Chapter 27
Assessment of the Most Sustainable Renewable Energy Configuration in Mauritius and Rodriques

M. Tsang Pun Yin, J. Jayasuriya, T. Fransson, Surroop Dinesh and Mohee Romeela

Abstract The Maurice Ile Durable (MID) initiative was launched by the Government of Mauritius in year 2009 to transform the country into a sustainable island. The wind sector is experiencing a sustained growth and many wind farm projects have been announced by the private sector under the Clean Development Mechanism (CDM) and sales of carbon credits namely the 18 MW wind farm project at Plaine des Roches and the 22 MW Wind Farm at Britannia. As land resource in Mauritius and Rodrigues is not unlimited and only a few sites have the necessary characteristics for exploiting wind potential. Therefore, it is essential for policy decision makers to consider the possibility of using other local renewable energy resource as part of the energy mix (including wind energy) for electricity production in Mauritius and not to concentrate solely on wind energy. In that context, this study was initiated to assess the renewable energy configuration system in Mauritius and Rodrigues including wind energy using a simulation optimization model. An economic assessment was carried out for different configuration of renewable energy system including wind energy for Mauritius and the island of Rodrigues using a simulation tool namely HOMER software. Two case studies were proposed for Mauritius and Rodrigues to include renewable energy sources such as the use of bio-fuel, renewable biomass, mini hydro plant and solar energy using PV Grid tied systems.

Keywords Renewable energy · Homer software · Mauritius · Rodrigues

M. T. P. Yin (✉) · J. Jayasuriya · T. Fransson · S. Dinesh · M. Romeela
Royal Institute of Technology, Stockholm, Sweden
e-mail: jmtpy@kth.se

W. Leal Filho et al. (eds.), *Climate-Smart Technologies*,
Climate Change Management, DOI: 10.1007/978-3-642-37753-2_27,

Short Introduction

Recently, in Mauritius and Rodrigues, wind sector is experiencing a sustained growth, but considering the fact that land resource is rather limited, it is essential for policy decision makers to consider the possibility of using other local renewable energy resource for electricity production in Mauritius. In this paper, the economic assessment for different configuration of renewable energy system (including wind energy) was carried out for Mauritius and the island of Rodrigues by using HOMER software. Two case studies to include renewable energy sources such as the use of bio-fuel, renewable biomass, mini hydro plant and solar energy using PV Grid tied systems were proposed.

Introduction

Exploiting renewable sources of energy for power generation is today the priority of the Government of Mauritius to reduce the high dependency on fossil fuels. The emissions of Carbon Dioxide (main GHG emitter) was about 3,256 thousand tons in year 2007 and has slightly decreased by 3.5 % to 3,075 thousand tons in year 2009 (Mauritius Central Statistic Office Report 2009).

Mauritius presently obtains around 17.5 % of its energy needs from renewable sources (mainly from bagasse which is a by-product of sugar cane, wind and Hydro representing only 4.8 %) (Mauritius Central Statistic Office Report 2009). Some 2,577 GWh (222 ktoe) of electricity was generated in 2009 in Mauritius and the peak demand for electricity in Mauritius continued to increase every year and have reached 388.6 MW in 2009 (Mauritius Central Statistic Office Report 2009).

In 1980s, a United Nations Department of Technical Co-Operation for Development (UNDTCD) funded project entitled 'Wind Energy Resource Assessment for Mauritius' was conducted to identify the most potential sites for wind power generation in Mauritius. Only a few sites were recommended by the study and since Mauritius is a small country where land is an important resource, it would be wiser for the Government or the private sector to explore and invest on other economically sustainable renewable energy sources other than wind energy. Therefore, there is a need to assess the cost and environment benefits of having other renewable energy source together with Wind energy such as bio-fuel or synthetic gas-fuel, PV solar energy or other types of renewable sources.

In recent years, a feasibility study of wind farming in Mauritius has been conducted in 2002 by Palanichamy and the wind potential has been estimated to be 60–65 MW taking into consideration wind speed data obtained, the CEB grid capacity and the available land resources (Palanichamy 2002) (Table 27.1).

