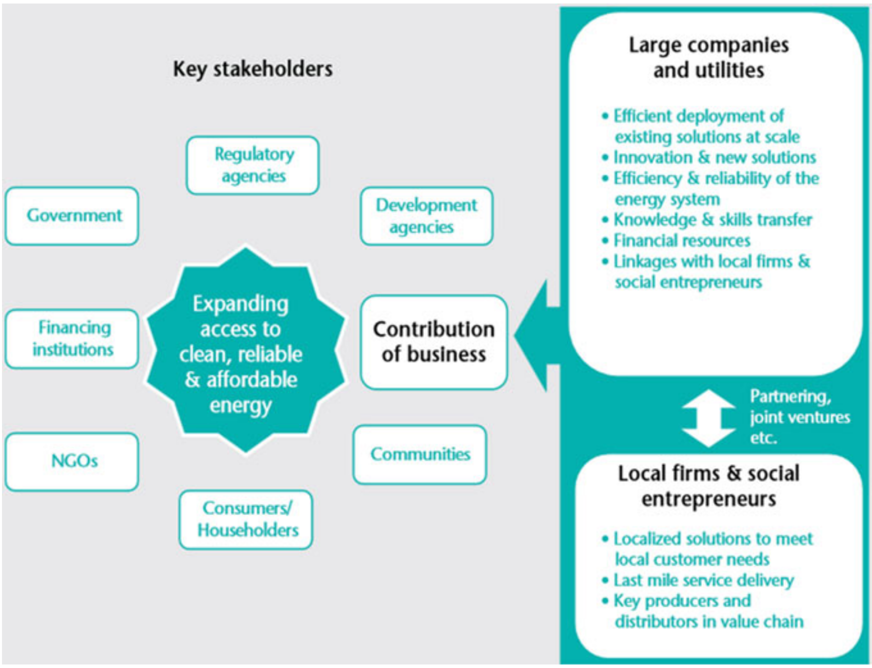


**Fig. 10.3** Example of partner network in expanding energy access. *Source*: [19]

The customer perspective includes customer segments, customer relationship and distribution channels. It is worth noticing that different energy products or service require different models to manage customer-related activities [20, 21]. Some products, such as solar lanterns and efficient stoves do not require extended interaction with the customer whilst other products, such as large scale generators, require maintenance, training, and a continuous and long lasting customer relationship management [22]. With specific reference to rural areas, we can identify three different approaches in terms of customer perspective.

- Community-based project implementation, based on participative approaches to facilitate the adoption and use of energy technologies and relying on the active presence of the enterprise within the customers' community. In many cases, enterprises using this model are non-profit and social enterprises that develop market and non-market strategies to improve socio-economic conditions and generate social value for their members [13, 23, 24]. Enterprises embracing these approaches widely interact with their customers which are recognized as part of a community. The most common mechanisms used to ensure interaction rely on training and workshops on technologies and product maintenance as well as on capacity building for local production, technology and entrepreneurship development.
- Contract sales, consisting in the sale of products or services on a contract basis to other companies or organizations. Some contract sales are made for institutions serving poor customers, whereas other types of contract sales are made by commodity-production enterprises to large consumers such as railways and industry.
- Micro franchising, characterized by a strong social nature with a focus on the well-being of the micro franchisee and residents of underserved communities [25]. Micro franchising involve limited initial investments typically not exceeding $1,500 [26].

The financial perspective includes considerations on costs and revenues thus leading to define organizations with diversified financial structures. Some of these organizations are financed by grants and donations or start up as grant-funded, but aim to become profitable businesses. Others are for-profit organizations that rely on loans and equity [27]. Some energy enterprises have been able to finance themselves through the sale of carbon credit [19]. Whether to rely on grants and public finance or to move to a more diffused financing mechanism, involving investment grade financing sources such as debt and equity, is hence a key issue that organizations have to confront [28]. Financial performances, though relevant, is not enough to understand the broader sustainability performances, the long term impact of these projects and to evaluate the success of business models for energy access [29, 30].

## *Case Studies Analysis*

Based on the above considerations, in this section we analyze three case studies as examples of different business models for energy access that have been developed in rural areas. The three case studies were selected based on the amount of available and accessible information and on their diversity, in order to illustrate:

- the type of organization;
- the energy products and services;
- the socio-cultural context;
- the business model.

We refer to the business model dimensions highlighted above to guide the analysis. However, we take into considerations the specific features of these dimensions in connection to business models for energy access (e.g. role of the stakeholders, partnership between business and NGOs, relevance of participative approaches, etc.). The cases analyzed [31] are also mapped against the "4As framework" in order to highlight their ability to (i) develop and bring to market more affordable and reliable products and services; (ii) increase the scalability of servicing customers living at the so-called bottom of pyramid (Table 10.1).

**Table 10.1** Mapping BlueEnergy case-study against the "4As framework"

| BlueEnergy | | |
|---|---|---|
| Criteria | Level | |
| Availability | High | The customers are able to readily acquire and use the products and services. Indeed, Blue Energy offers small-scale hybrid wind and solar installations, based on the local manufacture, operation, and maintenance, with a strong focus on local capacity-building and community development |
| Affordability | High | Blue Energy produces low-Cost Products indeed the application systems are sold to local households at affordable prices |
| Awareness | High | Customers become aware of the product thanks to intensive training initiatives handled by the company: community workshop aimed to understand the community's needs and expectations; choice of the village energy committee. Local technicians are trained to carry out maintenance activities |
| Acceptability | High | Different players of the supply chain are willing to consume, distribute or sell BlueEnergy products, due to its focus on the empowerment of local manufacturers and the development of the local community. Furthermore, the BlueEnergy model is replicated through a network of renewable energy producers at the national level in Nicaragua (Renewables), and a network of local wind turbine producers at a global level (Wind Empowerment) |

**BlueEnergy (non-profit)**

BlueEnergy is a non-profit organization that installs small-scale hybrid wind and solar systems in rural villages in Nicaragua. It brings affordable, sustainable electrification, water, and sanitation systems to marginalized communities implementing a reliable clean energy model. Its activities strongly rely on the idea of supporting the development of the residents themselves by emphasizing the local manufacture and maintenance of wind and solar energy systems.

**Value proposition**

BlueEnergy offers small-scale hybrid wind and solar installations based on the local manufacture, operation, and maintenance with a strong focus on local capacity building and community development. By combining wind and solar technology, BlueEnergy's systems are a cheaper and more reliable source that can generate continuous power under different weather conditions.

The 'typical offer' is carried out in three phases. First, BlueEnergy installs a solar panel system connected to a set of deep-cycle batteries; generators are generally used to power community buildings such as schools. Secondly, villagers buy home electrical systems, including lights, battery and wires to power TV and radio. Finally, BlueEnergy trains local technicians to maintain the systems in order to build self-reliance.

**Key activities**

To offer its value proposition, BlueEnergy relies on a broad network of different partners and stakeholders, including the National Technological Institute of Nicaragua (INATEC), BlueEnergy's employees (either Nicaraguans or international volunteers) and energy operators within each local community.

BlueEnergy teaches underserved people how to construct energy systems using solar panels. To this purpose, it collaborates with the INATEC hosting workshops and providing training materials for technicians. BlueEnergy's employees manufacture the turbines in their local plant and install them in Caribbean coast communities. Following the training, local operators are thus able to operate and maintain the power stations autonomously.

**Customer perspective**

The model adopted by BlueEnergy is community-based, therefore its primary focus is the local community that is at the center of the customer perspective. Before installing a system in a community, BlueEnergy holds a community workshop to understand the community's needs and expectations. It then supports the community to elect a village energy committee responsible for the installation and for long term management of the system. In addition, BlueEnergy makes a broader impact by helping others replicate its implementation methods through a network of renewable energy producers at the national level in Nicaragua and through a network of local wind turbine producers at the global level, (Wind Empowerment). BlueEnergy designs its own community power systems to meet its target users' needs, manufactures and assembles these systems locally and trains target communities on how to maintain them.

**Financial perspective**

The financial structure relies on different financial sources. Installation costs, including a solar power system, battery bank, and 3 years of maintenance visits, amount to $10-15,000 and are generally paid by donors. Home systems, whose cost is $1500 on average, are generally bought on credit from a local microfinance bank. Customers pay $3-5 every few weeks to charge the batteries. The sale of these systems to local households at affordable prices generates revenue for reinvestment by BlueEnergy and also contributes to community development beyond mere electrification. For example, the residents of one community have begun charging their cell phone batteries at the community charging station for $.40 a piece, and this is fueling the success of BlueEnergy's model through local demand. Thanks to BlueEnergy, entire communities are benefiting from the new economic opportunities brought by electrification.

**DESI Power, (for-profit)**

DESI Power is an Indian for-profit organization, operating as an independent rural power producer committed to socio-economic development of villages. DESI Power aims at reducing endemic rural poverty by income generation through the provision of electricity and other energy services.

**Value proposition**

DESI Power relies on a decentralized electricity-driven development process, aimed to local job creation, exploitation of agro-residues, renewable energy and other resources, to offer its value proposition.

**Key activities**

DESI Power offer is designed as an integrated solution where power plants, energy services, local enterprises and agriculture have to work closely together to make each other profitable. DESI Power exploits various renewable energy technologies and combines them according to the needs of the village. DESI Power provides each micro-enterprise with technical and commercial solutions for decentralized renewable energy based power generation, micro-generators and biogas plants. In order to ensure the proper transfer of knowledge, DESI Power has created a management training program called DESI Power Mantra, providing training and capacity building to enable local communities running plants on their own.

**Customer perspective**

DESI Power customers include both individual villagers and business activities. Villagers generally buy power for lightning and fuel for cooking. Enterprises buy power for a wide range of activities including services for mobile phones, irrigation and agro-processing. To handle customer relationships, DESI Power appoints a full time manager assisted by an experienced team with the task of coordinating all activities in the village. All installations are managed locally by a village cooperative that is trained by the company itself and is responsible for maintenance activities.

Lighting is delivered to villagers either through home wiring systems connected to the plant or lanterns recharged at a central station, both sold by DESI Power. While villagers can easily pay the monthly costs of charging a lantern or powering their home (as it is generally cheaper than the kerosene they are replacing), buying a lantern or connecting their home to the plant is often too expensive. In these cases, DESI Power seeks subsidies from donors or provides these products and services through a financing scheme. Such model is coherent with the so-called community-based implementation.

**Financial perspective**

DESI Power's investment structure is made up for 50 % of equity, 10 % of funds from the Indian government for delivering renewable energy, and 40 % of a loan which is paid back over 7 years. DESI Power sells the power to villagers paying for lighting, to enterprise power, to agribusinesses and mobile phone companies. DESI Power seeks equity investment of US$100,000 for each installation, offering investors a 5 % return for the first 7 years and then a dividend return of 12–15 % in the following years. Installations typically cost $200,000 of which 60 % is required for the plant, 30 % for the enterprise development, and 10 % for capacity building and training.

**D.light, (social enterprise)**

D.light is a social enterprise whose purpose is to design, manufacture and distribute solar light and power products in rural areas. In particular, D.light serves 44 countries, including Haiti, Nigeria, Mozambique, Vanuatu, Pakistan, Colombia, and China, through over 10,000 retail outlets, 10 field offices, and four regional hubs. The company employs over 100 people directly and hundreds more indirectly worldwide.

**Value proposition**

D.light sells low-cost durable solar light, including the world's cheapest solar lantern, the S1, and other power products such as mobile phone charging products. D.light strongly leverages on innovative design and cutting-edge solar and LED technology to ensure quality, reliability and affordability of its lanterns. The range of their products includes lights that work for four hours (costing US$8–$10) as well as more expensive and longer-running devices that may offer additional services such as charging phones (costing approximately US$45).

**Key activities**

Since it is not cost-effective to manufacture the products locally, they are usually mass-produced in China. D.light develops all its own products and begins the development process with field-based research on consumer needs so that the products result attractive, versatile, of high quality, durable and extremely affordable.

**Customer perspective**

The customer segment is composed by three target markets: rural households, off-grid businesses and off-grid schools. For the distribution D.light established partnerships with organizations that already operate locally, including microfinance networks, urban gasoline and rural liquid propane distributors, and NGOs. In order to ensure the transfer of competencies about the products, the distribution partners are trained in consumer education and product demonstration. D.light offers a one year warranty on all products.

**Financial perspective**

D.light is primarily financed through equity, by both traditional venture capital and social impact investors, but it has also received loan and grant financing. D.light puts particular emphasis on making its products extremely low-cost; the cheapest light, the S1, is sold at approximately US$8. For this reason, the company has developed the Give Light program in order to connect NGOs with individual donors that donate D.light products to customers who cannot afford them. It is worth noticing the broad impact that D.light products have on the customers, since the possibility of exploiting energy allows customers to extend their workday and reduce kerosene usage, resulting in a monthly income increase of 30–50 %

The following tables summarize the results of the analysis based on a three levels scale.

- High, indicates that the organization is totally able to ensure these characteristics to the products or services.
- Medium, indicates that the organization is partly able to ensure these characteristics to the products or services.
- Low, indicates that the products or services need to be rethought in order to be consistent with the characteristics.

**Table 10.2** Mapping Desi Power case-study against the "4As framework"

| DesiPower | | |
|---|---|---|
| Criteria | Level | |
| Availability | High | The customers have directly access and are able to use the products and services through the active presence of the enterprise in customer communities. Lighting is delivered to villagers either through home wiring systems connected to the plant or lanterns recharged at a central station, both sold by DesiPower |
| Affordability | Medium | Villagers can easily pay the monthly costs of charging a lantern or powering their home (as it is generally cheaper than the kerosene they are replacing). By contrast, buying a lantern or connecting their home to the plant is often too expensive for them. For this reason, DesiPower seeks donor subsidies for these products or offers them through a financing scheme |
| Awareness | Medium | Customers become aware of the products and service by the activities of a DesiPower unit, dedicated to coordinate and supervise all village activities. To ensure the proper transfer of knowledge, DesiPower has created a management training program that provides training and capacity building to enable local communities run their plants on their own. In particular, training activities are performed towards a village cooperative that is responsible for maintenance activities |
| Acceptability | High | Different players of the supply chain are willing to consume, distribute or sell DesiPower products, because DesiPower creates a local infrastructure and promotes its businesses at a local level, so that a large part of the value generated by its installations remains to villages themselves, thanks to the creation of new jobs |

## Lesson Learnt and Final Remarks

This chapter has addressed the problem of ensuring energy access from a business model perspective, hence considering the set of managerial and organizational arrangements whereby an organization creates value from economic, environmental and social perspectives. In particular, we analyzed three case studies of social organizations in the energy sector in order to highlight how these organizations have proactively succeeded in combining social values with environmental and financial sustainability, creating new business models. To this purpose, we relied on the framework developed by Osterwalder and Pigneur [11] to guide the analysis of the different components of a business model, assessing the contribution of these organizations to sustainable development through the 4A's framework [13] (Table 10.2).

A number of success factors can be identified as key elements to ensure the business model provide energy access to the poor:

1. A partnership approach with local institutions, organizations, companies and communities.
2. An appropriate mix of finance models, which include investment assistance, microfinance systems, public and private donors to mobilize capital costs and financial contributions to ensure the customer ability to pay.

**Table 10.3** Mapping D.Light case-study against the "4As framework"

| D.light | | |
|---|---|---|
| Criteria | Level | |
| Availability | Medium | The customers have access to the products only in the purchase phase. The company sells through distribution partnerships with organizations that already operate locally, including microfinance networks, urban gasoline and rural liquid propane distributors, and NGOs |
| Affordability | High | D.light produces the world's cheapest solar lantern, the S1. Products design based on consumer needs: attractive, versatile, high quality, durable and extremely affordable |
| Awareness | Medium | Customers *become* aware of the products mainly in the distribution phase. Distribution is performed in partnerships with existing organizations, in order to ensure the transfer of competencies about the products, D.light also trains its distribution partners in consumer education and product demonstration and provides a one year warranty on all products |
| Acceptability | Medium | D.light products are mass-produced in China, hence the value from production is not captured locally. This limits the acceptability of the products in certain parts of the value chain, and makes their price the main leverage for attracting customers |

3. The establishment, whenever possible, of local companies, cooperatives or organizations to provide, manage and maintain the service with targeted training and capacity building for local staff.
4. The use of multiple energy sources and products to actually meet local energy demands (households, collective, commercial and productive uses).
5. The identification and implementation of local appropriate technologies, process and management methods through the direct involvement of the local community.

The empirical analysis provides a few lessons that are discussed below (Table 10.3).

Private sector interventions alone can hardly reach poor customers. Traditional for-profit models are unlikely to ensure energy access in rural areas because profit margins and timeframes are less attractive [32]. In these cases, the involvement of 'non-traditional' business partners, such as government, non-government organizations, enterprise associations, social enterprises and communities themselves, is required. From this perspective, a key challenge is targeting government and donor support to stimulate and enhance private sector involvement. One of models of interest is represented by social enterprises, defined as businesses with "primarily social objectives whose surpluses are principally reinvested for that purpose in the business or in the community, rather than being driven by the need to maximize profit for shareholders and owners" [33].

Understanding the socio-cultural context is important to effectively design business models that reach BOP customers. This chapter highlights the importance of understanding the socio-cultural context, to identify new entry points for capturing the needs of BOP customers and how their needs evolve over time. This is crucial to properly interpret local expectations and ensure the long term viability of the business model.

A key element is the integration of training activities into the delivery model. This is a key element emerging in all the three case studies which represents a specific feature in the delivery of the value proposition in rural areas. BOP customers may need to become aware of energy products and services because these products are not yet well distributed and available in the market as they are in developed countries. Hence, training customers, local cooperatives or, more in general, local communities become a channel to establish and manage the customer relationship, but represent also a key leverage to disseminate energy and improve life conditions over a broader swath of customer or potential customers that otherwise would remain excluded. Moreover, the lack of knowledge and understanding of delivery models is a key obstacle to investment, thus working on training and capacity building can contribute to overcome this additional barrier.

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# Part IV
# Energy and Policy

Together with technologies and business models, policies are an essential element of any successful energy strategy. It is well known that a major trend is underway to develop renewable energy (RE) policies around the world. While much of the interest is often focused on developed countries, there are now dozens of developing and emerging countries that have or are on the way to design their own energy policy frameworks. A number of reasons lie behind this growing interest in developing countries: fast electricity demand growth, RE technologies increasing cost-competitiveness, low overall rates of electrification, constraints in the availability of investment capital, and renewable energies potential to create new socioeconomic opportunities.

Chapter 11 explores how existing or new policy instruments could be tailored to stimulate the use of locally available resources for energy production and how to trigger socioeconomic benefits at the local level. Such benefits could include the use of biomass resources which are available as by-products of agricultural and forestry sectors to be used for electricity, heating, or transport when they do not compete with food crops. Energy policies should promote the establishment of renewable energy enterprises in order to benefit the local economy through employment creation and income generation. Within this scenario, distributed generation has a big role to play and therefore, appropriate policies and measures to support its growth must be envisaged.

Drawing on experiences from the Caribbean, Africa, and Southeast Asia, Chap. 12 examines some of the common practices in energy policy design that can help to accelerate the development of renewable energy in the developing world, while reducing the key risks that continue to hold investment back. While the process leading from policy design to implementation varies by country, many developing countries face similar hurdles which are discussed in detail: governments face other competing policy priorities, local human and institutional capacity tend to be weak, political uncertainty can slow RE penetration, local utilities are often in precarious financial shape, and finally the perceived investment risks is high. To conclude, a difference is made between best practices, those related to the business as usual attitude, and ‘next’ practices, which refers to innovative arrangements and seeks to solve local challenges by addressing existing barriers in new ways.

