OFF-GRID DEVELOPMENT OF SUSTAINABLE ENERGY RESOURCES FOR ECOTOURISM FACILITIES IN KALPITYA PENINSULA SRI LANKA

MTAP Wickramarathna, Member SLEMA
SM Rifai, GD Sellahannadi, SRK Gamage, HHD Hewage, R Wimalasiri, RR Abeyweera

Abstract:

Tourist industry, although contributing substantially to the GDP of Sri Lanka, pollutes the environment at an unprecedented rate. Therefore, having realized our commitments to a better global environment, Sri Lanka Tourism Development Authority (SLTDA) has moved towards establishing new tourist resorts under eco-tourism concepts. This paper attempts to analyse how green energy could be supplied for business operations in an eco-friendly hotel with 400 rooms proposed in Uchchamunai Island in the proposed Kalpitiya Integrated Tourism Resort Project. Wind and solar are the primary energy sources considered for this project to provide 6 million kWh/year of electricity with max demand of 780 kVA, and 2026 GJ/year of thermal energy. Although wind and solar resources are available in abundance, their temporal variations have a large impact on quality and reliability of the energy/power system. Thus, a storage system is inevitable. Producing hydrogen with renewable sources is the ideal option to overcome these uncertainties, but economy is of great concern. Three scenarios were modelled and it was found that wind with grid connected model provides the optimum overall performance with the fraction of renewable energy reaching 99.5%, along with a 34,735 tonne/year of CO_2 emissions. In the absence of a grid connection, a model which use only wind plants provide the optimum results with a fraction of 99.5% renewable energy with 241 tonne/year CO_2 emissions.

Introduction

Kalpitiya Peninsula is one of the most beautiful coastal areas in North Western region of Sri Lanka. This peninsula is a marine sanctuary with a diverse ecological system ranging from bar reefs, flat coastal plains, saltpans, mangrove forests, salt marshes and vast sand dune beaches. As this area has a significant potential for tourism, SLTDA has formulated a master plan, called 'Kalpitiya Integrated Tourism Resort Project' (KITRP), to develop this area as a tourist destination. There are 14 small isolated islands in the KITRP area which have been identified to carry a potential for ecotourism. Ecotourism is the best available option for the development to comply with the rules and regulation set by the environmental authorities. According to The International Ecotourism Society (TIES), Ecotourism is "*Responsible travel to natural areas that conserves the environment and improves the well-being of local people*". This means that those who implement and participate in ecotourism activities should follow the following ecotourism principles such as Minimize impact, Build environmental and cultural awareness and respect, Provide positive experiences for both visitors and hosts, provide direct financial benefits for conservation, Provide financial benefits and empowerment for local people, Raise sensitivity to host countries' political, environmental, and social climate. Geographical locations of all the 14 islands including the island selected for this study are shown in Figure 1. Islands and their land extents are provided in Table 1. One of a major obstacle to ecotourism development is the non-availability of energy that is vital for business operations. Norms set by TIES Standards demand sustainable energy for ecotourism facilities but the problem is the supply of sustainable energy since these islands are isolated and away from the national grid. Again, electricity supply off the national grid consists of about 35% hydro, 55% fossil fuel based and about 10% other forms such as mini hydro and wind. Hence grid supply is not truly 'green Energy'. The only option available to overcome this problem is captive power generation using renewable energy sources. Studies [1] conducted by a US organization, National Renewable Energy Laboratory (NREL), in collaboration with Ceylon Electricity Board (CEB) shows that this area has 1100MW Good-Excellent wind and on average 5.1 $kWh/m^2/day$ solar energy potentials. However development of sustainable energy systems is a challenging task due to non-availability of infrastructure and other associated issues such as adverse climatic and environmental conditions.