The proposal of an assessment of the most economical and sustainable mixed Renewable Wind energy Configuration System in Mauritius and Rodrigues using a simulation optimization model will enable future investors or policy decision

Table 27.1 Total installed capacity for electricity production 2008 and 2009 [*source* Mauritius Central Statistic Office Report (2009)]

Years	Effective capacity (MW)	Peak power demand (MW)		Electricity generated from wind	Electricity generated from thermal	Total electricity
		Mauritius	Rodrigues			
2008	612.2	378.1	6.0	0.4	2,448.8	2,557.2
2009	656.3	388.6	5.6	1.5	2,453.5	2,577.4

makers to understand the important parameters to achieve a mixed sustainable renewable power generating system in Mauritius while decreasing at the same time our dependency on fossil fuel.

Objectives

The main objective of this report is to use HOMER Simulation and optimization tool to economically assess the different combinations of Wind energy with other renewable energy resources at namely;

1. The existing wind farm at Grenade and Trefles region in Rodrigues;
2. The two proposed wind farm in Mauritius namely the 22 MW Wind Park at Britannia and the 18 MW Wind farm at Plaine des Roches.

Different combinations of Wind energy with other renewable energy resources will be proposed and analyzed for the above projects to see which mixed renewable system configuration would have been the most cost effective and at the same time which will be the most environmentally sustainable system. An optimization model will be formulated for this project using the HOMER free software. The HOMER simulation tool a computer model developed by the U.S. National Renewable Energy Laboratory (NREL) and is used to simulate and compare different design system based on its technical and economical aspects.

Proposed Configuration System for Mauritius and Rodrigues

The proposed system configuration system for Mauritius will include the proposed Wind Farm at Plaine des Roches and Britannia, proposed two mini hydro plants at Midlands Dam (350 kW each) and Bagatelle Dam, PV grid tied power generating unit (430 kW) and the Gas to energy project (3 MW) at Mare Chicose land fill site.

The proposed wind farm at Plaine des Roches will consist of 18 wind turbines of model Vergnet GEV HP 1 MW aero generator each rated 1 MW. The promoter Aerowatts (Mauritius) ltd through the Clean Development Mechanism (CDM)

involving reduction of greenhouses gases has actually finance the 18 MW wind farm project at Plaine des Roches over 7 years using 210,000 carbon credits contract sold to the Swedish Government represented by the Swedish Energy Agency (Press release 2010).

Similarly, the proposed renewable system configuration for Rodrigues will include the existing wind farm at Grenade and the possibility of considering biomass resource (1 MW) and a PV grid tied system (1 MW), mini hydro plant (350 kW) and generators running on coconut oil instead of diesel.

Modeling Using Homer Simulation Tool

Methodology

The simulation results for each proposed hybrid wind configuration can be easily evaluated by HOMER simulation tool and can be discussed in terms of economic sensitivity of hybridization and the economic and environmental benefits. HOMER performs three principal tasks: simulation, optimization, and sensitivity analysis.

In the simulation process, the performance of a selected design configuration is determined each hour of the year including its technical feasibility and life-cycle cost. In the optimization process, simulation of different system configurations is carried out to find the most appropriate system configuration that satisfies the technical constraints at the lowest life-cycle cost. In the sensitivity analysis process, HOMER software performs multiple optimizations under a range of input assumptions to gauge the effects of uncertainty or changes in the model inputs (Lambert et al. 2006).

When proposing a hybrid configuration and simulating its technical and economical behavior using HOMER, many important criterions that can impact on the proposed system need to be input into the simulation tool. Examples of such input that need to be identified are namely;

1. Daily power load requirement

A baseline load profile data for Mauritius is created using one typical daily load profile 24 h average (Month is March 2008) obtained from the sole distributor of electricity in Mauritius i.e. the Central Electricity Board (CEB) Central Electricity Board Report (2008).

Information on daily baseline load profile for Rodrigues is could only be obtained from CEB for year 2003. The maximum peak for 2003 was 3.8 MW whereas the maximum peak demand for Rodrigues Island in year 2008 was obtained to be 5.97 MW. (5) Similarly, a baseline load profile data for Rodrigues Island can be created using the above information and a typical daily load profile 24 h average for Rodrigues (data November 2003 scaled to November year 2008) and HOMER Software will scaled the data for the rest of the year.

2. Wind data input

The user needs to input wind data for the proposed system since wind power is an integral part of the proposed hybrid system. HOMER application will use this wind data to calculate the output of the wind turbine in each time step specified. For Mauritius the wind dataset will be computed using data received from the Mauritius Meteorological Services Institute services (Cahoolessur 2010).