# Chapter 11
# Enabling Environment for Promoting Energy as an Income Opportunity

**Diego Masera and Vittoria Paramithiotti**

**Abstract** Policy has been central for the deployment of renewables by creating a predictable and stable framework for investors to operate. A good policy should be an instrument to achieve a vision; it is a tool that allows society to work on an agreed goal and the market to contribute to it. This is particular relevant for energy policy due to the cross cutting nature of energy and its impact on all levels of society. This chapter will explore how existing or new policy instruments could be tailored towards stimulating the use of locally available resources for energy production and how to trigger socio-economic benefits at the local level. Such benefits could include the use of biomass resources which are available as by-products of agricultural and forestry sectors, or as purpose-grown non food competing resources for electricity, heating or transport. It will be argued that renewable energy policies should promote the establishment of renewable energy enterprises at the local level in order to benefit the local economy through employment creation and income generation comparing favorably in terms of sustainability with fossil energy resources.

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## The Importance of Renewable Energies

Today, in the context of the current climate crisis and the obligation to provide energy access to a fourth of the global population, the need for a clear, stable and predictable energy policy that focuses on a low carbon and a more equitable future is paramount. Thus, renewable energy policies should be based on a sustainable development vision of local participation and access to energy by promoting energy as an income opportunity rather than a cost. To this end, the use of a multi objective framework that incorporates social and environmental dimensions in the energy policy development process is necessary. This framework should allow going beyond the simplistic cost benefit analysis based only on financial indicators such as the cost of kWh and provide a more holistic perspective.

Participatory approaches for renewable energy projects, as commonly adopted in several EU Member States (including Denmark, the Netherlands and Germany especially for wind energy), can ensure that the financial benefits reach the local community. Long-term, stable policies which allow for a multiplicity of actors to invest in the energy sector will provide a secure basis for development of the industry in a decentralized manner. Particularly if supported by ownership considerations which promote investment opportunities by the communities closest to the installations themselves. According to Mendonça [1], this is especially pertinent for wind farms and solar systems. As he further argues, the cumulative effect greatly increases contact between people and the industrial and social changes that we must make in order to protect the climate. The swift transition to a renewable-based energy system is not only necessary for climate protection, but can provide a global demonstration of the positives of greening the economy, in which citizens have been involved [1].

Additionally, policies should consider the promotion of local manufacturing of renewable energy components or the assembling of renewable energy systems to increase their employment creation potential. This is relevant for both developing countries and economies in transition, where access to affordable energy is still an important barrier to economic development, and for European countries being affected by the current economic crisis. Renewable energy systems are an opportunity to revive the local economy and create local jobs. IRENA recently analyzed the existent data on green employment and estimated how many jobs are created per megawatt (MW) of installed capacity based upon the type of renewable energy source: biomass gasifiers result to be the most attractive in terms of job creation, followed by SPV in off-grid solutions, biomass power in grid solutions and finally small hydropower (Fig. 11.1) [2]. In addition to manufacturing, different other sectors are involved in renewables development, such as engineering studies, legal services, etc. As a producer of wind turbines, Tulsi R. Tanti affirms that at the end of 2009 more than 600,000 people were employed in the wind energy sector globally, that is equivalent to almost 15 jobs per MW installed [3].

There is a wealth of experience on policies aimed at increasing electricity production by promoting renewable energies through feed-in tariff, subsidized

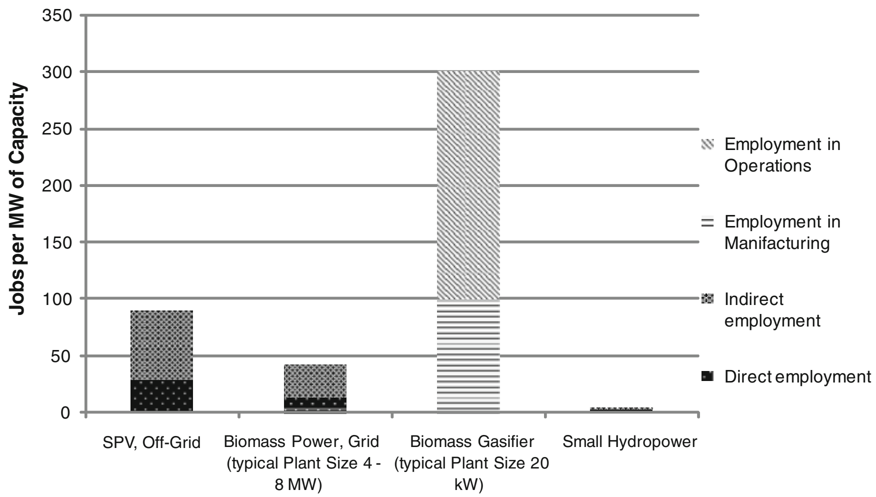


**Fig. 11.1** Jobs created per MW of installed capacity based upon the type of renewable energy source. Data from [2]

capital or reserved quotas. The challenge is however to design and adopt a policy instrument that reflects a long term vision based on inclusive and equitable development that integrates short-medium term gains with a low carbon future.

Renewable energy has emerged as a significant source in the global energy mix, accounting for around a fifth of worldwide electricity production. Much of this success has stemmed from economic incentives and significant policy effort. Large investments have taken place on a global scale, with costs for most technologies falling steadily. As a result, renewable energy technologies are becoming more economically attractive in an increasing range of countries and circumstances, with China, India and Brazil emerging as leaders in their deployment.

While renewable energy has been the fastest growing sector of the energy mix in percentage terms and investments in renewables surpassed the investments in fossil fuels in 2011 according to Bloomberg New Energy Finance [4], its continued growth will depend upon the evolution of policy and market frameworks. The 2013 World Future Energy Summit (WFES) [5] highlighted the fact that renewables offer great opportunities in terms of growth perspectives and jobs, helping “national economies foster new competitive industrial sectors with significant export potential for a growing world market”. The business environment needs stable and predictable policies in the long term as shifting legislation and policy uncertainty, as seen in recent years, threatens investment and market momentum.

Current analysis of the long-term potential for renewable energy in industrial applications suggests that in 2050 up to 21 % of all final energy use and feedstock in the manufacturing industry could be of renewable origin. In addition, using renewable energy technologies in industry could lead to 10 % reduction of all

GHG emissions projected for 2050 or 25 % of the total expected emission reductions of the industry sector [6].

One of the main forces driving renewable energy policies and development is the potential to create new industries, particularly small enterprises, and generate new jobs, which are more urgent than ever in the current economically challenging times.

The recent discovery of unconventional gas reserves in countries like USA, Canada and Australia is already affecting the price of gas while at the same time oil has reached its highest price in 2013 according to the IEA. In this context, the projected scenarios look at an increased share of gas in the global energy mix while alternatives for oil will be pursued, in particular for the transport sector.

Several countries are debating significant changes to renewable energy policy or deeper electricity market reforms. Although energy use is essential for industrial development and economic growth, sustainability and climate change concerns mean that economic development must be decoupled from high carbon energy intensity. The Intergovernmental Panel on Climate Change (IPCC) assessed that greenhouse gas (GHG) emissions "from the provision of energy services have contributed significantly to the historic increase in atmospheric GHG concentrations" [7]. It follows that GHG emissions arising from energy generation, transmission, supply and use must be lowered substantially in order to attain a sustainable climate resilient development [6]. Renewable energies could lead to cumulative greenhouse gas savings equivalent to 220–560 Gigatonnes of carbon dioxide ($GtCO_2eq$) between 2010 and 2050, holding the increase in global temperature below two degrees Celsius [7]. Most importantly, a good number of the IPCC scenarios estimate that renewables will contribute more to a low carbon energy supply by 2050 than nuclear power or fossil fuels using carbon capture and storage (CCS) [7]. Furthermore, according to the GEA renewable energies should have the potential to provide all the energy services needed (10–100 times the present world energy demand) [8].

## Need for Supportive Policies

For many years renewables were considered a privilege for developed countries, only accessible to affluent markets while at the same time billions of dollars in developing countries were spent annually on fossil fuels subsidies in oil importing countries. The IEA estimates that $ 500 billion are spent annually on fossil fuel subsidies while only $ 88 billion are supporting renewables. "IEA Fatih Birol called $ 23 billion fossil fuel subsidies in 2011 (up by 30 % from 2010) the No.1 enemy of the fight against climate change. No wonder CO2 emissions continue in the wrong direction" [9].

It is clear that without a leveled playing field for all energy technologies, countries will continue to depend on fossil fuel imports.

Experience from across the world shows that the introduction and success of any renewable energy market is to a large extent dependent on policy and regulatory frameworks. Despite the world's economic crisis, the renewable energy sector hit the record of $257 billion of global investments in 2011. Nevertheless, instable policies in some developed countries have led to slower investment growth in 2012 compared with previous years [10]. Appropriate government policies are thus essential in the creation of the enabling environment for mobilizing resources and encouraging both local and foreign private sector investment in the renewable energy sector. The lack of adequate policy, legal and regulatory frameworks to guide the development of the renewable energy sector results in a market environment that is fraught with uncertainties and risks, thereby limiting potential investment by the private sector.

To understand the barriers that prevent the wider adoption of renewable sources for electricity generation, it is important to look at the criteria traditionally used in the design of energy policies. Policymakers have historically favored large-scale investments that provide electricity access to urban areas [11]. Due to population density, it is simpler and cheaper to connect inhabitants of urban areas than of rural areas. The lack of financial resources leads to priority being given to connecting urban areas using conventional sources of electricity generation. In fact, evidence shows that the financial system is reluctant to finance projects using technologies that are still perceived to be unproven or more risky. In many developing countries the current strategies continue to favor conventional energy systems (often through state subsidies), despite them being more costly and polluting in the long term, making it virtually impossible for renewable energies to compete because all the costs have to be borne by the end-users while conventional energies are heavily subsidized by the state.

Different support mechanisms to promote electricity from renewable sources are now quite common such as feed-in tariff system, quota obligation system backed by green certificates and tender systems among others (Table 11.1). Feed-in tariff systems, investment subsidies and tax incentives are so called price-based

**Table 11.1** Overview of supportive policies [13]

| | |
|---|---|
| Regulatory policies | Regulatory policies |
| | Feed in tariff (FITs) |
| | Electric utility quota obligation/RPS |
| | Biofuels obligation/mandate |
| | Heat obligation/mandate |
| | Tradable renewable energy certificates (REC) |
| Fiscal incentives | Capital subsidy, grant or rebate |
| | Investment or production tax credits |
| | Reductions in sales, energy, CO2, VAT, or others taxes |
| | Energy production payment |
| Public financing | Public investments, loans, or grants |
| | Public competitive bidding |

mechanisms (i.e. the mechanism primarily aims to influence the price for renewable energy), whereas quota systems and tender schemes are quantity-based measures (the mechanism primarily aims to achieve a given amount of renewable energy) [12].

Supportive policies for the diffusion of renewable energies in developing countries are based on direct and indirect subsidies to promote low-income households and achieve energy access amongst the poorest. In order to build a solid structure of subsidies, a system of differentiated social tariffs equally distributed across the income categories is often used. This system has proven to be effective when applied with transparency and with specific targets among local urban or rural communities, and supplemented with additional funds to overwhelm the initial barrier of the technology's cost.

At a national or regional level, public investments, loans, or grants represent the first step towards the expansion of the existing grid or the deployment of off-grid solutions. Financing mechanisms derived from the coordination of governments with international organizations and investment banks have been the only feasible way to target energy programmes for the poorest, who in most occasions do not represent an attractive target for private investors. However, non-economic barriers such as administrative procedures slow down the deployment of renewables by decreasing the expected return on investment. An analysis of IEA ASEAN countries shows that the lack of coordination between different authorities is the most significant regulatory hurdle, followed by the lack of recognition of the side-benefits of distributed generation, the unclear grid connection rules and/or pricing mechanisms, the high number of authorities involved, the complexity of regulatory/support framework for RES-E and the complexity behind obtaining permits and legal appeal procedures [14]. Simplifying permitting procedures and improving skills training are instruments that should be reflected into policies for achieving a wider deployment of renewables in developing countries. Therefore, an effective strategy to foster the diffusion of renewable energy technologies is the establishment of local dedicated institutions providing capacity building, technical assistance, and organizational support. Their ultimate task is the empowerment of end-users and the enhancement of a collective consciousness, which are key factors for long-term policy effectiveness. Furthermore, supportive policies for renewable energies that achieved their targets so far are those integrated in a multi-objective policy framework for sustainable development [15].

**Table 11.2** Expected additions to the global renewable electricity capacity over 2011–2017. Data from [16]

| Country | Additional capacity [GW] | Relative contribution [%] to the global renewable electricity capacity addition expected over 2011–2017 (i.e. +710 GW) |
|---|---|---|
| China | +270 | 38.0 |
| United States | +56 | 7.8 |
| India | +39 | 5.5 |
| Germany | +32 | 4.5 |
| Brazil | +32 | 4.5 |

In fact, the use of renewable electricity is rapidly growing in developing countries and in particular in BRIC nations through clear policies. China's expansion is characterized by ambitious policy targets, fast-growing electricity demand and ample financing. India's favorable policy environment and rural electrification needs are expected to result in the strong deployment of on- and off-grid renewable electricity capacity while Brazil's hydropower and wind sectors should grow strongly. Table 11.2 shows the expected additions to the global renewable electricity capacity over 2011–2017, with China leading the classification, followed by the United Stated, India, Germany and Brazil. According to the IEA [16], in 2017, non-OECD countries should account for 65 % of hydropower generation and almost 40 % of non-hydro generation.

Renewable electricity growth is expected to accelerate over the medium term based on the assumption of persistence of supportive policy; the IEA affirms that by 2017 "renewable electricity generation should expand by 1 840 terawatt-hours (TWh), almost 60 % higher than the 1,160 TWh growth registered over the 2005-11 period". Global power generation from renewable sources is projected to grow 5.8 % annually reaching almost 6,400 TWh in 2017 compared to 4,540 TWh in 2011, 5.8 % higher than in 2010. "Even as the annual average growth in renewable generation accelerates—to 5.8 % over 2011–2017 versus 5.0 % over 2005–2011—expansion trends and geographies remain specific to technologies" [16].

## Energy Policies in Different Regions

Different countries in the world have been applying renewable energy policies in recent years for promoting sustainable development and although it is difficult to generalize, some common patterns can be identified in different regions.

Asia–Pacific [1, 13, 17]

In the Asia–Pacific region 800 million people lack a reliable access to electricity and more than half of them lack access to clean cooking facilities. While India and China are making huge efforts to achieve rural electrification, and many programs exist in the region for promoting renewables, some countries such as Bangladesh, Afghanistan, Myanmar, and Pakistan are still experiencing low electrification rates. The supportive policies commonly applied to achieve energy access through hydro, wind, biogas, solar PV energy sources in grid-connected or off-grid systems are mainly: a) public and international financing, b) grants and low-interest loans from the government, c) FITs and d) subsides for low-income communities. In many countries, such as Bangladesh, Sri Lanka, Nepal and India, solar technologies have been successfully disseminated demonstrating that off-grid programs, in association with the private sector and rural microfinance institutions, are realistic. Projects can be scaled up appropriately, with improved access to capital, development of effective and reliable after-sales service, customer-focused market development, and routine stakeholder participation. Many experiences in this region show that the common denominator to successful policies for energy access is the involvement of local communities and end-users into the process, as well as the establishment of energy-dedicated institutions. Community-based organization, technology transfer and skills improvement are the main focus of the schemes.

**Sub-Saharan Africa [18–21]**

Sub-Saharan Africa has the lowest electricity access rate (24 % in 2008), but paradoxically it is a net exporter of energy sources. Renewables energies have seen a great growth, with 66 % of total new electricity produced through RE systems from 1998. In recent years, several countries have made concrete efforts to implement supportive policies for renewables, including public loans coming from government allocation or levies on all electricity bills, residential tariffs, and subsidies to poorest households to guarantee their energy access. According to ECREEE, in West Africa, Senegal, Ghana, Mali, Liberia, Guinea, and Nigeria have developed a detailed renewable energy policy. Cape Verde is considered the pioneering country making renewable energy a priority for the development of the country: it aims at 50 % penetration of renewables in the electricity mix by 2020 and has taken a number of steps towards implementation (e.g. RE law and other incentives). Ghana and Senegal have passed a renewable energy law and feed-in-tariff systems are under preparation. Liberia, Mali, and Senegal have adopted ambitious RE targets of 30, 25 and 15 % (of installed capacity) respectively in 2021, and Ghana and Nigeria 10 % by 2020. However, there is a general lack of integrated and multi-objective policies for poverty alleviation and energy access. Only few countries have dedicated agencies and separate directorates, and most of them are poorly staffed, funded and organized. For these reasons, the presence of private investors into the market is limited. Virtuous examples of successful policies in Eastern Africa are found in Kenya, where FITs have been implemented to subsidize wind, hydro and biomass power generation since 2008, and solar, geothermal, biomass and biofuels since 2010. Despite the great renewables potential of the East African Communities (EAC), the lack of appropriate policies, capacities, knowledge, finance and the respective business environment restrict the dissemination of renewable energies and energy efficiency technologies. On the other hand, the South African government has established the South

African Renewable Initiative (SARi) "to support the rapid and ambitious scaling up of renewables in a manner that will deliver economic, social and environmental benefits without imposing unacceptable costs on the nation's citizens and economy".

**Latin America and the Caribbean [13, 17]**

Across Latin America, an estimated 7 % of the population (nearly 31 million people) does not have access to electricity, and almost 19 % (85 million) depends on traditional biomass for heating and cooking. In many countries of the region the relationship between energy and poverty is either lacking or treated superficially in national development plans, energy policies, or poverty-reduction strategies. There is also little research on the linkages between access to energy services and national development goals, poverty alleviation and reduction, and environmental issues. The policies applied to support the diffusion of renewable energies are a combination of subsidies for equipment importation of off-grid solutions and for the payment of energy bills, as well as social tariffs. Public investments are particularly strong in Brazil, e.g. within the project "Light for all" promoting rural electrification and decentralized renewable energy-based systems. In Argentina, the Renewable Energy for Rural Markets Project (PERMER) aims to provide about 35,000 remote rural households, 1,750 public services (rural schools, health posts), and 500 productive uses with electricity through provincial 'off-grid concessions' that are negotiated or bid out for minimum subsidy and regulated by independent provincial regulating agencies. The concessionaire is free to choose the least-cost technologies applied to meet its obligation to provide universal service. However, subsidies to fossil fuels remain a barrier in some countries of the region for the large scale deployment of renewable energy systems.

## *Multi-objective Policy Analysis*

The aim of a renewable energy policy and its regulatory framework is not just to introduce competition to improve financial efficiency, but more importantly to promote a sustainable and equitable growth of the country. The discrepancies in the potential results of the promotion of conventional or renewable sources of energy have to be approached through a multi-objective analysis.

An appropriate policy should include a regulatory framework that prescribes a comparison between all sources of energy in a given location, considering not just the short term benefits but also the long-term aspects. Since investments in renewable sources are different than those in conventional ones (higher upfront cost but lower or no running costs), an appropriate regulatory framework must adopt a life-cycle perspective in appraising and comparing projects. For example, every time a remote village is to be given access to electricity, the comparison should be made between the different sources of off-grid energy and the extension of the network. This means that when assessing the appropriateness of a given technology, the cost-effectiveness should, take into account social (e.g. market development, job creation and income generation) and environmental (e.g. health and climate change) considerations, other than economic ones, along the entire life time of the technologies. Renewable sources in general have a lower impact on the local and global environment compared to conventional sources [11].

Many tools that are helpful for evaluating emissions mitigation measures, such as carbon abatement cost curves, focus exclusively on cost and emissions reduction potential without quantifying the direct and indirect impacts on stakeholders. As Casillas et al. [22] show, an effective way to assess the sustainability of a given energy technology from different perspectives consists of the deployment of carbon abetment cost curves complemented with various indexes highlighting the impact on poverty and equality. Quantifying the behavioral changes, the increase in the household income, the decrease in inequality, and the health improvement through indexes (e.g. the poverty headcount ratio, the Human Development Index, the Gender Inequality Index, etc.), allows to connect the carbon mitigation and poverty dimensions in order to identify the co-benefits of a certain measure for local communities [22].