Figure 1: Location of Project Site and 14 Islands in Kalpitiya Peninsula

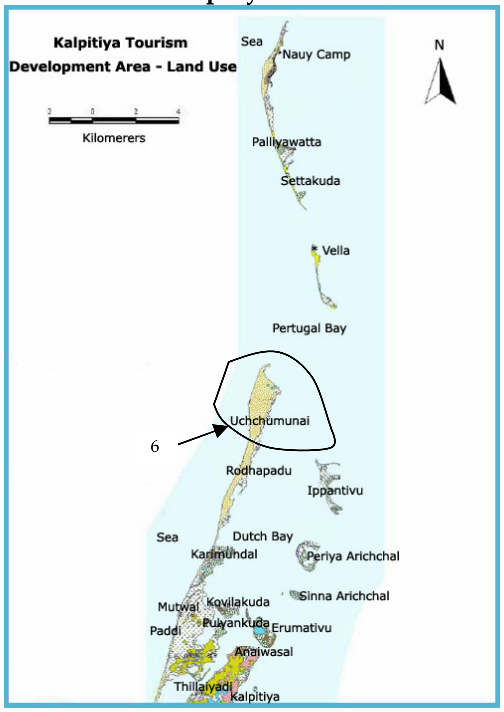


Table 1: Name of the 14 Islands and its Land Extent

Location Identification	Name of the Island	Extent (ha)
1	Baththalangunduwa	145
2	Palliyawatta	60
3	Vellai 1	2
4	Vellai 2	11
5	Vellai 3	14
6	**Uchchamunai**	**443**
7	Ippantivu	6
8	Periya Arichchalai	46
9	Sinna Arichchalai	17
10	Erumativu	86
11	Sinna Erumativu	3
12	Erumativu West	5
13	Kakativu	29
14	Mutwal (Dutch Bay)	611

SLTDA has requested green power/energy supply for the project area and this required a study on the development of sustainable energy systems for the islands. Thus one of the islands under KITRP project area, Uchchamunai Island was selected for our project. Primary reason for that is SLTDA plans to construct first eco-friendly hotel in Uchchamunai Island. The secondary reasons are it is closer to main island Sri Lanka, comparatively larger in size. It is an island with an approximate land area of 443 ha. Land size is the important parameter in developing this type of technologies. It is a barren land with bushes, and a few fishing families live there only during the fishing season.

The main objective of this study is to conduct a feasibility study and propose a techno-economically attractive solution to provide the power and energy requirements of the eco-tourism industry in Uchchamunai Island. To facilitate quantifying and measuring the achievements of the objective, it is necessary to divide the main objective into three sub-objectives, namely:

(a) Identify major activities which require electrical and thermal energy in hotels, and estimate the energy demand.
(b) Study on available energy options and their feasibility for utilization.
(c) Study the sustainability and techno-economic feasibility of electricity generation, storage and energy carriers, and supply backup.

These three sub-objectives are described below.

(a) Energy is needed for human comfort, transport, cooking and recreation less compared to conventional hotels. Thermal energy is necessary for hot water, cooking and transport whereas, air conditioning, lighting, small appliances and motors for water supply & treatment, etc. require electrical energy.

As Ecotourism developments are new to Sri Lanka, no historic data is available to assist estimation of energy demand in similar hotels. However, it has been observed that some of the hotels in Sri Lanka built along the coastal area do have employed eco concepts to a significant extent. Also 'Hotel Kandalama' built in mid 1990s and owned/operated by Aitkin Spence Ltd. has been built with strong eco-concepts. Therefore, the data obtained from these sources, with suitable adjustments, will be used for this study. The analysis of these data would yield reasonably accurate estimation of energy and power consumption for different categories of activities.

(b) Conventional energy sources in local hotel industry are electricity supply from the national grid backed up by local diesel generators. The 55% of Sri Lanka installed capacity contributes by thermal power plants which used fossil fuel. Therefore consuming energy from the grid does not allow in ecotourism projects. Therefore, local eco-friendly power generation is to be explored with the possibility of exporting power to the national Grid which increases the overall benefits. The region has good potential of wind energy in Sri Lanka. Being a tropical country near the equator, sun shines throughout the year indicating the abundance of solar energy. Therefore, prospective sustainable energy options are wind and solar. Supply of the base load will be the major concern, as the availability of these two sources varies with time. A solution to this problem is to use a secondary energy source with storage capability.