3. Wind Turbine data

Since different wind turbine will be used in Rodrigues and Mauritius, the wind turbine data for each sites namely at Grenade in Rodrigues, Plaine des Roches and Britannia need to be input in HOMER individually. For the island of Rodrigues, the wind turbine type assessed will be the four new 275 kW Wind turbine Vergnet GEV MP 275 which was commissioned in 2009 and 2010. Similarly, for the island of Mauritius, the wind turbine type to be used at the proposed project Plaine des Roches and Britannia is the model Vergnet aero generator each rated 1 MW.

4. Temperature

The effect of temperature on the efficiency of PV system is also taken into consideration. The output of the PV system is dependent on temperature. The PV cell temperature is the temperature of the surface of the PV array and during the day the cell temperature can exceed the ambient temperature.

5. Grid data

The user has to input grid information data such as the cost of buying power from the grid, emission data of the grid and other advanced economic information such as interconnectivity charges and standby charge of the grid.

6. Solar data resource

The user needs to input the solar data resource information for both Mauritius and Rodrigues to calculate the output of the PV array if included in the hybrid system configuration. The solar radiation data for Mauritius is calculated using the Photovoltaic Geographical Information System (PVGIS) website designed by the European Commission whereby solar data for the region of Mauritius can be found.

The solar PVGIS radiation estimates for long-term monthly average for Mauritius is obtained by entering the longitude and latitude data (20°20′40″, 57°31′27″). Similarly the data for Rodrigues is obtained by entering the longitude and latitude data (19°42′, 62.25).

7. PV data

The user needs to input data for PV power system that will be used. Other parameters such as the lifetime (years) of the PV system, the de-rating factor and

ground reflectance etc. need to be input together with its associated costs. A proposed system of 430 kW PV grid tied system is proposed for Mauritius and a 1 MW grid tied system is proposed for Rodrigues.

8. Biomass data

For Rodrigues Island, the user has to input biomass resource data for a proposed 1 MW BIONERR gasification unit. About 8,450 t of wood is required annually i.e. 23.08 t/day. HOMER will use this information to calculate the amount of biogas produced from the 1 MW proposed unit for each hour of the year.

The average cost of fuel is estimated by ARER (2007) to be 60 USD/t. The gasification ratio is 3.5 kg of wood is necessary to produce 1 kg of biogas according to ARER report (2007). The LHV of biogas produced comes mainly from hydrogen gas, CO and CH_4 is 10.4 MJ/m^3.

The LHV of bagasse in Mauritius is estimated to be 17.9 MJ/kg.

9. Current Power plant Capacity data

The user needs to input data on the type of generator to be used. The size of the generator and the capital cost need to be input together with the type of fuel. Diesel fuel and coconut oil fuel will be investigated here.

10. Economics data and any constraints

Other important parameters such as investment costs on different technologies, technical features, maintenance requirements and lifespan of equipment and the cost of energy produced by different energy configuration will also be computed. Economics parameters that will be considered in this project are namely;

- Annual Real interest rate (%)
- Project life time (years)
- System Fixed capital cost.

The project lifetime is also set to 25 years and the system fixed capital cost and system fixed operation and maintenance cost is set to zero. Calculated annual interest rate is calculated to be 1.85 % taking into consideration present inflation rate of Mauritius which is 6.8 %.

A total of 500 MW is allowed to be purchased from the Grid for Mauritius at a purchase price of 0.11 USD/kWh. This figure of 500 MW represents the contribution of electricity production from the CEB and two IPPs Belle VUE Ltd and FUEL Ltd to meet the daily load requirement. This is due to the complexity of estimating the capital cost price and operating cost of fuel running of both bagasse and coal due to lack of cost data.

Results and Discussion

For the above mentioned case studies, simulation have been carried out by HOMER simulation tool, the latter simulating the operation of the different proposed system by making energy balance calculations for each of the 8,760 h in a year. HOMER then performed energy balance calculations for each system configuration that is proposed and have considered whether a configuration is feasible. After simulating all of the possible system configurations, HOMER have displayed a list of configurations, sorted by net present cost (NPC).