The decision-making process of an investment should allow for a true socio-economic comparison of the most efficient technology to be used, taking into account not only its immediate financial costs, but also its environmental and social impact, including job creation and impacts on the local economy.

The extension of the grid to areas where the level of consumption per household is low and the households are scattered, is often considered a financial burden for large utilities. Small-scale energy generation projects, however can make a big difference to the everyday lives of inhabitants and the local economy, therefore the promotion and establishment of decentralized energy solutions should be prioritized. Fortunately, the cost of renewable has fallen constantly in recent years mainly due to the economies of scale reached in large markets. According to recent analysis from Bloomberg [4], unsubsidised renewable energy is now cheaper than electricity from new-build coal- and gas-fired power stations even in Australia, a country with some of the world's best fossil fuels resources [23]. Some estimates made in 2011 on a global scale revealed competitive and unsubsidized low costs of power generated from different renewable sources (Table 11.3). Today, in many developing countries, where large areas are not connected to the grid, renewable energy is in some cases already the cheaper option [24] even without the financial support of the state or any kind of subsidy. Updating diesel-based grids with

**Table 11.3** Estimated cost of power generated from different sources without subsidies. Data from [26]

| Power source | Cost (USD per kWh) |
|---|---|
| Onshore wind | 0.06 |
| Landfill gas and municipal solid waste | 0.05 |
| Geothermal | 0.08 |
| Biomass | 0.10 |

renewables in Africa is very profitable due to high local diesel prices and good solar irradiation in rural areas located far from both the national grid and the large trade routes. Some recent estimations show that in many African and South American regions PV mini-grids can reach attractive payback periods of 5–7 years, or even less than 4 years in very remote areas [25].

In some countries, energy companies have been privatized and, as profit-making companies, they are supposed to make efficient decisions on how to best allocate their resources. Issues, such as access to supply for the poorest households in rural areas, will often not necessarily be prioritized by private companies. On the contrary, they might be inclined to concentrate their services on higher income households or on industrial and commercial customers. One of the roles of regulators and policymakers is therefore to ensure that all consumers have access to energy services at a reasonable cost and within a reasonable timescale. In countries with low rural electrification rates, private energy companies need policies that establish appropriate incentives to expand their services into these areas. In particular, it should ensure that energy companies are encouraged through innovative business models to provide the poorest households and the most remote locations with access to energy services.

## Policies for Energy Access: New Commitments

Promoting the access to modern renewable energy not only avoids the health and environmental hazards associated with traditional and fossil energy sources, but can also increase the quality and efficiency of basic services like lighting, communications, heating, and cooling.

Significant technological innovation and cost reductions, along with improved business and financing models, are increasingly creating clean and affordable energy solutions for people and communities in developing countries, providing them with sustainable rural electrification, heating, and cooking solutions.

Access to energy is not just a simple matter of energy supply in terms of kWh generated, but rather an essential developmental service for the local communities. The importance of the social impact of energy policies cannot be underestimated. This social dimension is widely accepted and is a political goal in itself. Policy makers and regulators should promote distributed energy generation and facilitate the establishment of a market for energy production and distribution in off-grid areas through local rural energy enterprises and independent power producers.

Achieving universal energy access has become an important international goal by 2030. The Sustainable Energy for All initiative is currently focusing on creating action and generating commitments within an initial number of High-Impact Opportunities. One of these is carried out by the Solar Sister organization, training "female entrepreneurs to become saleswomen in their communities, enabling them to offer affordable solar technology to their networks for profit. With the money they earn from selling clean renewable energy, the women can reinvest in new inventory, improving their economic situation, and providing benefits to the entire community through its access to a reliable energy source" [27].

The IEA [28] estimates that nearly $1 trillion in cumulative investment—around $49 billion per year—is needed to achieve universal energy access by 2030, namely more than five-times the level of investment observed in 2009. On the other hand, it is clear that achieving energy access for all would bring new threats in terms of climate change and energy insecurity. Nevertheless, the IEA defines these concerns as unfounded since energy access for all is projected to only increase global energy demand by 1 % in 2030 and $CO_2$ emissions by 0.6 % [28].[1]

Universal energy access can be seen as a huge challenge but also as a great market opportunity for the local economy to benefit from the provision of energy services. It is interesting to notice that when the oil industry was starting to develop in 1850s, the world population was about the same as the population that has no access to electricity, today, 1.3 billion people. Furthermore, the original aim of the oil industry was to provide a solution for lighting.

In its first decades, the oil business provided an industrializing world with a product called by the made-up name of "kerosene" and known as the "new light," which pushed back the night and extended the working day. At the end of the nineteenth century, John D. Rockefeller had become the richest man of the United States, mostly from the sale of kerosene. Gasoline was then only an almost useless by-product, which sometimes managed to be sold for as much as two cents a gallon, and, when it could not be sold at all, it was poured out into rivers at night [29].

Today, the renewable energy sector is clearly becoming more economically attractive in an increasing number of developing countries and circumstances and is evolving from a niche market to a major industry. It is now recognized that investing in renewable energy creates local jobs and growth, and improves energy security for countries that lack domestic fossil resources. Increasing the share of energy from renewable sources can reduce greenhouse gas emissions and local pollution, insulate countries from fuel price volatility, and improve their balance of payments.

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[1] These estimates are based on the hypothesis that each household consumes a specified minimum level of electricity (250 and 500 kWh for respectively rural and urban households), i.e. the threshold for achieving "modern energy access".

The renewable sector has been reliant on subsidy support; however, it is now starting to transition to a phase in which "projects are competing on their own merits" [16]. In general, established technologies such as large and small hydropower, geothermal and onshore wind compete well with new coal- and gas-fired plants in many areas. As it was mentioned previously, small-scale distributed and off-grid applications, such as biogas and solar PV, are economically attractive compared to small diesel generators in South Saharan Africa [25, 30]. A study made for the 27th European Photovoltaic Solar Energy Conference reveals that in well electrified countries like the US, Germany or Spain hybrid mini-grids are used to replace expensive diesel power systems, currently powering very remote areas like islands, national parks or mountain lodges. A relevant number of mini-grids supplying villages with cost efficient power can be also found in Brazil and Mexico. Even though Brazil and Mexico are quite well electrified countries, very remote areas are powered by stand-alone hybrid mini-grid systems [31]. Moreover, in areas with good solar resource, residential solar PV competes increasingly well with retail prices.

The rapidly growing share of renewable energy in many markets around the world is bringing the business models and revenue streams of many existing utilities and energy companies under stress. Some utilities and manufacturers are re-evaluating their strategies and finding new ways to create value by considering off-grid solutions and innovative methods of payments such as pre-paid as well as net metering. In remote areas, multi-user mini-grids can be managed by smart control systems which limit the power available for the community and the energy use, in order to avoid black outs due to overloads or to ensure the fulfilment of the contractual agreements. Existing prototypes of energy management systems which predict the load demand and calculate the actual energy price depending on the system state are used for helping the users to adapt their consumption behaviour to the generation profile of the system [32].

Off-grid solutions represent a valuable alternative for providing energy access and economic development to rural communities, when either private sector- or community-based models are applied. New policy commitments will have to focus on setting up effective business models, recognizing the potential of SMEs in developing countries, while offering the right incentives and stability to de-risk investments.

## Decentralized Development of Energy: From Cost to Opportunity

Centralized electricity generation systems are the product of the socio-technical context of the decades during the last century in which electrification took place in the developed world. It is not necessary for new systems to be developed in the same manner since the needs, the technological options and the energy market have all changed (see Chaps. 4 and 5).

Firstly, electricity generation from big power plants with traditional sources such as coal, oil or gas, require high initial levels of investment. These sources emit Carbon dioxide into the atmosphere and contribute to global warming. Secondly, transmitting electricity over long distances might not be the best solution, since building transmission networks is costly and transmission losses have to be taken into account. Planners are aware that the rate of electrification in Africa is not likely to increase significantly if the same development models are used [11]. In fact, at the rate of electrification during the last decade, it would take more than 80 years to electrify sub-Saharan Africa [33].

Established financial and institutional practices, as well as political interests can nevertheless marginalize renewable sources of electricity. New policies will therefore often be required to support the large-scale utilization of renewable technologies.

The relative employment intensity of renewables is a key argument for policies to promote them as the main pillar of energy access initiatives. Future estimates of the requirements for universal energy access by 2030 suggest that of the 952 TWh of electricity generation required annually, 400 TWh will come via mini-grids and 172 TWh from isolated systems [34]. This would result in a large number of jobs created in the decentralized energy sector. The supply of energy itself represents an important employment sector with great potential for growth if access to energy supplies and services are supported.

The idea of generating energy for self-use as well as for sale to a grid is already quite common in larger industrial plants and companies in developed countries. However, the full spectrum of possibilities available to smaller-scale energy service providers—especially in terms of deployment of renewable energy in rural areas—require further promotion and the support of appropriate policies. Decentralized renewable energy systems have a good potential to become an important revenue stream for local enterprises. For example, modernizing the use of bio-energy in agro and forest industries can improve the efficiency of these operations, and benefit from self-generation. Companies have the potential of integrating electricity or heat generation into their industrial activities. Bio-energy can be modernized through the application of advanced technology to convert raw biomass into electricity, liquid or gaseous fuels, or processed solid fuels, bringing significant social and economic benefits to both rural and urban areas [35].

Small-scale renewable systems can be established close to where the demand is, which means that costly transmission networks are not needed. Switching to locally produced energy services such as biofuels, improved stoves or mini-grids can have a positive effect on local job creation throughout the supply and maintenance chain [36].

Indeed, off-grid technologies have seen significant advances in recent years: technologies such as combined heat and power plants and biomass boilers are cost-competitive and technology that better manage the biomass supply, such as pelletting or briquetting are available. The widespread use of biogas digesters is demonstrated by the fact that by the end of 2009, nearly 2,000 large and medium-scale biogas digesters had been installed at industrial enterprises in China, a further 22,570 digesters had been installed at livestock and poultry farms, and 630 in municipal waste and sludge treatment facilities had also been installed. By the end of 2010, China's total biogas power generating capacity stood at 800 MW [13]. Moreover, several Asian countries such as China, Japan, India, Malaysia, and Thailand produce briquettes of loose biomass materials (for example, crop residues and sawdust). With the exception of Asia, the total global wood briquette production is estimated to be 1.3 million tons, while China produced roughly 0.5 million tons in 2010 [13].

Growing biomass is a rural labor-intensive activity and thus represents a way to create jobs and help stem rural-to-urban migration, whilst, at the same time, providing convenient carriers to help promote other rural industries. By generating their own energy, enterprises themselves can become more competitive, save on energy bills and sell electricity to other users on the grid or mini-grid. It particularly makes sense for local enterprises far away from utilities generating for the grid, as they end up paying high electricity prices that factor in the distance of transmission as well as the rising prices of fossil fuels. To unleash this potential, it is important that governments and policy-makers create a favorable environment for decentralized activities. The benefits in terms of local job creation and reducing fossil fuel consumption are important factors in terms of energy policy. The use of bagasse for energy in sugar mills in Brazil is a successful example. Bagasse is the fibrous matter that remains after sugarcane or sorghum stalks are crushed to extract their juice. Bagasse is also used for pulp and paper or board production or for kettle feed, but much of it was traditionally wasted and burned. Most sugar mills in the world now use bagasse to produce electricity and/or steam to meet their needs during the processing season but, with efficient generation technology, they are also able to export electricity to the grid. Bagasse in Brazil has therefore become an abundant and stable source of renewable energy, with the consequent economic and environmental benefits. According to Ackom et al., during the 2010 sugar harvesting season, sugarcane bagasse generated 18.5 TWh of electricity, including 8.8 TWh of excess electricity that was exported to the grid [37]. Some of the success is down to the Alcohol Programme incentivizing the production of ethanol (from sugarcane), but also the fixed feed-in-tariffs for renewable electricity. At the same time, it became apparent that the environmental and social aspects associated with sugarcane-ethanol production needed to be addressed. Since then, major policies on bio-energy sustainability have been established, including legislation banning cane field burning and zoning of land used for sugarcane production in the country, aimed at protecting fragile ecosystems, such as the Amazon rain forest.

Based on the examples outlined above, there is an opportunity to also develop policies that promote decentralized energy solutions in developing countries with low rates of electrification and low population density in rural areas. This would allow for more flexibility than grid extensions, as potential systems can be upgraded according to the needs of the users. Distributed generation in developing countries is and will remain quite different from that in European countries. In the latter, connected local systems are complementary to the grid; in developing countries stand-alone systems are and probably will remain for a long time to come the only sources of electricity for isolated populations. The search for economies of scale no longer seems to be the only driving force for the electricity generation market. Economies of scale are not considered as important as they used to be, owing to technological progress and the low price of some renewable sources of energy such as mini hydro, solar PV and biomass.

## Conclusions

While 1.3 billion people do not have access to modern energy, greenhouse gas emissions keep rising demonstrating that the current energy system is locked into a model that neither brings socio-economic development nor environmental sustainability.

A new energy paradigm is required to get us out of this vicious cycle, a paradigm based on a vision of sustainable development that promotes a more resilient, low carbon economy while creating new jobs, new businesses opportunities, and a more equitable society.

Energy policies should not only promote access to energy for lighting and clean cooking in households, but rather the option of using energy for economic development and for community services such as health and education.

Renewables provide an answer to all these issues if guided by the right set of policies and a long term vision. They are a concrete solution for the people that do not have access to energy today and a business opportunity for small enterprises and industries through decentralized energy systems. Since energy investments are a long term enterprise, appropriate renewable energy policies should reduce investment risks by creating a stable, transparent, long term and predictable business environment. This is particularly important for local entrepreneurs that thanks to the modular nature of renewables can invest in them and start looking at energy as an income opportunity rather than a cost.

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# Chapter 12
# Energy Policy Design for Low and Middle Income Countries: From Best Practices to 'Next' Practices

**Toby D. Couture and Christina Becker-Birck**

**Abstract** Growth in the global renewable energy market has far exceeded expectations and this is largely due to policies that have created an enabling environment for investments in renewable energy. The main factors fueling this growth are discussed in this chapter as well as similar hurdles that many developing countries face along the process of transforming policy design into action. Risk is also discussed and 'next practices' are introduced as the innovative, forward-looking policies that are built on community participation and involvement.

## Snapshot of Renewable Energy Development Worldwide

In 2000 the International Energy Agency projected that the global installed wind capacity would reach 30 GW by 2010 [1]. With the spread of RE support mechanisms around the world, over 200 GW of wind power were installed by 2010 [2]. Additionally, in 2000 the IEA also estimated that China would have 3.7 GW of wind power installed by 2020. Already in 2012, 62 GW of wind power were operational and China is now the world leader in installed wind power capacity m [3]. A similar story is found in solar photovoltaic (PV): as far back as in 1997 the European Commission projected 3 GW of solar PV in Europe by 2010 [4] and instead over 29 GW were installed by 2012 [5].

This growth is largely a result of policies that have created an enabling environment for investment in renewable energy. To date, there are over 118 countries with renewable energy targets, an increase from the 45 countries in 2005 [3].

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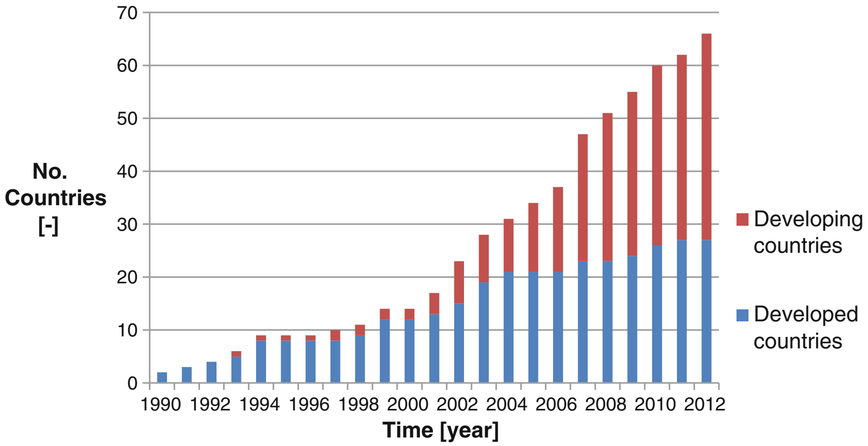


**Fig. 12.1** Feed-in Tariff Policy Growth in Developing and Developed Countries [6]

The most prevalent policy mechanism is the feed-in tariff (FIT), the use of which has taken off in developing countries (Fig. 12.1).

As of 2012, over 65 countries have implemented feed-in tariff policies, which have driven 64 % of global wind and 87 % of global PV development [5, 7]. With this rapid policy uptake, investment in renewable energy nearly reached $257 billion in global investments, of which 35 % was invested in developing countries [6, 8]. According to a recent report by UNDESA, it has been estimated that "it would cost up to $250–$270 billion per year to shift developing countries to 20 % renewable energy by 2025" [9]. This financing need combined with estimates that 20 % of the global population lacks electricity access [10], makes clear the need to fill the energy gap, and to improve energy access in the developing world.

## Renewable Energy Drivers in Low and Middle-Income Countries

There are a number of factors fueling the growth of renewable energy policies in developing countries. First, electricity demand and consumption are projected to continue increasing at a rapid pace. While exact predictions range, research overwhelmingly cites developing countries as outpacing developed countries for overall growth in energy consumption and electricity demand. The US Energy Information Administration (EIA), for example, predicts that energy consumption in non-OECD countries will increase 84 % between 2008 and 2035 compared to a 17 % increase in OECD countries [11]. Additionally, the EIA states that electricity consumption is growing the fastest of all end-use energy consumption categories [11]. These rates create significant pressure for developing and emerging economies to keep up with the growing demand.

To draw on one example, electricity demand growth in Tunisia averaged approximately 6 % per year in the 1990s, while certain countries such as Ghana have sustained electricity demand growth rates of between 10 and 15 % for the last two decades [12]. This rapid growth in electricity demand has created significant strains on electricity systems in many countries, and has made grid failures and black outs a routine part of life in many parts of the developing world [13].

A second major factor fueling interest in renewable energy policy is that after several decades of technological improvement, many RE technologies are now cost-competitive with (and in a growing number of areas, cheaper than) conventional energy sources, presaging a major shift in the electricity industry worldwide. According to a high-profile study published recently in the journal Renewable Energy, the cost per watt of solar PV has declined from US $4.50 in 2006 to well below US $1 per watt today [14]. Industry benchmarks now put the market price of polysilicon modules at between US $0.55 and US $0.85 per watt [15]. In fact, levelized energy costs of solar PV, wind, and biogas options in particular are now well below the costs of fossil fuel-based options in many parts of the world. According to a recent report by the IEA-RETD, which makes the comparison to diesel powered systems, "RETs can undercut, on a levelised basis, the cost of traditional sources such as diesel, providing valuable savings for governments, utilities and ratepayers" [16]. This rapidly shifting reality was recently captured by IRENA, which stated that renewable energy technologies are now the default economic option in off-grid regions of the world, and that RE sources are "increasingly the most economic solution for new grid-connected capacity where good resources are available" [17].

When added to the significant costs of large transmission build-outs, which are often not required for small and medium-scale RE projects, distributed renewable energy technologies can provide significant net savings over more centralized, fossil-based supply options.

A third factor is that overall rates of electrification in developing countries are typically much lower than in developed countries, providing significantly more opportunity for electricity projects of all kinds to take root. In fact, despite the growth in investment in the electricity sector worldwide, the UNDP-GEF estimates that the number of people without access to electricity in sub-Saharan Africa will actually *increase* by 10 % to 645 million by 2030 under a business-as-usual scenario [6].

Figure 12.2 provides an overview of the rates of electricity access in a selection of 34 countries, according to data compiled from the World Bank.