(c) For any energy system, a back up is required to meet an emergency situation. The energy carrier is required to counteract temporal variations of renewable energy sources. At the same time, it is essential to store the energy and to operate the services such as transport. Biogas from solid waste and hydrogen are the two energy carriers identified for the project. The estimated electricity demand of Uchchamunai Island is 780 kVA [2]. The system boundary will be the beach front. Wind energy, solar PV and solar thermal collectors are the energy options considered for development. The potential energy carriers identified for further investigation in the scope of this project are Battery backup, Hydrogen storages, Bio-gas from MSW. HOMER software and Polysun software were used for modeling and simulating the solar energy system. HOMER software of National Renewable Energy Laboratory – USA was used for micro generation system modeling. This software has the capability to model both off-grid and grid connected power systems for a variety of applications. In the design of a power system, it is necessary to consider several factors such as the configuration of the energy system, components of the power system and their quantity & size, technological options, costs and the availability of energy resources. These factors make decisions difficult. The optimization and sensitive algorithm of HOMER software makes it easier to evaluate system configuration in terms of technical, economical and environmental constraints. *(Source: http://www.homeregergy.com.)*

Solar Thermal System Modeling Software– Polysun 5: The solar thermal system was designed and simulated using Polysun software provided by Vela Solaris AG. Polysun 5 is simulation software which can combine solar thermal, PV, heating, cooling with other energy sources such as geothermal. Polysun provides easy-to-use pre-defined modules as well as yield and economic viability calculation.
Source: www.velasolaris.co

Methodology and Data

The methodology followed can be broadly described as understanding (i) the nature and magnitude of energy supply requirements, (ii) their periodic and seasonal variations, (iii) limitations imposed by the project, (iv) exploring the potential candidates for energy supplies (v) their economics, and (vi) selecting the optimum set of options for the island. Thus, basic steps in this methodology can be illustrated as in Figure 2.

Facility and Tourism Data

Historic data is available for conventional hotels and not for ecotourism operations. Most of the data used here is from conventional hotels of a similar nature. Hence they required to be suitably adjusted to reflect energy efficiencies expected of ecotourism. Fuel switching for eco-friendly environment is another task to undertake in this regard. Referring to the data given in USAID, Energy and Sustainable Tourism, Energy Supply and Use in Off-Grid Ecotourism Facilities document, we assume the average electrical energy consumption of eco-friendly type 4-5 star class hotel will be about 30-50 kWh/guest/day in Sri Lanka context [3]. As the hotel in Uchchamunai is with eco-tourism norms, the expected energy consumption target was set in this study, not to exceed 70% of conventional hotels. Table 2 shows the important data [4] of proposed resort at the island. This is the basic information required for designing the energy system.

Figure 2: Basic Steps in the Methodology

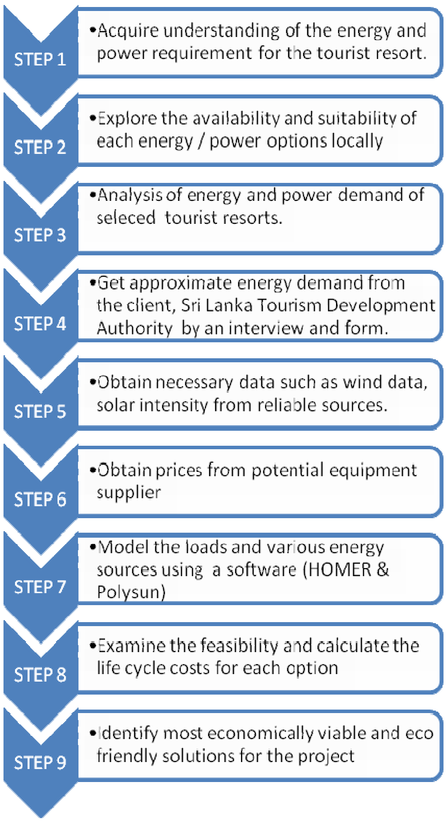


Figure 3: Occupancy Rate of Tourist Hotels in Sri Lanka

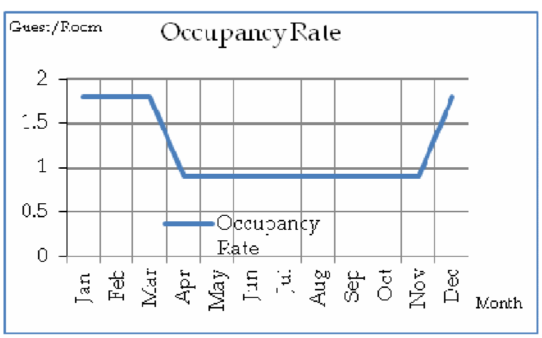


Table 2: Basic Data of the Proposed Resort at Uchchamunai Island [4]

Parameter	Value	Unit
Extent of Island	4.43	km²
Area of Buildings	15,000	m²
Roof Area	9000	m²
Number of Rooms	400	
Average Occupancy Rate	1.2	guests /room /day
Maximum Demand	780	kVA
Total Length of Road within the Island	5	km

For estimating the maximum demand and energy profile, occupancy rate of the rooms is required. The recent annual statistical report [4] published by SLTDA shows that the tourist arrivals peak during the period of December to March, and would be the occupancy rate of hotels. Rest of the year, on average, it is half the rate of the peak period. Figure 3 shows the variation of average room occupancy rate. Although there are fluctuations on a daily basis, a flat occupancy profile was considered for this study, for the sake of simplicity.