Rodrigues Results and Discussion

The renewable energy system configuration that has the lowest Net Present Cost (LCOE of 0.345 USD/kWh, cost of electricity generation) of 239.6 Million USD for Rodrigues Island has the following renewable energy resource component namely;

- Renewable Biomass resource running a 500 kW gasification unit
- 1 MW PV array is considered economically feasible by HOMER
- Mini Hydro power station at Grenade is not considered feasible (Least NPC cost)
- Bio-fuel renewable resource (coconut oil) running a 1 MW generator unit
- A 1,000 kW PV grid tied system array
- Trefles and Grenade Wind Farm are considered economically feasible
- The total installed power capacity for the existing 6 × 500 kW MAN diesel generator to be reduced to 1 MW installed capacity
- The total installed power capacity for the existing 2 × 1.9 MW diesel generator to be reduced to 1.9 MW installed capacity.

The annualized cost amounts to 12.2 Million USD and it is interesting to note that the fuel component account for most of this annualized cost, 10.94 Million USD (Fig. 27.1).

For the island of Rodrigues, the PV array component that has the least cost benefit is the 1 MW PV array system and for the Biomass generator, a 500 kW unit is the most appropriate one (category winner) and a 1 MW unit coconut oil generator is the best option in term of cost. The existing 6 × 500 kW MAN diesel installed capacity remain 3 MW whereas the 3 × 1 MW MAN diesel generators can operate as only 1 MW power capacity. Moreover, the 2 × 1.9 MW diesel generators can also reduce to a 1.9 MW capacity i.e. using one generator set instead of two.

This is economically possible by adding 1 MW generating running of renewable fuel oil such as coconut oil. Reduction of the import of diesel in Rodrigues by coconut oil (CNO) is economically feasible and sustainable and can serve as a

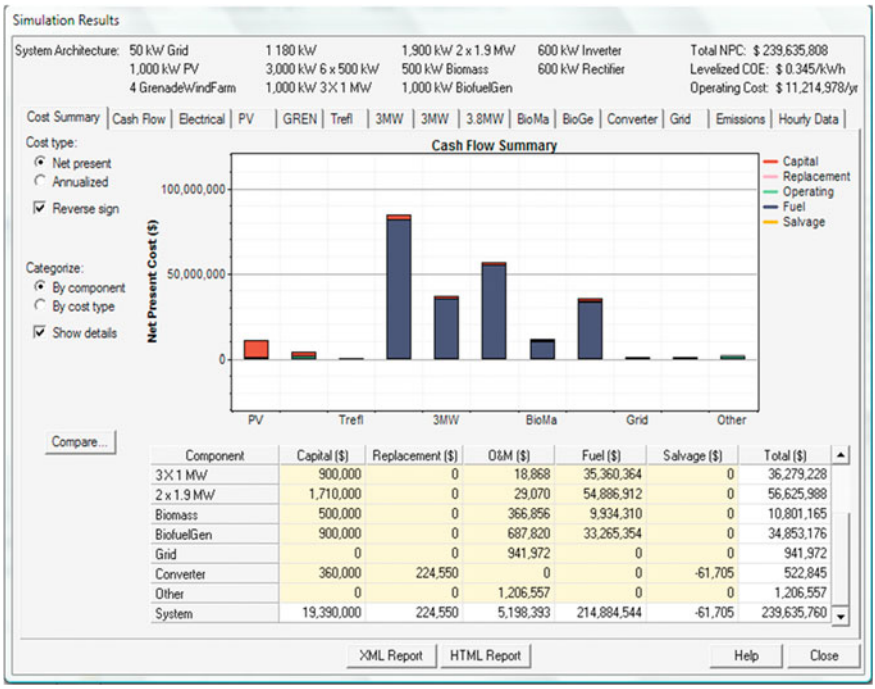

Fig. 27.1 Cost summary for the least NPC system configuration for Rodrigues

successful case study for Mauritius. About 2,870 t of CNO fuel will be required for the 1 MW generators running of bio-fuel. The question is whether the 2,870 t of CNO fuel can be 100 % available is Rodrigues is further investigated here. The coastal strip of Rodrigues could easily be planted with coconut trees. If all the coastal area is planted with coconut trees, 180 hectare of plantation can be achieved and using an estimate of 1 hectare of land containing about 200 coconut trees, around 36,000 coconut trees can be harvested.