This chart shows remarkably low rates of electricity access in a host of countries, particularly in sub-Saharan Africa. These lower rates of electrification also often indicate a lack of infrastructure, including transmission and distribution lines, which significantly increase the total cost of providing electricity service, particularly in sparsely populated rural and remote regions. This underscores why a growing number of countries are increasingly looking at renewable and distributed energy solutions, as distributed supply sources and mini-grids are often more suited to the scale of local needs, and they can often be installed and operated

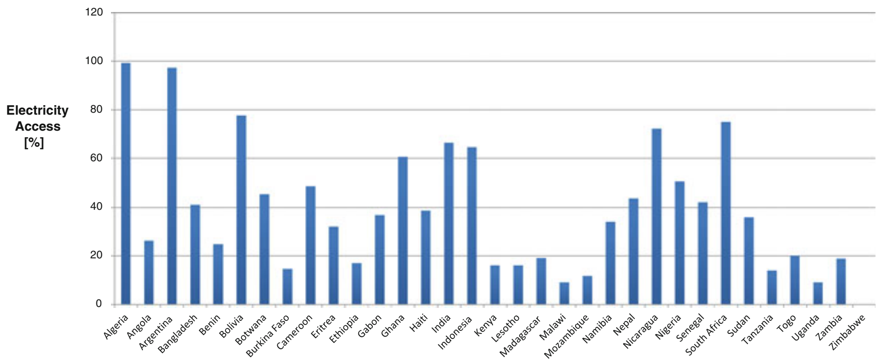


**Fig. 12.2** Electricity Access in the Developing World: Select Countries (%). Data from [18] (*Note* that even these rates of access hide important asymmetries within countries. For instance, electrification rates may exceed 60 % in many of the countries highlighted, but fails to underscore that most of this electrification is in the urban areas, and that many rural and remote regions have rates that scarcely exceed 3 % in many parts of the world.)

at a lower cost to residents. In fact, in 2011 it was estimated that fully 30 % (or US$76 billion) of total investment in renewable energy was allocated to small-scale projects, understood as projects smaller than 1 MW. Figure 12.3 provides a snapshot of the total annual investments in small RE projects.

Small, distributed electricity projects can therefore play an important part of meeting electricity supply needs, suggesting that policymakers may consider a mix of approaches and policies suited to a range of different project sizes.

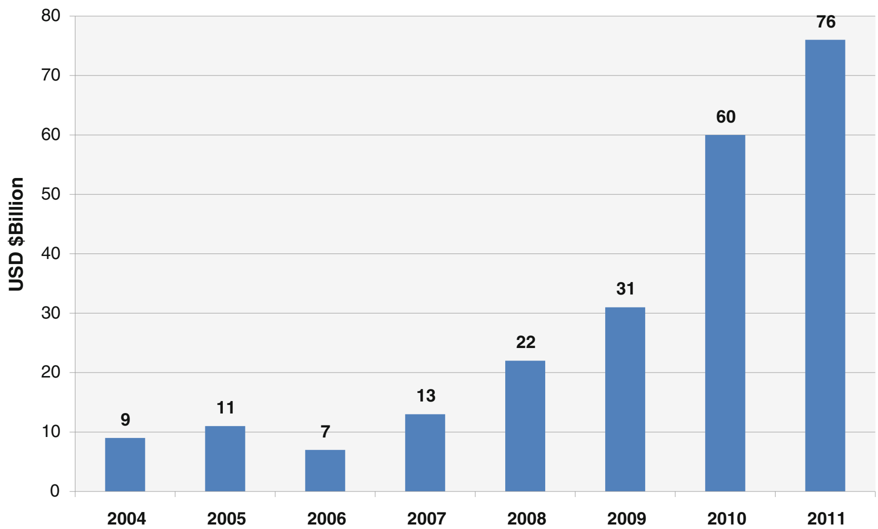


**Fig. 12.3** Global Investment in Small (less than 1 MW) RE Projects ($Bn). Data from [8]

A fourth factor fueling interest in RE policy is that capital availability has been significantly more constrained in all developing countries (with the exception of certain countries in the Asia-Pacific region). For many policymakers, this has helped underscore the need for targeted policies to improve investment certainty, and to create an environment conducive to attracting external capital.

A final driver is that renewable energy is seen as one of the leading ways to diversify local economies, and create new economic opportunities for local residents. Many governments ranging from Malaysia to Brazil, and Morocco to South Africa have sought to encourage renewable energy development in order to create jobs. Job creation is often a primary motivator for policymakers, who are seeking to gain a foothold in the growing market for renewable energy products and services.

## Challenges to Renewable Energy Development

A wide range of developing countries including Botswana, Egypt, Ethiopia, Ghana, Morocco, Nigeria, Peru, Saudi Arabia, Suriname, Trinidad and Tobago, and Tunisia have expressed interest or are in the process of developing renewable energy policies. While the process of getting from policy design to implementation varies by country, many developing countries face similar hurdles along the way.

First, governments face a wide range of competing policy priorities, many of which may be unique to a developing country context. Given the limited time and budget to address health, economic, employment, and other issues, governments have to determine the extent to which energy policy can support their wider government objectives. Developing and implementing renewable energy policies can be a difficult, time-consuming, and conflict-ridden process, with many false starts before investment really starts happening at scale.

Second, there is often limited human and institutional capacity to design and sustain the implementation of RE policies. This makes it hard to keep policies on track once implemented, and to adjust them appropriately over time.

Third, political uncertainty can often slow or undermine RE policy development processes, as has been the case in several countries in recent years ranging from South Africa and Ghana to Tunisia and the Philippines. The impact of broader political uncertainty can deter investors from participating in new markets and should not be underestimated.

Fourth, incumbent utilities in many low and middle-income countries are often in precarious financial shape, unfriendly if not hostile to competition, and routinely erect barriers to impede the progress of independent power producers. While this is a problem in both developed and developing countries, it remains particularly acute in certain developing markets. This opposition can make it very difficult to get favorable contract terms, consistent enforcement of rules and regulations, and other critical elements essential to project success.

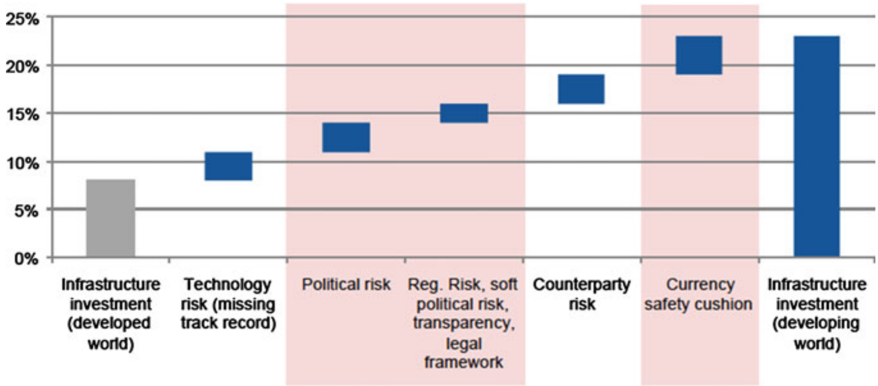


**Fig. 12.4** Impact of Risk on ROE for Infrastructure Investments [19]

And finally, developing countries face a number of challenges due to the higher perceived investment risks. These risks range from political and regulatory risk to economic and off-taker risk. These additional risks often lead to significantly higher discount rates. This increases the cost of capital and therefore makes developing renewable energy technologies slower, costlier, and more politically challenging.

Figure 12.4 provides a snapshot of the cumulative impact of different risks on the returns-on-equity of infrastructure projects in the developing world.

## Mitigating Risks

Given the importance of risk in determining both the cost and the scale of renewable energy deployment, much effort has been devoted to mitigating the various sources of project risks highlighted above.

Broadly speaking, there are two major camps in the 'de-risking' discussion: first, there are '**policy de-risking instruments**,' which seek to address the underlying barriers that are the driving causes of risk [6]. These include a host of measures such as support for policy design, institutional capacity building, training programs, operation and maintenance support, and the like.

Second, there are approaches focused on **'financial de-risking instruments'**: these approaches do not directly attempt to reduce the endogenous sources of risk, but rather focus on shifting the risks, hedging against them, or concentrating them with particular entities such as governments, or multi-lateral institutions [6]. These measures include sovereign guarantees, political risk insurance, and public-private partnerships, among others.

As seen in Fig. 12.4, Deutsche Bank has reported that equity return expectations for infrastructure investments in mature markets like the EU are approximately 8 %, while the return expectations for comparable projects in developing countries may be higher than 20 %. This can introduce a significant differential in the cost of capital, which in turn has a significant impact on the levelized cost of energy that is generated [19].

Table 12.1 below provides a more granular look at different risks that can impact RE project development, and that are therefore particularly important for energy policy in developing countries. Policymakers should consider the real and perceived risks that project developers may face when designing RE policies.

As these various examples highlight, successful RE policy is in large part about reducing key investment risks, either through policy de-risking (e.g. institutional support and capacity building), or through financial de-risking (off-taker guarantees, political risk insurance, etc.).

**Table 12.1** Types of risks affecting renewable energy project development

| Key risks | Description and examples |
|---|---|
| Economic risk | Risk that economic factors beyond the control of the project impact revenues, or profitability: e.g. recessions, inflation |
| Political risk | Risk that political instability, change of government, etc. impacts the viability of a project, or alters the framework under which it operates |
| Performance risk | Risk that the renewable energy resource will not live up to performance projections. This is particularly disruptive if it occurs in the early years of a project's life before costs have been recovered |
| Regulatory risk | Risk that regulators change the rules of the game (e.g. retroactive changes to feed-in tariff pricing or contract requirement changes). Success relies critically on a stable regulatory regime |
| Off-taker risk | Risk that the electricity buyer (e.g. utility) experiences financial difficulties, and can no longer honor the power purchase agreement or FIT contract |
| Technology risk | Risk of technological malfunction, or higher-than-projected downtime, repairs, etc. |
| Construction risk | Risk that construction faces local opposition, or delays due to operational or project management failures |
| Revenue risk | Fluctuations in revenues due to fluctuating prices of green certificates, variable electricity pool prices for power plants that sell directly into the market, etc. |
| Currency risk | Risk that the currency in which sales are denominated changes abruptly or significantly over time in relation to the currency in which the project was financed (e.g. EUR, USD) |

## Energy Policy Design: A Look at Best Practices

While there is a wide range of policy instruments to support RE development, including feed-in tariffs, net metering, quota obligations (or renewable portfolio standards), and tax incentives, among others, the policy that has led to the greatest impact on RE supply growth is the feed-in tariff. As highlighted earlier, FITs are responsible for approximately 87 % of global solar PV capacity, and approximately 64 % of global installed wind capacity, making them by far the most successful RE policy of the past two decades [5, 7].

However, this does not necessarily mean that the lessons from RE policy development in countries like Germany, Denmark and France can be directly transplanted into developing countries. In fact, there are a number of additional considerations that need to be taken into account and that suggest that pure, 'German-style' FITs may not be the best solution for many countries, particularly for off-grid regions.

According to the US National Renewable Energy Lab, "A feed-in tariff is an energy supply policy focused on supporting the development of renewable energy projects by offering long-term purchase guarantees for the sale of RE electricity" [20]. They typically involve long-term contracts (10–25 years), and are often designed to offer different payment levels to different RE producers based on generation cost, which includes differentiating payments based on a range of factors including technology type, project size, resource quality, and location.

However, FITs are also typically accompanied by a purchase and interconnection guarantees, provisions that are only meaningful (and indeed, enforceable) if there is a grid to which RE projects can connect. In many rural and remote regions, power projects either have to be accompanied by distribution infrastructure, or be tailored to serve a specific on-site load. This may require more innovative designs that establish clear rules and guidelines for sales of excess electricity, spanning a range of advanced net metering possibilities, rather than a FIT in the traditional sense. It also suggests that the definition of FITs may need to be broadened to include a wider set of accompanying policies, such as regulatory provisions, interconnection requirements, purchase and dispatch rules, and so forth.

Integrating variable renewable energy supply works well when the share of renewables is comparatively small in the overall power mix and when either the utility (or the system operator) competently executes the key functions of grid integration, balancing, and reliability. In these cases, RE sources displace other forms of generation, and can even put downward pressure on electricity spot market prices. However, in many developing countries, particularly in areas with small grid systems and modest peak loads (e.g. less than 20 MW), integrating significant shares of intermittent renewables can contribute to instability in the grid, particularly in areas with highly unpredictable power demand. In these contexts, committing to long-term, must-take contracts may not be practical. In some cases, generators may be required to be more responsive to fluctuations in market demand; in addition, some may be required to contribute to ancillary services provision, such as reactive power and voltage control. Experience in many off-grid and micro-grid contexts show that the responsibilities of the generator are often increased beyond what they are in a mature FIT market, as the reliability and dispatch functions are often not centrally administered. It goes without saying that in many rural regions, there simply is no system operator. As a result, this can significantly increase the operational and technical responsibilities of RE project operators in small grid systems. In turn, this can introduce additional uncertainty into the operation and project financing of rural and remote power projects [21].

Third, while Germany's FIT has historically not included a cap on total renewable capacity, this kind of un-capped FIT may not be possible in developing countries, and procurement strategies may need to be scaled appropriately, and adjusted according to the size of local loads, and projected electricity demand growth. As these few examples highlight, directly transplanting energy policies from one jurisdiction to another is impractical because the policy must be tailored to the country's specific goals and context. Indeed, 'best practices' may be different for utility-scale projects than those for rural and off-grid projects, as each will require a different approach.

Regardless of which policy approach policymakers adopt, RE policy design in developing countries should be designed to address, as much as possible, the two major factors highlighted earlier: namely, policy de-risking, and investment de-risking. This may mean that in certain contexts, FITs will need to be accompanied by caps, and may need to be supported by government off-taker guarantees, or other financial de-risking instruments, to be truly successful. It may also mean that for rural and remote regions, innovative net metering approaches that set out clear, enforceable guidelines for excess power sales will be more practical, and will do more to advance the underlying objective of improving energy access, at least in the near-term, where grid infrastructure does not yet exist.

Another important point is that broadly speaking, energy policy design in developing countries should seek to leverage local resources wherever possible. Given their vital role in the community, renewable energy projects should (where possible) be managed and controlled locally, to reduce down times during maintenance, and to create community buy-in and participation. Not only does this reduce reliance on costly imports and periodically unreliable supply chains, it provides a more direct contribution to local employment and economic activity. In the process, greater resources should be devoted to supporting local skills and knowledge development to increase local control over the O&M functions of RE projects. This helps reduce reliance on outside experts and creates greater autonomy, a particularly important factor for rural and off-grid regions.

Finally, policies should be designed to attract both domestic and foreign capital, by creating stable conditions that enable cost recovery for electricity sector investments. In order to further this objective, governments should ensure that credible payment systems are in place to allow bill arrangements to be standardized, potentially with different packages tailored to different levels of usage (e.g. 50 kWh per month, 200 kWh per month, etc.) Ultimately, developing credible and transparent billing arrangements is likely to be among the most important factors in accelerating the flow of capital to the sector, and to boost electrification rates in many parts of the developing world.

Naturally, all of these considerations will differ from one country, and indeed one culture, to the next: energy policy design should always take into account the local cultural, economic, infrastructural, and political context.

## Beyond Best Practices: A Look at Next Practices

While the previous section examined 'best practices', this section takes a brief look at a few so-called 'next practices'.

C. K. Prahalad, writing in the Harvard Business Review in April 2010, stated that 'Next practices are… about innovation: imagining what the future will look like; identifying the mega-opportunities that will arise; and building capabilities to capitalize on them' [22].

In the context of energy policy, we define 'next practices' as innovative, forward-looking policies that are built on a foundation of community buy-in, participation, support. They often make use of innovative arrangements, and seek to solve local challenges by addressing existing barriers in new ways. A few examples of 'Next Practices' is provided below.

Given the high rates of cell phone usage in many parts of the developing world, and the success of payment systems like M-Pesa [23], there are a host of innovative billing arrangements that could be developed to help facilitate access to electricity, while still providing investors (whether domestic or foreign) with assurances that they will be able to recover their high upfront costs. These approaches could build on the 'coin-operated' models that were once common in certain parts of the developed world, substituting coins with digital transfers.

One approach that was highlighted during the UNIDO conference may also be of interest to policymakers around the world [24]. In this example, project developers established an innovative community-based management model for hydropower development in Tanzania. This arrangement relied on financially rewarding residents living up river for their sustainable water management practices, effectively encouraging them to reduce activities that directly reduce power output down river, such as silting.

Another approach that was pioneered on Ramea Island, off the southern coast of Newfoundland in Canada, is the 'split-the-difference' model. By collaborating with the local utility, the wind project owner and operator struck an arrangement where the price paid to the project was based on an transparent split between the high avoided cost of diesel generation (approximately USD $0.30 per kWh) and the approximate levelised cost of the wind power project (roughly USD $0.15–0.18 per kWh). This resulted in an arrangement that simultaneously saves money for the utility, reduces carbon emissions, and provides the prospect of a solid return on investment for the wind project owner [16]. In light of the high avoided cost of generation in many rural and remote regions, this could provide a workable (and bankable) solution for many regions worldwide.

## Conclusions

The potential for a sustained scale-up in renewable energy development in low and middle-income countries is vast, and growing. As renewable energy technologies continue to come down in cost, they are rapidly becoming the default economic option for supplying electricity, particularly in rural and remote regions. This has stimulated considerable interest in the policy measures required to support renewable energy development in these regions worldwide.

However, as this article has underscored, it may not be possible to directly transplant policies that have been successful elsewhere (notably in Europe) to developing country contexts. The local political, cultural, economic, and infrastructural context is often different and can significantly determine which policies will work, and which will not.

Moreover, this article has pointed to the need for a local involvement and participation, directly for consultations and awareness-raising, for knowledge and skills development, as well as to create new local economic development opportunities. Engaging local citizens in renewable energy projects help boost projects' sustainability and reduced reliance on outside experts for operations and maintenance. It can also help improve project performance, as it contributes to reducing down time, and can therefore improve overall efficiency. Indeed, decentralized renewable energy development can and should play a growing role in improving energy access and in promoting better development outcomes in low and middle-income countries worldwide. And promoting better outcomes starts with promoting better participation.

However, in order for sustained RE development to occur in many of regions, greater emphasis needs to be placed on developing sound billing arrangements, and on implementing credible (i.e. bankable) cost recovery models. This is often underestimated, and yet, it remains an essential condition for attracting local and foreign capital to the sector, regardless of the particular country, or context. In the process, this may also require further development of innovative business models.

Ultimately, one of the major barriers faced by renewable energy projects in low and middle income countries is that traditional analyses of technology and policy costs do not consider the radically different *risks* of different energy supply options. Having a high reliance on imported fuels (which is the status quo in many low and middle-income countries) can expose local economies to a host of economic, political, and security risks that are often beyond the scope of policymakers' control. As countries become more aware of these risks, energy policymaking will have to gradually move from a narrow discussion of costs, to a broader conception of the risks and vulnerabilities of different energy development pathways. For low and middle-income countries, these factors can make all the difference.

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# Part V
# Public and Private Players: Italian Insight

As it has been stated throughout the book, different players are required to scale-up access to energy and to achieve the objectives of sustainable energy for all by 2030. In Part V a perspective from some Italian experiences is given. This selection, though not exclusive of the overall Italian experiences, wishes to underline some typical examples ranging from public institutions, civil society, academia, association of SMEs, and multinational companies.

All the players mentioned in this part attended the conference in Milan, bringing their specific contribution to the discussion on sustainable energy strategies for middle- and low-income economies.

In Chap. 13, the vision of public donors is presented. It provides the example of the Italian Ministry of Environment, Land and Sea due to its high commitment at the international level.

In Chap. 14, the added value of civil society is discussed thanks to interviews realized with a number of NGOs that are quite proactive in the field of access to energy.

In Chap. 15, the role of the academia is highlighted starting from some considerations about the role of universities within sustainable development and then introducing the specific case of the Italian network of universities as well as the case of Politecnico di Milano.

In Chap. 16, the mandate of the association of renewable energy producers is discussed in detail, thus focusing on the specific activities of SMEs in the field.