Bradley et al. (2006) mentioned in a study entitled "Cocos Nucifera: An Abundant Renewable Source of Energy" that Palm oil and coconut oil have extremely high yield. About 0.1 L of coconut oil can be extracted from a coconut or about 2.7 Kilo-liter of coconut oil per hectare can be obtained using standard extraction techniques (Bradley et al. 2006). Around 500 t of coconut oil can be obtained locally and the rest of the 2,370 t of CNO have to be imported from Agalega or purchased internationally. Thus **although a 1 MW bio-fuel generator is the most economically feasible system configuration, the constraint of availability of CNO oil should be carefully addressed.**

In a latest study conducted in the year 2007 by the Reunion Island Regional Energy Agency (ARER) for Rodrigues with regards to the potential of exploiting renewable energy resources in the island, a 1 MW biomass unit has been recommended. **However, HOMER simulation tool have shown that only a**

500 kW biomass system is sufficient for the input electricity demand curve for Rodrigues.

With regards to the electricity production for the least NPC cost configuration system, Trefles 180 kW wind farm and 1.1 MW wind farm at Grenade, the biomass unit 500 kW, the 1 MW PV array and the bio-fuel generator 1 MW will contribute to 47 % of the total electricity production. The 1 MW PV array proposed system and the 500 kW biomass gasifier will account to 5 and 7 % respectively of the power generating capacity whereas the Bio-fuel generator of 1 MW using coconut oil will have the greatest share of electricity production from renewable energy resource if implemented (24 %).

Although the potential of hydro power exist at Grenade, it is still not considered as economically feasible by HOMER simulation tool to install a 350 kW mini hydro power station.

Mauritius Results and Discussion

The renewable energy system configuration that has the lowest Net Present Cost of 6.45 Billion USD (COE of 0.124 USD/kWh, cost of electricity generation) has the following component namely;

- Mini Hydro station at Bagatelle and Midland Dam with total installed capacity of around 700 kW
- 3 MW Gas To Energy system at Mare Chicose Land Fill site
- No PV grid tied system array is considered economically feasible by HOMER
- The 18 MW Wind Farm at Plaine Des Roches and the 22 MW Wind farm at Britannia is economically feasible.

With regards to the economics of the most feasible hybrid system configuration, the annualized cost amounts to 335 Million USD (Fig. 27.2).

With regards to the electricity production for the least NPC cost configuration, the 18 and 22 MW wind farm at Plaine des Roches and Britannia, the Gas to Electricity 3 MW, the two mini hydro power stations (total installed capacity of 700 kW) and the bio-fuel generator 1 MW will contribute to 5.1 % of the total electricity production. The potential of two mini hydro power stations (total installed capacity of 701 kW) at the existing Midlands Dam and at the future Bagatelle Dam has been considered economically feasible by HOMER simulation.

Moreover, based on the actual solar resource available energy and the price of PV technology, neither a 430 kW nor a 1 MW PV array is considered feasible by HOMER simulation tool. The price of PV technology is still on the high side requiring an investment of around 4.3 Million USD for a 430 kW PV system.

The 3 MW Gas to Energy proposed unit at Mare Chicose landfill station has been considered feasible by HOMER simulation tool requiring a total initial investment capital of 6.5 Million USD. When implemented the Gas To energy unit will provide electricity to around 20,000 households.