Finally, Chaps. 17 and 18 represent two contributions from two multinational companies. They both are members of the Global Compact and act according to its principles. Eni Corporate focuses on the approach to sustainability and corporate social responsibility, while Enel and Enel Foundation focus more on their specific program “Enabling Electricity.”

Although these contributions are not exhaustive of the overall Italian experience, they represent a comprehensive example given by different groups of stakeholders.

# Chapter 13
# The Vision of Public Donors

**Annalidia Pansini**

**Abstract** The European policy should be directed towards an improved North-South market integration, aimed not only to the exchange of goods and services, but also to a transfer of technologies, good practices and capacities. Market integration and infrastructure development should go beyond the electricity market, thus becoming an engine of technology cooperation.

## Italian Ministry for the Environment, Land and Sea

The significant historical events of the past years in the Southern Mediterranean countries have laid the foundation of a strong and renewed policy of Euro-Mediterranean integration. An effective European policy should attain political convergence on crucial themes such as "environment and energy", key to the development of the whole region, through the promotion of joint projects, upholding quality and proposing structural solutions to the challenges of countries in this area, which should fully take part in the decision making process.

The Mediterranean region offers a suitable context to achieve these objectives: European countries are the owners of advanced renewable energy technologies, while the Northern African countries have a high territorial potential in developing renewable sources, thus being able to satisfy a significant market quota for the related technologies.

In this framework the Italian Ministry for the environment, land and sea has promoted since 2002 an intense program of environmental cooperation in the Mediterranean region aimed at designing and testing a regional strategy for sustainable development. To date, projects launched in Egypt, Morocco, Tunisia, Algeria and Israel promote:

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- the take-up of distributed solar energy and energy efficiency in the target countries, by achieving an effective cross-border co-operation among the partners and by raising public awareness on the related benefits for the environment and for sustainable local development;
- the implementation, demonstration and dissemination of examples of good practice on legislative, regulatory, economic/organizational frameworks and innovative financing mechanisms;
- the improvement of enhanced competences of the public administrations and regional institutions representatives, through know-how and best practice transfer from Italy and training in Italy of professionals and future policymakers from the Southern Mediterranean countries.

In order to coordinate and monitor the projects for promoting renewable energy sources, the Mediterranean Renewable Energy Programme (MEDREP) has been launched by the Italian government during the World Summit on Sustainable Development (WSSD) in Johannesburg in 2002.[1]

The Programme aims to promote renewable energy sources in the Mediterranean region, through the dissemination of technology, supported by innovative financial instruments and mechanisms, as well as to strengthen the local institutions, in order to give certainty and continuity to the legislative and regulatory framework needed for supporting the investments on clean energies technologies.

As part of the MEDREP partnership, the *Mediterranean Renewable Energy Center (MEDREC)* was set up in 2004, in Tunis: a Centre for training, dissemination of information, "networking" and the development of pilot projects. The Centre, created by the Italian Ministry of Environment in collaboration with the Tunisian government, is the "focal point" for the activities of MEDREP in all North African Countries. The projects are carried out in collaboration with Ministries, local institutions, Universities and research centres, agencies of southern Mediterranean countries, United Nations agencies (UNDP, UNEP, UNIDO) and the World Bank.

The work of these years has been inspired both by the European Union's strategies for sustainable development and climate change, and the United Nations conventions and multilateral agreements for the protection of the environment at global and regional levels.

The projects were identified in the framework of the objectives and programs of the Conventions and the Protocols of the United Nations on climate change, biodiversity protection, the elimination of persistent organic chemicals, and the fight against desertification. Furthermore, projects on energy efficiency and

[1] The partners of Medrep are: the United Nations Environment Programme (UNEP), the New and Renewable Energy Authority of Egypt (NREA), the Tunisian Ministry for Industry and Energy, The Tunisian National Agency for Energy Conservation (ANME), the National Agency for Renewable Energy and Energy Efficiency Development of Morocco (ADEREE) and the Renewable Energy Authority of Lybia (REAOL) and the Observatoire Méditerranéen de l'Energie (OME).

renewable energies promotion and forest management were designed to generate emission credits in accordance with the Kyoto protocol.

The guideline of the different programs and project activities was the integration of the environmental concerns into sectorial policies, with particular reference to research and education, industry and energy issues.

In general, the programmes and projects have been designed and developed on the basis of the following principles:

- defining the priorities of the southern countries through framework agreements for bilateral and multilateral cooperation, which usually include training programs and assistance for national and local environmental authorities;
- optimising the resources available through the promotion of projects that enable the participation to the additional funding channels from international institutions, the European Commission and by private companies;
- promoting the participation of Italian Universities, as well as Italian engineering companies and companies involved in know-how and technology transfer in order to expand markets and industrial co-operation opportunities.

Working from this perspective has been and still remains a cultural and organisational challenge for a public administration. The Italian Ministry's experience has always offered original ideas to the international debate, partly because it is supported by concrete experiences.

A successful model of this co-operation is represented by the PROSOL Initiative implemented by the Italian Ministry for the Environment in collaboration with the Tunisian Government and UNEP-DTIE.

PROSOL is a financing mechanism designed to support the large-scale diffusion of solar water heaters by involving all the actors active in the sector: the Government, the electricity state-owned Utility (STEG), Multi-lateral and bilateral donors, the banking sector, consumers, technology suppliers and installers.

It is characterized by a range of institutional and financial support, including:

- A 20 % investment subsidy to lower the customers capital cost (75 US dollars per square meter);
- A mechanism to facilitate the consumer's access to the credit by a temporary interest rate subsidy (which was gradually phased out after 18 months) and a longer 5-year term repayments of the loan made via the customer's electricity bill;
- A communication campaign for the consumers;
- Training and capacity building for the technology suppliers and installers.

These *ad hoc* measures were established in order to address the main barriers related to SWH development such as: financial incentives for the demand side, capacity building for the financial institutions and technology providers to develop long term knowledge and expertise, quality standard requirements for the reliability of the systems, awareness raising campaigns targeted for addressing the consumers scepticism, local and international public funding [1].

By 2012 more than 636,000 $m^2$ solar water systems were installed in Tunisia, with a stable market totalizing, since 2008, around 70–80,000 $m^2$ per year [2].

Indeed, the development of renewable energies may be even more a stimulus for growth if it succeeds in developing satellite industries, fostering local production of parts and on-site maintenance, facilitating at most local employment.

In this regards it is worth to mention that PROSOL had also an impact in terms of social and economical development, having stimulated the development of the domestic solar thermal industrial cluster. Local stakeholder's analysis suggest that PROSOL contributed to create 3,000 new direct jobs and up to 7,000 indirect, 50 sales company, and 1,200 eligible installers are active today in the SWH industry while there were only 8 suppliers and 100 installers in 2002 [3].

The companies involved range from the components manufacturing to the installation of the systems for residential and commercial use, thus covering the entire value chain.

The industry turnover 2005–2010 has been estimated of about 120.2 million US$, of which 106.8 million US$ associated to manufacture and 13.4 million US$ associated with installers [3].

The support programme for the solar thermal market encourages the Tunisian industrial initiatives and fosters partnership and cooperation between the two shores of the Mediterranean region.

PROSOL residential can be considered as a clear example of a multi-stakeholders approach to promote clean energy technology cooperation in the Mediterranean region. Government authorities, industries, local institutions and multilateral organizations worked in partnership for the market deployment of a viable and mature technology for the increase of the security supply, competitiveness of local industries and the environmental protection through the implementation of a mix of different measures.

Building on this successful initiative the Italian Ministry, in collaboration with UNEP and local governments, has decided to replicate its results over other areas such as Montenegro, Egypt and Morocco and technologies such as distributed photovoltaic and green electric appliances.

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# Chapter 14
# The Contribution of Civil Society

Lorenzo Mattarolo and Claudio Di Benedetto

**Abstract** Ranging from single individual to institution and groups, civil society encompasses all structures that have the goal of advancing a common purpose through ideas, actions, and demands on governments [1]. Civil society also includes non-governmental organizations (NGOs). NGOs do not include profit-making activity and are not created by intergovernmental decision [2]. NGOs are defined according to different terminology: UN has depicted them as "non-profit citizens' voluntary entities organized nationally or internationally" [3]. NGOs have been involved in the UN since its inception and their rate of involvement has grown exponentially since then. The role of civil society, in particular NGOs, the main focus of this chapter. has been explicitly recognized from Agenda 21, the sustainable development blueprint adopted at the 1992 Rio Earth Summit [4]. In the action plan, Agenda 21 presents and discusses the key role of NGOs in supporting sustainable and responsible development and contributing to policy and decision making.

## The Distinctive Character of NGOs

Stromquist [5], Lewis and Kanji [6] have individuated roles that NGOs play in the cooperation framework. The main ones may be summarized as follows: provision of service delivery, advocacy, promotion of innovation and empowerment of people.

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### *Service Delivery*

The provision of service delivery is one of the main functions of NGOs. The involvement in energy service delivery may take many forms, but organizations appear as the actors more tailored to face some of the main issues whether technical, economic or political, that delay efforts to provide access to energy in DCs. The approach varies according to the action planned and depends on the community and collaboration history. In certain cases NGOs act on the technical infrastructure, taking care mostly of the physical delivering of services (for instance grid connection or replacement of old appliances) [7]. Other projects involve NGOs to address bureaucratic or normative obstacles, security problems or the preservation and safety of the installations. Projects may also start from previous led intervention, enhance effectiveness and solve the local vulnerability [8]. NGOs provide services for different reasons depending on the circumstances. On one hand, an NGO can operate to satisfy previously unmet needs. On the other hand, governments, donors or companies hire NGOs to take over the delivery of services that they were previously offering. Therefore, NGOs provide local communities with a wide range of services both directly and indirectly. The latter include giving training to other NGOs, government or the private sector [6].

### *Advocacy*

NGOs also have a role of advocacy: actions are addressed to face the root causes of poverty, while aiming at influencing decisions of public institutions, policy makers and advising donors. NGOs are also increasingly concerned with private entities, orientating companies with behavioral principles for international activities and business.

### *Promotion of Innovation*

Another catalyst role that NGOs assume is the promotion of innovation. Despite innovation being a difficult and complex process that implies challenges in all sectors, encouraging the selection of innovative approaches is recognized as a key element for a sustainable development in the long term. Improvement of existing technologies, scaling up new business models, introducing new maintenance procedures or devices and testing innovative policies constitute possible actions that NGOs may follow as innovative strategies in the energy access [6].

### *Empowerment of People*

NGOs should also work as mediators between the local context and the traditional approach which is often inadequate to satisfy local needs or small scale projects. In order to identify the best solutions, NGOs base on direct relation with people by valorizing local heritage and planning interventions with a participatory approach, with the role of facilitating the people's sensitization. Indeed, technical and infrastructural actions have to encounter a process of local people's empowerment, achievable through capacity building, self-reliance and microfinance [9]. Communities are hence supported by NGOs in the development of local activities and encouraged in the social, capital process and human development. Indeed, local associations have to be supported and empowered by NGOs in the development process, since capacity building is a strategy which fosters independence and builds active citizens. Referring to the specific role of NGOs, Langran [10] defines it as the "ability to strengthen the ability of local community through education, skill training and organizational support". Training and education is tailored to the potentiality which is used as leverage for wealth and to provide self-reliance to communities: creating self-organized clients associations that directly manage distribution service at the local level, for example, may ensure community commitment and assumption of responsibility [8, 11].

## NGOs and Partnerships for Energy

Partnerships consist of agreements between two or more stakeholders within a specific project or programme. This includes assigning responsibilities and roles, sharing risks and pursuing common goals [6]. Coordination thus constitutes the essence of partnerships in order to reduce vulnerabilities and mitigate risks from external factors during all the phases of the project, i.e. from technical implementation to training and capacity building. The strength of NGOs consists in the ability to network and act cohesively with other entities, taking advantage of their knowledge of local contexts [8]. Hence, the tight linkage with the field facilitates the promotion of tailored strategies and fosters strategic choices with the participation of actors at different levels: public (national and regional policy lobbying), private (strengthening energy provider), social (users' education and sensitization) and local (management committee). The creation of collaborative agreements acquires higher importance with the local institutions and partners, involving them and increasing the commitment of the local community. NGOs also have an intermediary role, by moderating and facilitating the link between local context and private companies interested to entry DCs energy markets as growing business opportunities [7].

NGOs also act in strict connection with public entities and governments and have a significant influence on shaping national or regional energy policies in many developing countries. NGOs have played a leading role in promoting sustainable energy technology transfer as well as the recognition of local knowledge and solutions raised from those contexts, reviewing existing energy policies, proposing alternative ones and focusing on environmental regulations [12]. Another major role of NGOs in shaping energy policies is through their influence on international institutions and policy frameworks that have consequences in defining energy strategies, like the UN Framework Convention on Climate Change (UNFCCC).

## Cooperation for Sustainable Development: The Increasing Relevance of Energy

In recent years the issue of access to energy in the international cooperation has changed, acquiring higher importance, and so did the NGOs to tackle this emerging challenge.

Energy matters have been widely present for years in the European Union cooperation policy, tailored especially to the African countries. However, energy was not seen as a primary aspect to consider with its own relevance, but rather a subaltern instrument spread among different sectors and needed for other aims. The energy sector did not receive significant aid, as donor funds were mostly channeled to other development areas such as: social promotion, environmental preservation or civil infrastructure diffusion [7, 11].

The European Commission started considering energy as a sector in itself, as a priority in the cooperation and fundamental requisite to the challenge of global poverty in 2002. At the World Summit for Sustainable Development in Johannesburg, the international community recognized a straight relation between energy and the Millennium Development Goals and agreed to dedicate special attention to energy as an independent theme. In that occasion, the EU launched the European Union Energy Initiative for Sustainable Development and Eradication of Poverty (EUEI). The Initiative aims at contributing to energy access and focus on stimulating policy dialogue, providing institutional support and technical assistance and facilitating the creation of innovative financial instruments [13].

Energy is now identified as a fundamental and necessary leverage for development, able to respond to potential opportunities, to activate people and enabling sustainability of entire projects. Cooperation actors, especially NGOs, operate to ensure that infrastructural interventions lead to a functional access and that the "last mile" is effectively reached [7]. Energy encompasses several sectors of application such as education, health, lighting, food security, agricultural and productive activities based on the community of people. Being functional to all these sectors, it has a transversal impact on the social context and on the environment [14].

Actions are often dictated by the policy applied (national development plan, rural access plan, national aid plan, etc.) and implemented infrastructures are functional and appropriately tailored to those plans [11].

## NGOs Role in Energy Projects: The ACP-EU Energy Facility

In energy projects, availability and choice of appropriate energy technologies influence the action of an NGO to provide services on a local scale. Although technologies are often available on the market, the lack of local resources and skills represent the main limits to the implementation of the whole energy system. NGOs can compensate for this lack with their range capacities such as choosing an appropriate technical design and optimization, modifying existing components, retrofitting old systems or developing new designs. The selection often involves RESs and relies on simple implementations which are independent from fuel supply or other upstream problems [14]. In some cases, NGOs can be involved in the actual provision of energy services, thus playing a role comparable to the private energy service companies (ESCOs), while maintaining their non-profit nature [12]. Furthermore, NGOs carry out relevant activities such as providing training and building capacity in technical as well as business issues within the energy service delivery arena. They also contribute to deliver public education and sensitize local communities about the technology options [15].

Long term sustainability is a key factor in energy. The reason often depends on maintenance capacity and the final use for which energy is produced. In case of mismanagement or inefficiencies in usage, energy systems become unsustainable and costs for users become high [9]. Within this issue NGOs may facilitate household access while preventing waste and promoting consumer sensitization, taking advantage of their strict relations and experiences with the local community.

The EUEI has played a major role in the creation of means for capacity building and funding resources. One of the most important results was the ACP-EU Energy Facility, established in 2004, as a financing instrument to implement EUEI aimed at improving access to energy in rural and peri-urban areas of low and middle-income countries [13]. The Energy Facility has strongly promoted the rise of European cooperation in the energy sector, making it increasingly relevant in the global agenda.

The first two calls for proposal launched so far have founded 139 projects (with a duration ranging from 2 to 5 years), representing a total cost of 578 million euros with an EU contribution of € 294 million euros, distributed as shown in Fig. 14.1.

In the first call NGOs were the largest recipients in terms of number of projects (26), with the majority being small-scale initiatives and a few concerning energy management and governance. Most of the NGO applicants were European entities, while only one-third were organizations from developing countries. Moreover

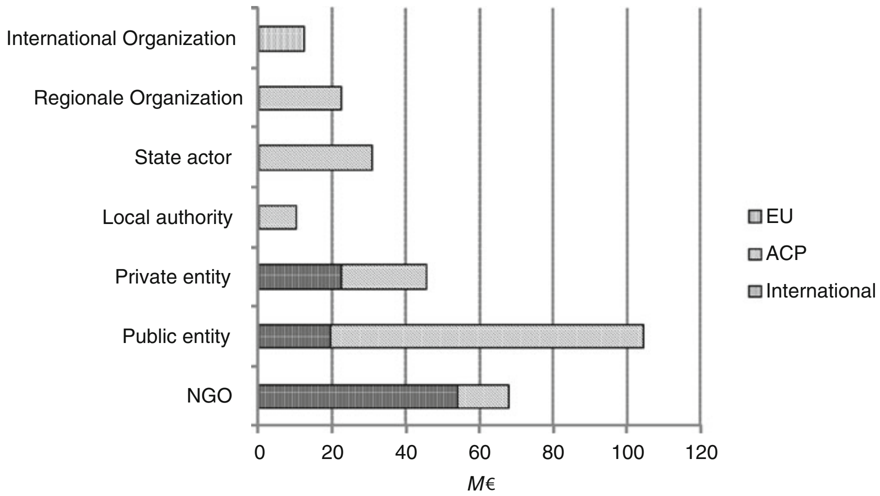


**Fig. 14.1** Distribution of funds by type of recipients, ACP-EU Energy Facility, first two calls

proposals for small-scale projects were more common since NGOs could adapt and better address the activities according to the situation in local context [16].

A new call for proposals has been launched (submission concept of notes, June 2013). The latest, unlike the previous calls, requires a minimum grant of 4 million euros, leading to large-scale projects, where the role of actors, particularly NGOs, can only be expressed through effective partnerships, with a strong commitment of partners able to provide finance (i.e. private sector).

## The Experience of Italian NGOs: Data and Perspectives

Italian NGOs have started operating in energy access projects in recent years, often choosing contexts where they were already present and had a consolidated knowledge, where they were able to better address interventions and to perform a correct assessment of needs and resources.

In 2011 the EnergyLab Foundation presented a survey carried out to monitor the presence of Italian NGOs in the international cooperation focused on access to electricity [17]. Considering all the NGOs registered to the Ministry of Foreign Affairs, data showed that only a restricted number of organizations (around 13 %) were related to actions for access to energy in DCs. Projects did not implicate high amount of money: 40 % were under the range of 100,000 euros and other 30 % under 500,000 euros.

Facing the energy issue as an emerging and new aspect, Italian NGOs do not dispose of specific competences, compared to other European NGOs where energy has been already faced for several years and activity based on private investments has been consolidated. External support is often needed and the involvement of other actors represents the only solution to properly face the technological issues. As mentioned by COOPI [8], the involvement of universities may contribute with a scientific approach and with a focus on innovation. However, the choice is more oriented on keeping the more systemic competences internally and leaving technical aspects to external advisory.

Italian NGOs have experimented different technologies of renewable energies to facilitate energy access in DCs: photovoltaic, hydroelectric, wind power, biomass. According to [17], technologies implemented by Italian NGOs include renewable energy sources in more than 90 % of cases, with the predominance of solar (52 %) and hydropower (39 %). Interventions have been addressed on grids and infrastructures (73 %) and secondly to maintenance operations (20 %). Interviewed NGOs listed different case studies, where a mix of technological solutions has been adopted. Each solution encountered a specific complexity, which the NGO had to solve with an appropriate design and implementation.

Some small-scale hydro plants were experimented in different contexts, in Africa and South America. Hydro plants constitute a long term solution: the expected life cycle is usually longer than other technologies, so that they ensure long-lasting energy provision to the community, enabling basic needs to be met and enhancing productive activities and development (Fig. 14.2 gives an example of hydropower supply). Water resource management assumed a prominent role in developing hydroelectric power plants. This technology required a direct and strong commitment of the community, organized in local associations, which enabled to maintain and preserve the field and the infrastructure, while also reducing the risk of potential conflict within the locals and without affecting the interest of potential investors. In some cases the commitment also included forms of users association with a small percentage in power plant shareholders board. Hydro systems were also combined with PV systems to meet the demand of storing or pumping.

PV installations were applied to private contexts (household systems of 10–20 W) to higher scales (300–1,000 W). The current challenge for this technology is the diffusion of an innovative supply chain, which can lead to a direct involvement of the local population.

Interviewed NGOs have also developed different projects on the efficient use of woods biomass, aiming at reducing the consumption of wood in order to preserve forests and decrease environmental impact, and at reducing respiratory disease due to inadequate heating or cooking systems. Among the listed projects, some also included the diffusion of improved cooking stoves with a self-built approach. The NGO performed an assessment of the local needs; however difficulties arose, mainly due to the application of a new device upon an existing and consolidated cultural environment, where traditional cooking uses were kept, and where trained women were not recognized in their new role of technicians. Other technologies implemented consisted of small biogas systems, wind generators and traditional heating systems for building.

**Fig. 14.2** EuropeAid (FED/2011/266-812) sustainable community based hydro-power supply in six villages of Ludewa District, Iringa Region (ACRA)

Italian NGOs mostly operate in Africa, with more than 70 % of projects located there [17]. NGOs started operating in areas which already experienced the provision of other services. Today the involvement encompasses different contexts, in rural and urban areas.

In urban areas NGOs are more focused on energy for productive and commercial uses, and public lighting. In rural areas, energy supply covers a wide range of basic needs, from health, to cooking and agricultural activities. A greater necessity for energy supply was found in extremely poor rural areas where electric coverage was nearly absent, national grid was not available and the use of traditional biomass was prevalent. In many cases the role of NGOs was not tailored only to the energy issues, but also encountered environmental problems and natural resources conservation.

An example of the increasing commitment of Italian NGOs for the Sustainable Energy for All initiative is the participation to the calls of the ACP-EU Energy Facility granted by the European Commission. Italian organizations have been present with the seven projects presented in Table 14.1 [18, 19]:

**Table 14.1** Italian NGOs participating to the ACP-EU Energy Facility call

| Project | NGO |
|---|---|
| Ligne électrique de Muhura | Movimento per la lotta contro la fame nel mondo |
| Best Ray (Bringing energy services to Tanzanian rural areas) | Istituto Oikos, Onlus |
| HydroBioPower: livelihood improvement in rural area through collaborative development of renewable energy sources in Oromia and Southern Nations Regional States of Ethiopia | Lay Volunteers International Association |
| Haïti: Déployer de nouvelles opportunités de développement socio-économique par l'accès aux énergies durables dans le Plateau Central | Progetto Mondo Movimento Laici America Latina |
| Support to and expansion of Malindi Bio—Fuel Cluster—Jatropha farming | Comitato internazionale per lo sviluppo dei popoli onlus |
| Support to efficient utilization of alternative energy sources to improve the livelihood of pastoral and agro pastoral communities in Southern Ethiopia | Associazione Cooperazione Internazionale |
| Community empowerment for efficient production, use and access of renewable and sustainable energy in rural areas in Malawi | Associazione Cooperazione Internazionale |

## NGOs Expertise and Challenges

Italian NGOs have just recently started working on energy access projects. Few of them are promoting collaborations and creating specialized networks. Pilot projects have been carried out in different contexts; however improvement is needed to implement a common and shared intervention strategy. At European level NGOs have gained more experience in the field and act through a systemic approach, where actors have clearly defined competencies and roles. In Italy roles are not clearly defined and the formalization of specialized networks able to carry out all the phases of an energy project from design to beneficiaries' education, blending multi-sector competencies is still needed. NGOs also need to develop specialized knowledge, especially related to the science of energy production, biotechnology and climate change in order to contribute convincingly and to promote innovation in these fields [6].

The following case studies give an insight of relevant experiences of NGOs in the field of energy.

**Opes Impact Fund and the Energy Sector (contribution provided by Stefano Barazzetta[1])**

Opes is a donor fund launched by Fondazione Opes, the creation of five Italian players active in the social sector: ACRA (an established high-profile NGO), Altro Mercato (one of the leading fair-trade organizations worldwide), MicroVentures (an international microfinance investment company), FemS3 (an organisation active in the diffusion of market-based solutions to poverty) and Fondazione Maria Enrica (a foundation which promotes women empowerment).

Opes is one of the first Italian initiatives in the Impact Investing arena. Impact investments are investments made into companies, organizations and funds with the intention to generate measurable social and environmental impact alongside a financial return. At the base of the Impact Investment movement there is the shared conviction that investments can play a crucial part in addressing social and environmental challenges. Impact investors position themselves at the intersection between philanthropy and mainstream finance. Opes strategy can be summarized as follows:

| | |
|---|---|
| Target | Social enterprises located in East Africa (Kenya, Uganda, Tanzania) and India |
| Sectors | Energy, Agriculture, Water and Sanitation, Health, Education and Fair Trade |
| Stage of Development | Early-stage companies, which are in the process of validating their business models and which need capital to consolidate their activities |
| Investment Size | Opes aims to invest from 50–400 k euros for each portfolio company |

Opes' support is not limited to investment capital, but also includes technical assistance and capacity building: Opes investees will have the chance to leverage on the extensive experience of Opes promoters.

Today, 1.6 billion people live without electricity and 2.5 billion people routinely face energy shortfalls: most of these people live in the developing world. This "energy poverty" affects more than 20 % of the world's most underserved people, who spend up to 30 % of their income on inefficient (and often dangerous) energy solutions.

Activities that many people take for granted in the developed world—like being able to read or study at night—is a luxury for many more. The amount of productive time that is lost as a result of lack of electricity has a significant negative economic effect, which hinders a family or country's path towards a brighter future.

[1] ACRA Foundation.

Opes is scouting with great attention the energy sector, with focus on solutions that take a decentralized approach and that involve the use of clean and renewable sources. Opes thinks that significant opportunities exist in micro-solar and waste biomass, with specific focus on rural electrification both for residential and productive uses. The fund pipeline currently includes energy companies from Uganda, Kenya and India.

**The BEST RAY Project (contribution provided by Matteo Leonardi[2])**

*BEST RAY—Bringing Energy Services to Tanzanian Rural Areas*, is a European Commission funded project (2008–2011) that intends to set up a system to provide energy services to poor un-served rural communities living in Arumeru District, Northern Tanzania, through appropriate, affordable, sustainable and renewable technologies and a good governance of the energy sector. Beneficiaries of the project are about 39,000 people (Maasai pastoralist and Meru farmers) who have no access to energy services and depend on wood-fuel and charcoal for cooking, boiling water and warming and on kerosene for lighting, with negative impacts on quality of life, health and environment.

The main objective is to address poverty issues (contributing to the achievement of the Millennium Development Goal) by increasing the use of renewable energy, maximizing energy efficiency and creating revenue generating activities in the rural energy sector. **Best Ray aims to provide an input in the development process of Tanzania** by establishing an efficient energy production, procurement, transportation, distribution and end-user systems in an environmentally sound manner and with due regard to gender issues. In particular, it is expected to **make sustainable energy technologies accessible and affordable to the rural poor**, thus reducing the harsh impact that the lack of adequate energy sources has on the living standards and the environment.

The project intends also to leverage additional investment and scale up successful initiatives, to improve governance and management in the energy sector by building capacity and creating awareness on energy needs and solutions at all levels (central and local government authorities, civil society, villagers). A strong support is provided to local institutions (Arumeru District, Oldonyo Sambu and Ngarenanyuki Wards) in order to achieve the national and local economic, social and environmental objectives in the rural energy sector.

The project focuses on un-served **poor rural communities of Oldonyo Sambu and Ngarenanyuki Wards of Arumeru District**, Northern Tanzania, (about 39.000 people) with the specific objective to **improve energy access and household economy**. Village leaders estimated that each family uses 15 kg of charcoal/week for a total of about 4,500 tons of charcoal per year.

[2] OIKOS Institute.

**Main activities**

- Installation of renewable technologies in local institutions. Through project activities all public institutions, primary, secondary schools, health centers, dispensaries, village offices have been provided with appropriate energy technologies.
- Realization of all installations with local technicians following an adequate period of training. The public installation serves as a practical training to assure technical skills of local people, once the project is over.
- Establishment of two Community Energy Resource Centers (CERCs) where rural people can access energy services, select most appropriate technologies and learn about them.
- Strengthening Arumeru District's knowledge, planning and management capacities in the energy sector.
- Supply of training, equipment, methodology, technology and institutional assistance to start small businesses in the energy sector.

**What has been installed**

Some 50 solar systems ranging from 40 to 900 W have been installed in public buildings. Future maintenance of the installation was assured through a contract between the institution and the local CERC. In some cases the electricity infrastructure was accompanied with the opening of computer laboratories. Computer training have been run both for teachers and students.

Following technical training and institutional solar systems, the technician has started installations for private and commercial places. Some 100 small-size systems have been installed during the project and additional 200 systems have been reported after 1 year from the project's closure.

Two small hydro systems have been installed on local irrigation channels. One imported from Italy of 3.2 kW supplying electricity to a secondary school. A second small hydro (banki turbine) was entirely build at the Arusha Technical College and installed in a local cooperative. Since the expiration of the project, 2–3 additional systems have been produced and installed locally.

High efficient stoves have been installed in all secondary and primary schools attended by 250–1,100 students. Stoves have been built with local technicians following training.

25 biogas tanks have been installed in residential premises. Best Ray, through Camertec-SNV joint the Tanzanian National Biogas Programme. The programme included extensive training and quality control procedures. Technicians were also helped in establishing their own company of biogas installations.

Considerable efforts have been dedicated in training local woman cooperatives (15) in building domestic efficient stoves. A promotional campaign managed to install approximately 400 energy efficient stoves in the area through woman cooperatives.

Afforestation activities have also been carried out. The Jotropha programme failed because in difficult environmental conditions the seed production was not enough to compensate plantation costs. The plantation of wood trees partially managed to survive in local adverse conditions.

Governance of the energy sector has been improved by

- Preparing together with District officials the District Energy Guidelines to implement basic policies for energy services in the area, with particular reference to renewable energy sources.
- Preparing together with Ward officials the Ward Energy Guidelines to implement basic energy policy in the Wards and establish a sustainability plant for the installed systems.

**Energy and Environment Program: COOPI's Contribution in Malawi (contribution provided by Paola Rosa Fava[3])**

COOPI's strategy on Environment and Energy tackles different issues such as conservation and efficient use of natural resources and the use of alternative and sustainable energy sources. This is part of COOPI's Environment and Disaster Risk Reduction policy. COOPI is currently running two important projects in Malawi and Ethiopia and other projects focusing on energy needs have been run in the past, such as the rehabilitation of a hydroelectric plant in Bolivia.

In particular COOPI is currently working in Malawi on an **Energy and Environment program** in order to promote the use of renewable energy to support rural communities and to promote and sensitize local population on environment protection. The project, responding to the Energy Facility call from the European Commission, provides electricity to several beneficiaries:

- local population, providing them with energy saving stoves and solar kits;
- farmers groups, empowering irrigation systems with solar energy;
- natural resources committees, by creating income generation activities through solar energy;
- schools, by lighting and providing computers for IT literacy courses for pupils and adults;
- tourism associations, by supporting activities of local tourist businesses by using solar and wind energy.

[3] COOPI Foundation.

At Nyonyo, one of the site for the energy project in Kasungu District, not reached by the national electrical grid, one small solar plant (about 500 kWh/year) has been provided to the local Village Natural Resource Committee (VNRC), that is made up of ten members, five men and five women. The provision of solar panels and related components has brought to the start-up of new income generation activities such as video shows, barber shops and phone charging businesses. The VNRC allows local entrepreneurs to have direct access to the solar energy to run their businesses by charging them a fixed monthly fee. This helps to ensure sustainability of the action as these fees will be used to pay off expenditure for maintenance as well as costs for further improvements of the system.

For example, in the month of May 2013, the fee earned by Nyonyo VNRC was 9,000 KWA (about 20 euros) while the total amount of money saved in their account since the system had been up and running (March 2013) was about 15,500 KWA (about 35 euros). Indeed, the availability of energy at village level created a huge demand for electricity. COOPI is currently studying new solutions to provide the requested energy, thanks also to the expertise of the Department of Energy of Politecnico di Milano, that is supporting COOPI in monitoring and impact studies for the project.

**Electrification and Improvement of the Energy Efficiency in Poor Urban Areas in Brazil (contribution provided by Giorgio Capitanio[4])**

According to Grant Potter, the author of the Worldwatch Institute report *Urbanizing the Developing World*, projects that in the next 40 years new and existing cities will have to cope with all the additional 2.3 billion people on Earth as a result of natural increase plus an extra 300 million people who move there from rural communities. This rapid and impressive urbanization phenomenon threats developing countries and especially poor urban areas that need appropriate measures and policies in order to provide the growing population with primary services. Thus, energy access and the safe-use of energy is a necessary but not sufficient condition for the socio-economic development of the population.

The project fostering energy access and energy efficiency in urban and peri-urban, low-income areas of Brazil is reported below. The project aims to promote the electrification, the improvement in energy efficiency, the proper use of electric energy amongst the low-income population in urban areas through the partnership with the entrepreneurial sector and the electricity authorities. This partnership is then supported by the Brazilian government that provides the poorest families with fiscal benefits.

[4] AVSI Foundation.

The main issues observed in low-income areas are listed below:

- diffuse phenomenon of illegal access to energy in poor neighborhoods;
- non-fulfillment of the bills payment;
- high levels of energy inefficiency;
- relevant costs to operate obsolete equipment;
- presence of dangerous electric plants.

On the other hand, the authorities that distribute electricity in low-income urban areas present the following issues:

- uncertainty of the service supply;
- conflicting relationship with the inhabitants;
- commercial losses.

The main activities carried out during this project include:

- supporting the installation of new connections;
- facilitating the access to social tariffs for those families entitled to this right (approximately 70–80 % of the total population);
- raising the awareness of the population about energy efficiency themes;
- defining energy consumption plans within each family with respect to the available utilities (refrigerator, light, television), to the household habits and to their payment capacity;
- defining payment plans for defaulting clients;
- replacing obsolete refrigerators with class A ones in order to promote energy efficiency;
- replacing existing lamps with low-consumption lamps.

Several results have been achieved, including:

- the improvement of the bills payment (decreasing the non-fulfillment from 50 to 20 %),
- the reduction of illegal connections (from 39 to 7 %),
- the adjustment of electricity bills with respect to the payment capacity of the low-income population,
- the lowering of energy consumption (by 55 %),
- new investments in the enterprise-consumers relationship thanks to the introduction of community mediators,
- the use of a combined approach to spread information and improve energy efficiency based on social tariffs and government subsidies,
- the successful partnership with the local NGO promoting trustworthy relationship between the consumers and the service provider.

**Rural Electrification: A Proposal for Smart Grid, Based on Off-Grid Mini-Hydro Experience (contribution provided by Giuseppe Biella, Serena Arduino[5])**

ACRA-CCS intervenes for rural electrification from renewable energy sources in the Njombe Region, Tanzania. Here mini-hydropower plants are possible thanks to the presence of a plateau and mountain ridges, and a first 300 kW mini-hydropower plant was completed (an off-grid system with two 150-kW turbines to better adapt to user needs and seasonal changes in water flows). By the end of the intervention in 2014, the system will count over 1,400 connections, serving nine villages of the Ludewa District with a total population of about 20,000. It has been funded through public funds (Italian Ministry of External Affairs, European Union), private funds (ACRA, Intervita, in-kind donations from Prysmian Group) and with contributions from the Rural Electrification Agency of Tanzania. The plant is owned by the villages and is managed by a user entity—LUMAMA (from the initials of Lupande, Mawengi and Madunda, the first 3 villages to be connected)—which is composed of village representatives. LUMAMA is being accompanied by ACRA-CCS and the local NGO Njombe Development Office–NDO. The Ministry of Energy of Tanzania is monitoring the sustainability of the project with the aim to replicate the model elsewhere.

Besides this running plant, studies are under way for two additional mini-hydropower plants (1 MW and 0.35 MW). As a result of these case studies, ACRA-CCS is in a good position to assess pros and cons and to issue recommendations on the role of mini-hydropower in rural electrification.

*Technical side*

Where a mini-hydropower plant is feasible, other renewable energies for the production of electricity seem less effective and more expensive.

Mini-hydropower schemes are flexible and adapt well to local conditions. They can work without large reservoirs (unpractical in long dry seasons), relying only on existing water flow; overnight micro-reservoirs are possible, to respond to peak day consumption. Multiple turbines allow for seasonal and daily flexibility.

Hydroelectric power can be produced at a constant rate throughout the day. It allows the functioning of industrial and non-industrial machinery, thus enabling productive activities and therefore driving economic development.

*Socio-economic and environmental sides*

Using water for mini-hydropower plants does not conflict with the use of water for personal and domestic use and for agriculture.

[5] ACRA Foundation.

If the community is part of the project and a user entity manages the energy scheme, the community has a bigger stake in protecting the water source and ensuring the sustainability of the plant. They will therefore implement integrated resources management within the basin (forest protection or reforestation, erosion prevention, water storage and reuse, etc.).

When designed and constructed appropriately, mini-hydropower schemes have very little environmental impact.

Electricity from hydropower can serve various purposes, addressing both basic needs and economic development: (domestic and public) lighting, use of domestic appliances, education, health, water supply, mills, machinery to transform and add value to local products.

**Business Model**

*Challenge*

Energy distribution in rural and remote areas, away from the main road network, is hard and costly; management costs for the distribution network are high, and control over misuse of electricity is difficult. National companies in charge of energy distribution (e.g., TANESCO in Tanzania, SENELEC in Senegal) and private investors generally have no interest in selling energy directly to the users of remote rural areas.

*Opportunities*

Rural villages near mini-hydropower schemes may organize themselves around an association of energy users (a user entity) and form a company for energy distribution, thus initiating a rural self-managed energy scheme. The user entity would then become an energy buyer, making energy sale in rural areas more attractive to energy producers. This would appeal to both the national energy company or a private investor who invests in a production plant—even though the price of energy would have to be low enough to allow the user entity sufficient profit to ensure the network operations and management.

Certain countries have introduced feed-in tariffs, accompanied by an obligation of the national energy company to purchase from off-grid systems the renewable energy produced in excess. In Tanzania, for example, TANESCO (the Tanzania Electric Supply Company) must purchase the energy produced from renewable sources and fed into the national grid. The price is set by the national Energy and Water Utilities Regulatory Authority-EWURA (it was 0.075 euros/kWh in 2012).

As a consequence, investors in rural electricity can sell both to the national grid (the national energy company) and to the rural communities (the user entities). This is quite attractive to investors, as they are interested in diversifying their sales and not selling to only one buyer.

*A proposal to private investors*

In Tanzania and countries with a similar approach, mini-hydropower plants between 1 and 5 MW can attract the interest of investors while triggering rural electrification. The vicinity of the prospective mini-grid to the national grid and the obligation of national companies to purchase energy from renewable sources can lead interesting returns on the investment. The connection of the plant to the national grid is crucial to the financial sustainability of the scheme, because it allows for the energy in excess to be sold to TANESCO.