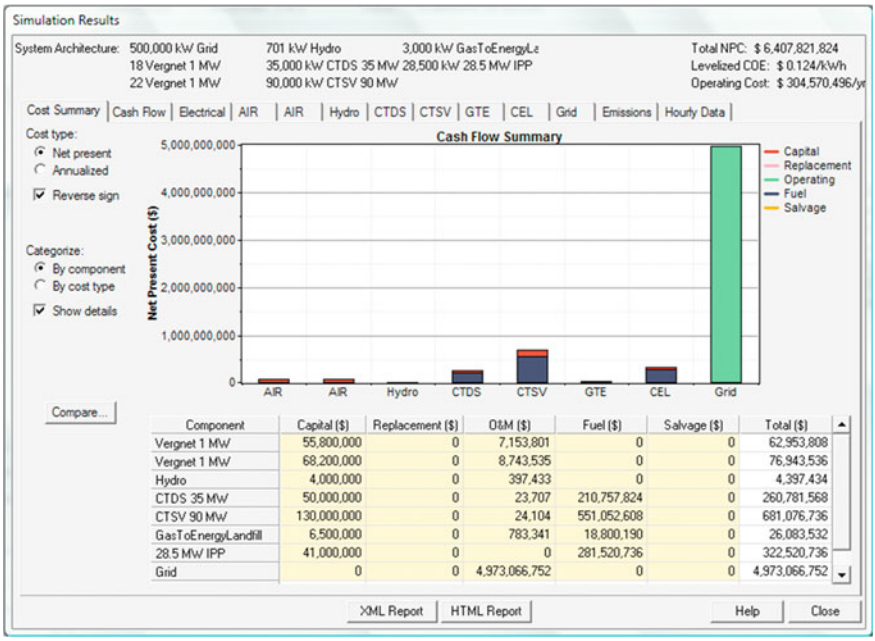

Fig. 27.2 Cost summary for the least NPC system configuration for Mauritius

If we compare the LCOE cost to produce 1 kWh of electricity for Rodrigues and Mauritius, the LCOE cost for Rodrigues is 0.345/kWh and is higher than the LCOE cost for Mauritius which is 0.124/kWh. The LCOE value for Mauritius calculated by HOMER is closer to was is actually paid by the consumer in Mauritius (around 0.103/kWh for the first 25 kWh for residential purpose and gradually increasing).

A sensitivity analysis is also performed by HOMER simulation tool for the least NPC hybrid configuration system for Mauritius. The main reason to perform a sensitivity analysis for Mauritius the cost price of PV technology is expected to decrease in the coming years. A multiplier factor of 0.4, 0.3 and 0.2 will be applied to see at what falling price the PV technology will be integrated in the least NPC cost configuration system. Sensitivity analysis results have shown that if the present price of PV technology should fall by 80 % to become economically feasible. Moreover, if the local authorities of Mauritius can decrease the present inflation rate of 6.8 %, the least NPC cost would decrease from 6.4 to 4.25 Billion USD.

Conclusion

From the above simulation results by HOMER simulation tool and sensitivity analysis for Rodrigues Island, it can be concluded that the most economically feasible hybrid configuration will include a 500 kW biomass BIONEER

gasification unit, a PV array system, no mini hydro power plant and a decrease in the use of diesel generator by replacing the latter with bio-fuel generator such as coconut oil (CNO).

A proposal for a mini Hydro power station at site Grenade is not considered feasible by HOMER simulation tool and this may arise from a very high initial investment of around 1.8 Million USD for a 350 kW unit.

The LCOE cost for Rodrigues system configuration is found to be high compare to that of Mauritius and this is due to high fuel cost coupled with high initial investment cost required and Operational and Maintenance costs involved especially that most of the electricity is generated from Diesel fuel.

From the above simulation results and analysis for Mauritius Island, it can also concluded that the most economically feasible hybrid configuration will include the 18 MW wind farm at Plaine Des Roches, the 22 MW Wind farm at Britannia, a 3 MW Gas to Energy power station at Mare Chicose landfill site, two mini hydro power station at the existing Midlands Dam and at the future Bagatelle Dam.

Therefore, exploiting renewable energy resources such as hydro and wind should be further encouraged by the Government of Mauritius in order to achieve the objectives set under the Maurice Ile Durable initiative for a sustainable island by 2020. However, no PV power generating plant is considered feasible by the HOMER optimization tool.

But although a renewable energy resource is not considered economically feasible, this does not mean that it should never be implemented.

Under the Maurice Ile Durable initiative, a 430 PV power generating unit has been built by a private firm to power its new eco-building headquarter.

References

ARER (2007) Reunion regional energy agency report, electricity energy self-sufficiency strategy for Rodrigues, security supply. Sustainable development and climate change, 100% renewable energy, Nov 2007

Bradley WL, et al (2006) Cocos Nucifera: an abundant renewable source of energy

Cahoolessur S (2010) Wind regime for Mauritius, Mauritius Meteorological services

Central electricity board report (2008)

Lambert T, Gilman and Lilienthal (2006) Micropower system modeling with HOMER. In: F. Farret Integration of alternative sources of energy, Chap. 15

Mauritius Central Statistic Office Report (2009)

Palanichamy C (2002) Renewable energy investment opportunities in Mauritius-an investor‘s perspective. Renew Energy 29(5):703–716

Press release (2010) Wind farm CDM project signed with aerowatts in Mauritius. EcoSur, Aerowatts and Swedish Energy Agency, 7 July 2010