The quality of the relationship between the private investor and the community of the water basin is of the utmost importance. An agreement between these two parties needs to be put in place, recognizing that water is a commons and a most precious resource, and at the same time one element of the hydroelectric system which requires to be maintained in good quality and quantity. Also, the community shall be seen not only as a customer but as an actor of sustainability and development. The agreement shall include clauses and commitments such as the following (for the Tanzanian case):

- the villagers establish a user entity;
- the user entity becomes a minority shareholder in the energy production company (communities who are shareholders in the company have a direct interest in increasing the life span of the plant and of the turbines, and therefore in conserving water in the catchment area and controlling soil erosion);
- the investor builds an energy distribution network to connect the villages within reach of the plant; the distribution network will be managed by the user entity (with contribution from the Rural Energy Agency);
- the energy production company (of which the investor is the majority shareholder) sells energy to the user entity at the same price as TANESCO;
- the investment undergoes socio-economic audits, and obtains all permits by local and national authorities as per the relevant legislation;
- a catchment management plan is developed, also addressing climate change mitigation and considering complementary approaches (biogas, improved stoves, appropriate land uses—which incidentally may provide additional benefits in terms of biomass for cooking and heating);
- incentives and disincentives (including share of dividends, and green water credits assigning benefits to upstream communities for being cus-

todians of land and water) are designed to ensure compliance with the catchment management plan.

With time, the rural network may expand to other villages, absorb and distribute other locally-produced renewable energy, and connect to other off-grid mini-schemes.

There is not *one* business model or *one* governance system which fits all rural electrification projects: the proposed guidelines shall be adapted to the different local situation. In all cases, private investors shall seek the approval and the engagement of the community and act in coordination with local authorities (also through the collaboration of local and international organizations in good standing with the community and the local authorities).

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# Chapter 15
# The Role of Academia for Sustainable Development

**Emanuela Colombo and Fabio Inzoli**

**Abstract** Access to energy is one of the pillars of sustainable development and therefore may be considered as part of this wider research topics. Today the role of university within sustainable development is quite debated at the international level. A double volume has recently been dedicated to this issue by the Journal of Cleaner Production, representing the most updated review. In some circumstances, universities are recognised to have contributed in transforming the society and promoting the common good. At the same time, other examples proving that universities have contributed to the dissemination of unsustainable practises may also be found. Nevertheless, the responsibility of universities and higher education institutions becomes increasingly important when knowledge, skills and innovation are needed to deal with today's global challenges such as those linked to energy. The role of Academia and some of the main related issues are discussed in the chapter.

## Academia and Sustainability

According to many authors, the dichotomy between the Newtonian and Cartesian approaches has promoted two different behaviours for Academia [1, 2]. On one side, some universities have contributed to the transformation of society by educating generations of decision-makers, leaders, entrepreneurs, and academics to serve the public good. On the other side, others have maintained the traditional paradigm, sometimes accelerating unsustainable development models. The issue of Sustainability has only recently been introduced in universities and therefore it will take some time for Higher Education Institutions (HEIs) to become true leaders of Sustainable Development [1, 2]. Anyhow, the current claim of society

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for a sustainable growth and therefore for a more equitable distribution of energy, water and food, represents today a big challenge which cannot be overcome without the proactive role of academia [3]. Indeed, at the global level, a number of international initiatives has been lunched to activate the scientific community.

The launch of the United Nations Sustainable Development Solutions Network (SDSN) by the UN Secretary-General in 2012 is a recognition of the role of science and education [4]. SDSN aims at accelerating joint learning and helps to overcome the compartmentalization of technical and political work by promoting integrated approaches to the interconnected economic, social, and environmental challenges faced by the whole world.

A more specific initiative devoted to the universities is the Academic Impact promoting a network of HE institutions, which, together with the United Nations, promotes ten universally accepted principles in the areas of human rights, literacy, sustainability and conflict resolution and acknowledges the role of higher education in economic and social development.

These initiatives contribute to underline the central role of education as a pillar of socioeconomic development, foundation for world peace and long-lasting engine for facing the many global challenges, including sustainable energy strategies.

Looking at the Italian experience there are different initiatives following this new challenge. We report a few of them particularly related to the experience of Politecnico di Milano with the aim to give evidence of the growing attention in this field.

## Italian Institutional-Academic Partnership and the CUCS Network

As above highlighted, within the complex challenge of development, universities can be a relevant player due to their general competences, educational tradition, scientific approach and commitment towards society. In this frame, since 2004, the Italian Ministry of Foreign Affairs (in particular the "Direzione Generale per la Cooperazione allo Sviluppo—DGCS") has been working in collaboration with the Italian universities, encouraging the creation of networks of national universities. Within the cooperation, the establishment and maintenance of a dynamic database of projects and courses related to development cooperation promoted by the Italian universities has been supported. The initiative includes a an online community, whose aim is to promote the cooperation, the exchange of ideas and experiences and the generation of joint projects.

Within this framework, a group of universities (27 as of today) signed a memorandum of understanding to constitute the CUCS (Coordinamento Universitario per la Cooperazione allo Sviluppo), an academic network with the aim of innovating the academic approach to cooperation and building a strong set of values for sustainable development within each university and the network as a whole. The mission of the network is to promote and disseminate the principles of cooperation for development and peace and the improvement of both theoretical and applied education in the sector. The CUCS members[1] organize every 2 years a scientific conference on academic cooperation. In 2013, to respond to the increasing interest on integrated resource management, a special session of the conference held in Turin was dedicated to water and its nexus with access to energy and food availability and security.

## Polisocial Programme at Politecnico di Milano

In times of crisis the theme of global development becomes more complex. The role of the University acquires higher importance because of the emerging need to prepare the future generations and equipped with the right skills and competences to face the present challenges and to work for the common good in an international, multidisciplinary, multi-ethnic society. In 2012, to contribute to meet this need, Politecnico di Milano has launched together with Fondazione Politecnico di Milano a programme of academic responsibility. Polisocial [5] has two main objectives: to enrich the training opportunities with new content and to promote scientific research and innovation for development.

### *Enrich Training Opportunities*

A necessary condition for living and working in an international context is the capability to understand and cooperate with different cultures, traditions, experiences, environments and economies. As evidenced by a survey of 2011 in collaboration with Assolombarda, engineering companies operating in the global context ask for highly specialized technical skills and also for a set of additional soft skills such as interpersonal and teamwork attitude, communication and leadership.

To meet this need, pilot experiences have been activated with multi-disciplinary teams combining students, faculty members and civil society players. The promoted projects cover different social needs and urgencies: accessibility of public spaces for people with disabilities, renewal of farms as places of historical roots, identification of places for social dialogue in prisons, communication strategies for temporary housing, technologies for communication between immigrants or refugees and their families/communities of origin and IT systems for social inclusion.

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[1] http://www.dabacu.polimi.it/cucs

In this context, projects on renewable energy technologies to mitigate environmental impact and increase social inclusion are required.

### *Promote Scientific Research and Innovation for Development*

Scientific research has a key role to play in development when technology and innovation meet ethics and social responsibility. In this way, scientific research can contribute to overcome the barriers that limit human and sustainable development. For this reason, Polisocial promotes internships, Master theses and joint research projects in developing countries and encourages communication and knowledge dissemination. The cooperation with local universities to promote joint researches and capacity building in the field of sustainable development is central and in recent years, following the raising interest at global level, most of the action has been devoted to access to energy and sustainable energy solutions.

In 2012–2013, many projects have started including a number of trainings with attendants from Africa and Latin America delivered both in presence in Italy and Tunisia and on line via open access sessions. The majority of research projects aims to promote sustainable development of local communities and focuses on capacity building, knowledge sharing and technological cooperation. Sustainable energy solutions, as far as technology, business model and policy are concerned, are one of the central topic for these researches. Tough a recent initiative, Polisocial is currently active in a number of projects related to energy and development:

- in Malawi with an Italian NGO to empower local community in efficient production and use of renewable and sustainable energy in rural areas;
- in Tanzania for capacity building in academia where sustainable energy strategy within the residential sector is one of the main topics;
- in Egypt, Kenya, Tanzania and Ethiopia as partner of the UNESCO Chair in Energy for Sustainable development.

## UNESCO Chair in Energy for Sustainable Development at Politecnico di Milano

The UNESCO Chair in Energy for Sustainable Development has been established at Politecnico di Milano since March 2012.

As highlighted by UNESCO, a lack of engineers who operate with competence and with global attitude is becoming more and more evident. In a rapidly changing world two key elements have recently assumed higher importance: the need to enrich the curricula of future professionals with new contents and the relevance of scientific research and innovation for global development.

Starting from this perspective, the Chair has promoted a new track in "energy for development" within the MSc in Energy Engineering. The track aims at combining engineering fundamental knowledge with a holistic approach to address global problems from integrate perspectives able to asses economic, environmental and social impact of technological solutions and sustainable energy strategies. Studies in this track have the goal to prepare a professional figure with a broad knowledge in technical and scientific fields, able to operate in the energy sector at a multi-scale level, including the development of specific technologies and energy analyses within different scenarios and areas.

Research activity is mainly focused on distributed generation, strategies for improving access to energy but also methodologies for evaluating the impact of energy projects on local development. The vision of the Chair is to contribute to the shift toward more sustainable and equitable energy systems in order to meet the need of global development. Two are the main lines of research:

- Sustainable energy strategies for improving access to energy: need-resource match, demand side planning; multi-criteria, multi-objective and multi-stakeholders decision support systems and appropriate technologies and optimization of mini grid based on renewable sources;
- Performance measurement system for cooperation project in the energy field: result chain evaluation based on OCSE DAC criteria and impact evaluation on the livelihood assets measured in terms of local environmental, physical, financial, human and social capitals.

The Chair also aims to foster international university partnership with developing and emerging countries, supporting capacity building and upgrading of Higher Education Institutions in the target countries, promoting joint research and staff exchange focused on sustainability, innovative technologies and modern renewable energies [6].

Two project proposals have received the grant by the European Commission and are now ongoing: one in Egypt under the TEMPUS programme and another one in Kenya, Tanzania and Ethiopia under the EDULINK programme. The two projects aim to upgrade the local higher education systems on sustainable development and sustainable energy strategies while promoting North–South and South–South cooperation. These projects aim to create a new generation of business and social entrepreneurs with the right skills to start-up green businesses, launch innovative ventures and products, and put in place public policy and social innovation.

Two lecturers from Cameroon and Tanzania are currently developing their PhD research under the flag of the Chair on energy technologies for efficient cooking (improved cook stoves and small scale biogas systems) and rural electrification (minigrid development and optimization).

The Chair also conducts advisory activity and joint projects with NGOs and private companies active in the energy sector at national and international level. In this technological cooperation, the role of the Chair focuses on research and is oriented towards capacity building, innovative solutions and methodologies for promoting penetration of sustainable energies technologies in different contexts.

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# Chapter 16
# The Mandate of the Association of Producers

**Nino Frosio**

**Abstract** Widespread and sustainable energy access is universally recognised as a key indicator of a country's development, and so is the importance of Renewable Energy Technologies (RETs) for health and environment preservation, satisfaction of local needs by local resources and independence from imported (fossil) fuels and their price fluctuations. What is more and more recognized (and increasingly incentivised) is the importance of private sector involvement for sustainable energy production and access, especially in low- and middle- income countries. Private producers have in fact the capacity and experience derived from their work, i.e. daily managing their plants in a profitable way. Their involvement can follow two main paths, not totally independent from each other: investment in energy sector and cooperation.

## The Italian Association of Producers

The Italian private sector's involvement in the energy strategies for low- and medium- income economies electricity market may be a common interest for both of the actors, taking into account that:

- RETs are the preferable way to guarantee access to sustainable energy for the economies in the title, being independent from price fluctuations of imported (fossil) fuels;
- a deep knowledge and expertise is necessary to implement Renewable Energy (RE) projects and to manage RES plants, and the Italian producers have actually been long time renowned for their great know-how and expertise in the sector;

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- last but not the least, at present in Italy the private sector engaged in RE suffers from development limitations (not only due to the natural limits of the sources or of the technologies themselves) while low- and middle- income countries often have a strong energy demand and good investment opportunities.

By way of example, Senegal, in spite of energy supply and lack of access, is nowadays experiencing a strong economic growth, which in turn further increases its energy demand.

Tanzania is another example of changes occurring in African low- and middle-income countries: Tanzania's national energy laws provide the so-called "purchase obligation" of energy from renewable sources (SPPs - Small Power Projects, actually based on RETs) by Tanesco (the national distribution company).

Some basic conditions are certainly needed in order to attract the private sector with mutual interest and advantage.

The main are

- Suitable legal framework, whose structure and complexity depend on the envisaged level of involvement:
  - in the case of engineering and equipments export, tenders with adequate warranties on payments are sufficient;
  - in the case of more complex projects also involving investments, the legal framework must include other factors [see Tanzania].
- Government help: warranties (e.g. for "non-payment") on investments in foreign countries.

Another issue of no less importance is cooperation in its more modern meaning that is not anymore simply donation but technology transfer and capacity building.

## APER and the Renewable Energy Producers

APER[1] (Renewable Energy Producers Association) is the largest association of RE producers in Italy and it has always believed in the outwards opening (towards foreign energy markets and countries) in the two aforesaid forms, i.e. export of technology, expertise and investments, and cooperation in the form of capacity building.

Regarding the first (business oriented) approach, (i.e. exporting technology and expertise to facilitate investments process), APER assists its members through its International Department.

The main activities that APER carries out within the International Department to facilitate the private sector involvement consist in expanding the knowledge of

[1] http://www.aper.it

the energy markets by collecting and creating reports and country profiles to show the elements of interest (authorization, regulatory, incentive, tax, operational, etc.).

APER acts therefore to develop a network of relationships with institutions, financial entities and the main operators of foreign countries, involving Italian and foreign institutions and interested individual associates.

Due attention is also devoted to monitor the experiences already operational, to coordinate any pilot projects and, finally, to organize and participate in trade fairs and business missions.

In order to act with the international cooperation actors and pursuing a non-profit approach, APER in 2006 established SPES (Sector for the Promotion of Solidarity Energy)[2] with the aim of assisting NGOs in managing their projects involving energies in middle- and low- income countries: SPES definitely represents APER's support to cooperation projects.

SPES acts to promote RE-technologies in a sustainable (economic, environmental, social) way for solidarity purposes in rural areas of low- and middle-income countries: its focus is on decentralized regions where the need for energy access (and therefore demand) is in rural areas, usually unserved by national distribution grids.

Our main activity consists in providing consultancy and technical assistance to all stakeholders, especially NGOs, willing to build RE plants to produce energy for their cooperation projects directed to the rural community.

Before assisting in the design and technical phase, SPES and the stakeholders involved perform a preliminary on-site analysis to verify the geomorphological conditions and social needs, in order to find the best solution to produce and distribute electricity and define the adequate tariffs to ensure the project's economic sustainability, both for the consumers (affordability and willingness to pay) and producers (profitability without incentive).

Moreover, the social context is also taken into consideration, particularly for the use and management of the energy resource. In this perspective, the creation of structures to manage the resource for social purposes and on-site training for the equipment operation are also core activities.

Finally, SPES works to prepare Italian NGOs operators to provide basic and advanced knowledge immediately applicable to specific cases by training courses involving internal and external experts for all renewable energy sources and grids.

Different producers are involved for different projects:

- on-grid projects, such as hydro-plants with large reservoirs or construction-extension of national distribution grids.
- mini-grid and stand-alone projects, mainly in rural areas.

[2] http://www.spesweb.eu

The importance of small producers and entrepreneurs characterized by flexibility, initiative, quick decision, capacity of taking chances by adapting to difficult -and not standardized-situations) is in fact fundamental in rural areas presenting a varied context which often needs ad-hoc solutions.

# Chapter 17
# The Contribution of Multinational Companies: Eni Corporate, Sustainability and Corporate Social Responsibility

**Luigi Sampaolo, Gloria Denti and Valentina Patricola**

**Abstract** The business sector led by multinational corporations has an increasingly prominent role in international development. Global consensus praises the role of the Millennium Development Goals (MDGs) agenda in challenging resources to poverty reduction and various dimensions of social development, yet poverty is still widespread and new multiple challenges at a time of financial crises undermine the world ability to eradicate poverty; poverty defined not only in terms of money, but in terms of food insecurity, unemployment, violence and humiliation, lack of health care, electricity and good housing. For these reasons, during Rio + 20 Summit, world leaders have emphasized the need for a new single coherent agenda with sustainable development at its core. In this complex architecture the new global partnership for sustainable development have reified the centrality of business to development and affirmed its central role in contributing to poverty reduction.

## The Global Agenda and the Eni's Contribution

As Rio + 20 Summit majors outcome called for the need to identify new goals and targets to help translate the global aspirations into practical actions, business leaders have been encouraged to contribute with their knowledge and expertise to the definition of new Sustainable Development Goals (SDGs). The SDGs framework is built on the MDGs and guided by the new development paradigm which reflects equally the economic, social and environmental dimensions of sustainable development and the interconnections between them. The SDGs, therefore, reiterate the imperative need for a new global partnership that enables a

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transformative, people-centered and planet sensitive agenda, realized through the equal partnership of all stakeholders and Governments' ability to define their own development agenda. To this end, SDGs aim to galvanize individual and collective actions and provide a new definition of good governance that not only applies to Governments and donors, but also to multinational companies and international organizations. What is about to be delivered is an accountability framework which demands for a global agenda in which all are equally accountable for its actions.

**eni** contribution to the development agenda has built on a partnership model with local Governments, especially developing countries, with multilateral and international organisations and other representatives of the private sector. As a matter of fact, nowadays strategic partnerships should include joint projects for the economic and social development of the Countries. One of **eni**'s distinctive features, useful for developing collaboration with producing Countries, is having operations and skills integrated in the entire energy business sector. The operational excellence and the integrated approach aligned with a culture of cooperation with the producing Countries enable **eni** to operate with the responsibility of an international energy Company whilst having the ability to invest in the Country's future as a national Company. This is the "dual flag" approach, through which **eni** shows its ability to take part in the design and implementation of sustainable development of Countries: one flag shows the six-legged dog, **eni**'s symbol, the other is the host Country's. From the dual nature of a local and global company, **eni** has the ability to dialogue with local, national and international institutions on the major sustainable development issues. Years of experience in the field have thought that **eni**'s "dual flag" approach has been successful to cater for diverse national realities. **eni** has long recognized that inclusive and sustainable development requires a stronger emphasis on the promotion of productive employment, the respect of environment as well as social transformation emphasizing inclusiveness. Among others, one of the reasons of the success of **eni**'s model and the basis of its ability to be "chosen" by the countries in which it operates is the will to create growth opportunities for the local people. **eni**'s model of cooperation relies on empowering human potential in the territories to promote a country's autonomous growth. The strategy adopted is to form the local people to take on more and more important roles within the company.

Thanks to this approach, **eni** operates in many developing Countries. The activities and initiatives promoted locally, as part of cooperation agreements, have a strong impact on the economy of the communities. As a consequence, **eni** is the leading international producer of hydrocarbons in Africa.

At a global level the company is committed to cooperating with multilateral and international organisations, governments, other energy companies and private organisations to define and develop collective actions to improve business efficiency and transparency, with positive effects for both international oil companies and oil producing Countries.

**eni** is active in a number of organizations and networks where the contribution of business to development is debated. For example, with reference to the United Nations networks, since 2001, **eni** is a member of the UN Global Compact. In

November 2010, within the Global Compact, **eni** was invited to join the LEAD platform, an initiative reserved for the global companies deemed able to play a leading role at international level for the sustainable development by actively promoting the MDGs of the UN. The United Nation LEAD platform is also involved in SDGs process with a related group, in which **eni** plays a proactive role. **eni** supports the UN Secretary General's Sustainable Energy For All initiative, acknowledging that energy illustrates well the cross-cutting challenge of sustainable development. Among the initiatives launched to promote sustainability, **eni** contributes with its extensive experience to the United Nation Sustainable Development Solution Networks (SDSN), led by Professor Jeffrey Sachs. The SDSN convenes global expert thematic groups on key sustainable development challenges that identify common solutions and highlight best practices. It also provides technical support to the High-level Panel of Eminent Persons on the Post-2015 Development Agenda and the related SDGs definition process. Within the SDSN, **eni** also leads the Solutions initiative on Energy for All in Sub-Saharan Africa.

## Energy as a Development Enabler

Energy is a prerequisite for development, supplying energy to populations who currently have a scarce access to it, gives **eni** the ability to indirectly, but efficiently, pursue the Millennium Development Goals defined by the United Nations. Addressing the lack of access to clean, reliable and affordable energy services for billions of people is one of the world's most critical development challenges. The different distribution of energy consumption worldwide represents both a barrier to the growth and a cause of inequality. People without access to electricity are around 1.3 billion equal to 20 % of the world population. 84 % of these live in rural areas, 95 % of them in Sub-Saharan Africa and in the least developed regions of Asia.

Therefore, access to energy is a particularly serious problem in Africa, which represents the paradox of countries that are major energy producers while suffering from energy poverty. In Africa, **eni** operates in 21 countries, and as mentioned above is the leading international oil company in terms of hydrocarbons production.

**eni** has been able to integrate the development of local energy systems in Africa into its core business by taking new opportunities and by creating the basis for the development in the Countries where it operates, especially in those areas where energy poverty is a crucial issue. The activities carried out in Nigeria and in the Republic of Congo are the main examples of this approach. **eni** has been active in constructing and rehabilitating grids and power plants fed by gas previously flared. The issue of gas flaring is particularly significant in Africa too. Using gas to produce electricity has enabled **eni** to turn gas flaring from an environmental risk into a business that offers opportunities for local development.

In order to play a leading role in making the change happen, under the Sustainable Energy For All initiative, **eni** registered two commitments at the UN Conference on Sustainable Development (Rio, June 2012). In particular, **eni** committed to reduce carbon intensity of hydrocarbon production, reduce gas flaring intensity of upstream activities and use associated gas, especially where flared and to improve access to modern energy. As a matter of fact, in Africa, **eni** has a flaring down strategic plan that seeks to address the dual challenge of fighting energy poverty while tackling climate change; an approach which catalyzes social and economic development, while taking into account an important environmental aspect.

## Accessing Electricity and Reducing Gas Flaring in Nigeria and the Republic of Congo

In Nigeria, as part of a Gas Master Plan defined in agreement with the Federal Government, **eni** responds to access to energy lack providing electricity and natural gas through three types of interventions:

- Supply of electricity and natural gas through the Independent Power Projects;
- Supply of energy to the community through creation of networks connected to industrial plants;
- Delivering of electricity through off-grid systems.

Regarding the Independent Power Projects, the Okpai plant inaugurated by **eni** in 2005, has an installed capacity of 480 MW and which answer to the electricity need of approximately 10 million people (estimated data based on the total annual consumption of population with access energy); in addition to the gas sent to Okpai, **eni** supplies gas to the Rivers State Government power station, with an installed capacity of 150 MW equal to need of 1 million users (estimated data based on the total annual consumption of population with access energy). **eni** promotes, also, access to electricity through the creation of networks connected to industrial plants such as the Ebocha Early Gas Recovery Project, with the result of: 28 communities reached, 26.5 MW of installed capacity, about 200 thousand people served. Furthermore, thanks to this project in 2012, the gas flared in Ebocha was equal to 0.32 million standard cubic metres per day with a 66 % of decrease compared to 2009 level. **eni** also provides electricity access through off-grid electrification systems: 32 communities served, 6.5 MW of installed capacity and 63.4 thousand beneficiaries.

Based on its first experience in Nigeria, **eni** signed a first agreement with the Republic of Congo in 2007. It presented a four-year plan to the Congolese authorities, setting out its commitment to produce electricity for the country thanks to two electric power stations. Gas flaring would be reduced reusing it in electricity production, and the remaining parts of it would be reinjected into the hydrocarbon deposit.

The Integrated Project foresees:

- the construction of the Centrale Electrique du Congo (300 MW, completed in November 2010);
- the revamping of the Centrale Electrique de Djeno (an additional 25 MW for a total of 50 MW, in full service since 2009);
- the installation of the associated gas treatment and transportation system from the gas field to the power plants (completed in 2009);
- the development of a gas and condensates to supply gas to the CEC;
- the revamping of the national electricity network (RIT project) to facilitate the distribution of electricity throughout the Country (officially delivered in December 2011);
- the revamping of the medium and low voltage electric network in Pointe-Noire (DEPN) (Medium Tension Phase Project delivered in 2011, Low Tension Project under way).

The interventions in the power plants fed by associated gas have led to a significant reduction in gas flaring. Overall, the two power plants represent 60 % of current electricity production in the Country. The energy produced is distributed to the Pointe-Noire where, thanks to these power plants, about 350,000 people are served today. In 2012, a new project started in the field of Kouakouala. The gas, which until a few months ago was burned in torch, is now being conveyed to a system of generators which supplies electricity to two villages located in the areas close to the field, feeding among other things water wells, schools, health centres and public lighting. These villages, which count about 4,000 inhabitants, did not have any access to electricity before.

Other pilot studies could be defined in Sub-Saharan countries in order to integrate and improve **eni**'s community development projects capacity related to local access to energy increase.

# Chapter 18
# The Enabling Electricity Programme: Enel Vision and the Role of Enel Foundation

**Mariano Morazzo and Giulio Lo Iacono**

**Abstract** This chapter is devoted to showcase the experience and the knowledge of a global utility and its research foundation and how it can contribute to the development and implementation of cooperation strategies and projects in the energy field, fostering energy access and the economic and living standards of the disadvantaged people around the world. In 1962 Enel came into being in Italy with the aim of completing the electrification of the country, equipping it with leading-edge infrastructure and bringing electricity wherever it was needed. Today, more than 50 years later, Enel is renewing its mission and its commitment to the benefit of global communities and future generations. Creating value for business may be considered sustainable and long-lasting when it also contributes to adding value for the people and the environment. Enel operates all along the entire electricity value chain in four countries with over 74,000 employees and supplies energy to over 61 million customers every day. It oversees the generation of 98 GW of net installed capacity and distributes electricity and gas through a network spanning around 1.9 million kms. Thanks to a technologically and geographically balanced production mix, over 42 % of power produced by Enel in 2012 was at zero emission. Sustainability has become part of the company's strategy as it is recognized having a direct impact on competitiveness and long-term value creation.

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## Enel's Approach to Sustainability

Sustainability is part of Enel's culture: it drives a process of continuous and transversal improvement within the Company and is key to its mission of growth and development.

In 2002, Enel adopted a Code of Ethics which defines ethical duties and responsibilities when conducting business and corporate activities and regulates and harmonizes operations according to standards based on the utmost transparency and fairness.

The creation of shared value in the medium-long term, both for shareholders and stakeholders, implies a solid governance capable of supporting market credibility and promoting accountability with investors.

In line with this commitment, Enel implemented environmentally-friendly industrial strategies and effective partnerships with all stakeholders, including people interacting with the company and communities in countries where it operates. Moreover, in 2012 Enel Board approved the Policy on Human Rights, following the UN Business and Human Rights Guidelines, which enhance and expand the commitments already expressed not only by the Code of Ethics, but also by the Zero Tolerance of Corruption Plan and by the 231 Compliance Program.

Since 2002, the Sustainability Report has been measuring Enel's commitment towards Corporate Social Responsibility using 450 Performance Indicators. As part of its commitment to accountability, Enel is part of the group of companies which assisted the Global Reporting Initiative in drawing up the next generation of guidelines (G4) governing sustainability reports and participated in the Pilot Programme of the International Integrated Reporting Council.

Enel's commitment to sustainability is witnessed by the presence of the Company in the Dow Jones Sustainability Index for nine consecutive years. In addition to the FTSE4 Good and Carbon Disclosure Project, Enel's commitment to sustainability has been rewarded by the trust of Socially Responsible Investors (SRI) who represent 14.6 % of the institutional shareholders.

Since January 2011 Enel also participates in the Global Compact LEAD, a programme launched by the United Nations Global Compact that brings together the top 56 international companies in economic, social and environmental sustainability.

## Access to Energy—Enabling Electricity

In the last century, the spreading of electricity was the driver for industrial growth. Now, at a time of economic recession, an efficient energy market can, for industrialized countries, go hand in hand with economic recovery and, for emerging countries, be a source of growth by allowing wider access to goods and services.

From this viewpoint, supplying electricity means more than simply providing a service: it can lay the foundations for the very development of people and communities.

Enel supports the United Nations in promoting access to electricity with the Enabling Electricity program. The program focuses on two targets: people who live in isolated areas and disadvantaged communities in peripheral, rural and suburban areas.

Enabling Electricity is based on three groups of:

- projects aimed at facilitating access to electricity through new distributed generation technologies and network infrastructure;
- projects to remove economic barriers to access to electricity in areas such as Latin America;
- projects with local communities for the development and sharing of know-how and knowledge through technical training and development of professional skills.

Over one million people worldwide already benefit from the Enabling Electricity Programme, and Enel intends to double this number by 2014. Here below some of the projects which Enel is developing in these three areas are presented. Other projects are under development, for example in South Africa and Central America.

## *Triangle-Based Omni-Purpose Building (TOB)*

Worldwide there are still numerous isolated areas where local populations do not have access to electricity and essential services owing to issues of technical feasibility or economic convenience. With a view to overcome these limitations, Enel Research Centre developed the Triangle-based Omni-purpose Building (TOB) as a system that can provide energy and basic services in off-grid areas.

The structure is an independent habitable module which integrates photovoltaic modules and accumulation systems and is designed to be able to house various technologies to exploit renewable sources according to local availability.

TOB produces and accumulates electricity to make it available when necessary. It is flexible thanks to modular components which enable easy assembly in various forms depending on the requirements and needs of the populations which use it. In addition, it is possible to include within it all the equipment for the supply of services that communities need (schools, sick bays, recharging systems, etc.).

The system's prototype was installed at the Enel Research Center in Pisa (Italy) in February 2012. Following the experience acquired in the second half of 2012 the second prototype was built, the TOB 2.0 system, which is characterized by a reduction in bulk and weight, thus making transport and setting up even simpler. During 2012 feasibility studies were started relating to the installation of TOB 2.0 systems in remote off-grid in Latin America.

The TOB prototype consists of two base units (two modules of approximately 30 $m^2$) with 5.4 kW of thin-film photovoltaic panels, and storage batteries to guarantee a 4 h supply of electricity even in the absence of sunlight.

## *Ecoelce, Ecoampla and Ecochilectra Projects*

The poorest urban areas in South America are often characterized by the presence of open dumping grounds, which harm the environment and the health of the local populations. In the same areas there are frequently thefts of electricity from the grid by the people who live there, which cause huge losses and represent a serious risk of accidents for the people who abusively connect to the grid.

The Ecoelce and Ecoampla projects in Brazil—and Ecochilectra in Chile—aim to stimulate, through economic incentives, waste collection and recycling and, at the same time, make "legal" use of electricity more accessible. Customers who bring their waste to specific collection points receive discounts on their electricity bills in proportion to the quantity and type of waste they bring.

The mechanism brings various types of benefits:

- social, as cheaper access to electricity is guaranteed, accident risks are reduced as is the rate of illnesses due to poor waste management, the quality of life improves for families, energy efficiency projects are promoted, development of the waste recycling industry is favored and awareness of "legality" in energy use is generated in customers together with knowledge of the efficient use of energy;
- environmental, in terms of a lower visual and environmental impact from waste, greater environmental awareness on the side of customers and greater responsibility in the use of electricity;
- economic, thanks to the lower number of unpaid accounts and the reduction in the phenomenon of thefts from the grid and the increase in the number of customers.

In 2012 alone the projects accounted for 356,700 new beneficiaries. Since the project launch in 2007, a total of 17,187 tons of differentiated waste has been collected, which has generated over 814,000 euro in discounts on bills for customers.

## *Barefoot College*

Barefoot College is an India based non-governmental organization that has been providing basic services and solutions to problems in rural communities for more than 40 years, with the objective of making them self-sufficient and sustainable.

Their model involves identifying young, illiterate grandmothers (aged 35–50), to be included in a special training program to transform them into "Barefoot Solar Engineers".

The choice of involving grandmothers derives from their solid roots in the local area and from the fact that they have less onerous family responsibilities compared to young mothers.

Once they have been chosen, the women spend 6 months at Barefoot College in India (Tilonia, Rajastan) where they learn to install and maintain small photovoltaic systems. The training is done through gestures, sounds and colours, so as to be able to communicate effectively even without having a common language. At the end of the training, the women return to their home villages where they run the business and train other women and export the model to neighbouring villages. In addition, the communities which take part in the project agree to make available a communal area to set up a laboratory/workshop for the women. The individual heads of household must pay a share for the service provided by the women in installing, maintaining and repairing the domestic photovoltaic plant. The amount to pay is very low and, in any case, is lower than the total cost families would pay to procure lighting systems (candles, kerosene, oil, etc.), but guarantees the sustainability of the service over time and at the same time income for the women.

The model has been brought to Latin America for the first time thanks to Enel Green Power. The countries initially identified for the project are Guatemala, Chile, Peru, Colombia, and El Salvador. In 2012, 16 women were trained and will bring photovoltaic systems to a total of 1,000 homes. 680 solar kits have already been sent to Chile and Peru, where the start of installation is envisaged for the first half of 2013. In addition, the program will be extended during 2013 also to Central America (Mexico and Panama) and Brazil.[1]

## Enel Foundation: Energy Knowledge to Foster Energy Cooperation for Development

Enel Foundation is a not-for-profit organisation promoted and fully supported by Enel. It aims at carrying out studies and research activities, at promoting executive training and dissemination initiatives on energy, socio-economic, sustainable development and innovation issues. Its mission includes exploring and analyzing current trends of utmost importance in the areas where the Foundation operates. The objective is two-fold: to provide a scientific and rigorous interpretation of these dynamics and to stimulate international scientific debate.

The results of Enel Foundation's research programmes are achieved by means of a close cooperation with international academies and research organisations.

[1] More information about the Enabling Electricity projects are available on the Enel website: www.enel.com.

The Foundation identifies research subjects and coordinates the implementation of the projects, while academic experts assist in the analysis of themes and development of methods. Some projects are also implemented with the participation of institutional actors, think-tanks, NGOs and other not-for-profit organizations.

A relevant value added of Enel Foundation activities lies in the close interaction between the Foundation and Enel Group holding and industrial divisions, which allows the valorisation of the competences and know-how acquired through the development and management of a wide range of Energy projects and activities, aiming at bridging the gap between research and industry.

The Foundation is also involved in partnerships, aimed at financing specific research projects. This is a fundamental tool in order to create and consolidate a network of scientific and institutional relationships that may increase the impact of Foundation's activities within the wide community of knowledge actors.

The capacity of interaction with different type of organizations for the development of knowledge, know-how and best practises is particularly well-suited to address global challenges such as energy access, which needs a comprehensive approach taking into account different objectives, drivers, constraints and the role and point of view of different actors.

Indeed, energy cooperation for socio-economic development, and in particular its ability to ensure an affordable and sustainable energy access to all mankind, is a wide and complex theme, which encompasses different inter-linked elements: the natural and energy resources availability and economic exploitation, the deployment of effective technologies to convert the primary sources into energy services, suitable business models to deploy and manage such technologies to provide the energy services, the adequate regulation to enable such business models (and investment), well-designed policies and institutional setting to ensure the fulfilment of many different policy objectives while ensuring the consistency of such elements of the value chain.

Since its inception in June 2012, Enel Foundation has launched a range of research activities on energy access focused on technical and non technical elements of access to energy:

- Low cost technologies for rural areas;
- Efficient regulation for grid connected energy services;
- Socio-economic impacts of energy access;
- Impact evaluation of energy projects;
- Capacity building for young researchers within access to energy;
- Dissemination of renewable knowledge within communities.

**"Low-cost energy technologies for universal access"** is a relevant example of research project undertaken by Enel Foundation in this field in collaboration with the Massachusetts Institute of Technology and Comillas University. The project aims at assessing appropriate low-cost energy technologies most suited to environmental, socio-economic and geographic/climatic conditions of those regions where access to energy is mostly lacking (Latin America, Africa, Asia). The study has an initial focus on Peru and Kenya and, in a second stage, it will be extended to

Brazil and Nigeria. The value of this project lays in providing insights on the specific technologies satisfying particular environmental and social local conditions, the appropriate business model to promote those technologies with an economically sustainable approach and in identifying the appropriate regulatory provisions to promote virtuous business models.

Considering the criticality of regulation to provide efficient and affordable energy services, a project developing a **"Comparative analysis of electric market regulatory systems in various Latin-American countries"** has been launched in collaboration with Comillas University and the Massachusetts Institute of Technology. The study aims at providing a comparative analysis of electricity-sector regulation in several countries of Latin America, to identify best practices, common trends, differences and criticalities, and will analyze and confront the different regulatory settings towards different cross-cut objectives, including their ability to provide an enlarged and affordable energy access. The project will also provide recommendations to policy makers and international inter-governmental organizations to foster the development of more integrated and efficient regional energy markets.

To contribute to a deeper understanding of the socio-economic impacts of clean energy access, Enel Foundation is supporting and collaborating to the project "**Powering Education**", jointly carried out by the Global Shapers Community of the World Economic Forum, the London School of Economics and Givewatts, a European NGO focused on North–South cooperation. The research focuses on the education dimensions involved in accessing clean energy sources. Currently, a pilot activity is being implemented engaging the local communities in southern Kenya. The project entails the development of a sustainable model through the installation of 350 solar lampsfor the diffusion of clean energy. This represents the foundation for a study on the impact of the replacement of kerosene lamps with solar lamps on education through the measurement of a set of key parameters (e.g. students' school achievements) in a group of more than 800 children. This exercise will allow building a compelling story about the strong connection between clean energy diffusions and access to culture. The lessons learnt with this project will be leveraged to allow for effective and efficient replication in other areas. In addition, the cooperation activities tested within this project will be shared with other stakeholders to design synergic scaled-up programs.

Moving from the consideration that many efforts and resources have been addressed to the cooperation in the energy field but still relevant advancements are needed, a research project focusing on the performance of energy cooperation projects has been started. The project **"Performance measurement systems for cooperation projects in the energy field"** is carried out in collaboration with the Department of Energy of Politecnico di Milano, and analyses recent developments in the evaluation of cooperation projects and programs, as far as access to sustainable energy is concerned. The aim of this study is to support policymakers by providing feedback over the performance of single energy access projects and full programs to drive the design of future strategies at local level and of guidelines at global level, exploring the connection between energy technology and physical and socio-economic impacts. The project holds the ambition to advise to donors and international development and financing organizations for an efficient allocation of development resources.

Enel Foundation addresses also some specific training efforts with respect to the energy access challenge. Enel Foundation "Energie per la ricerca" (Energy for Research) grants, organized in cooperation with Fondazione CRUI, are supporting a 10 month research period for post-graduate and post-doc researchers, which will develop a research project on specific themes, taking advantage of Enel facilities, know-how and network while keeping in touch with the own academy. One of the selected themes is Energy Access, to testify Enel Foundation commitment to contributing to this development goal.

Enel Foundation is also undertaking dissemination activities in this field. An international conference on international cooperation on energy for development and energy access will be jointly organized with Politecnico di Milano in December 2013. The Conference "International Cooperation for Sustainable Energy Strategies Energy Access & the Nexus with Water, Food and Land—Integrated resource management beyond 2015" will tackle the theme of international cooperation for energy development, with a focus on universal energy access. The event will be part of Politecnico di Milano's 150th Anniversary celebration program. The event will provide a forum for discussion among institutional, academic and industrial stakeholders to promote sustainable energy strategies.

Enel Foundation complements and integrates the Enel Group's contribution to the enhancement of energy accessibility, affordability and sustainability and embraces in its mission the fulfilment of this development goal, contributing with original and innovative knowledge and dissemination, educational and capacity building activities.