Data for Heat Demand Calculation

Through interviews with the management of a few selected hotels [5], the average energy demand and their use were established. Table 3 shows the composition of the heat demand of a conventional hotel.

As the system boundary of this project is the island, inland transportation was considered to be included in the scope. The island is about 4.4 km² and hence only limited transportation (between the boat yard and the hotel and for touring within the island) is required for the guests.

It is estimated that a conventional fuel (petrol or auto diesel) of about 0.5 litre/guest/day is required for inland transportation. A form of environmentally friendly fuel (electricity, hydrogen, etc.) was considered to replace this demand.

Table 3: Heat Energy Demand and Energy Source [11]

Heat Load	Conventional Heat Source	Demand with Conventional Sources [11]	Proposed Heat Source
Hot Water	Electricity	60 litre/ guest/ day at 50°C	Solar Thermal
Cooking	LPG	0.25 kg/guest/day	Biogas and Hydrogen

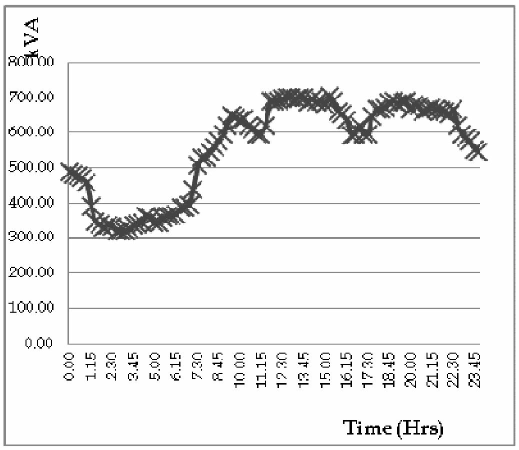
Electricity Demand

Analysis of the electricity consumption of some selected hotels in and around Colombo indicated that the annual electricity consumption pattern could be related to the number of rooms in a hotel as follows.

Annual electrical energy of Consumption (GWh) = 0.023 x No. of Rooms

Interviews with hotel management [5] revealed that the electrical energy consumption on usage-wise could be allocated as water heating: 15%, air conditioning: 35%, cooking: 15%, lighting: 25% and auxiliary services: 10%. On this basis, the hotel with 400 guest rooms in Uchchamuni Island would have annual electrical energy consumption about 8.83 GWh with a peak demand of 1600 kVA.

Figure 4: Daily Load Profile of Proposed Resort and Associated Facility at Uhchamunai Island.



However, experience of Kandalama Hotel indicated that green concepts could reduce some of these loads substantially. Some loads could be shifted from one source of energy to another, for example, electricity to solar thermal. Hence shifting of energy sources into different eco-friendly sources resulted in reduction of electrical energy requirement to about 70% of the normal load which, yield an estimated electricity demand of 6 GWh, with a maximum demand of 780 kVA [2]. The load profile shown in Figure 4 is a typical one for hotels in Sri Lanka, adjusted to reflect the demand of the proposed hotel at Uchchamunai Island.

Wind Data

The Table 4 shows the mean monthly wind speed variation in Narakalliya area, located near Puttalam, about 40 km to the south of the site.

Table 4: Mean Monthly Wind Speed Obtained from Narakalliya [1]

Month	Mean Monthly Wind Speed m/s
January	5.84
February	3.74
March	3.74
April	6.77
May	8.75
June	9.95
July	9.75
August	10.36
September	8.37
October	7.44
November	5.44
December	5.66

Solar Radiation Data

There is no direct solar radiation data available owing as there is no meteorological station in the close proximity to the island. Therefore it was decided to use Sri Lanka's national average for this project as given in Table 5. This will be a good approximation for initials studies. The drawback of this data is that measurements have been taken on a horizontal surface and not on the exact inclination angle. However, as the geographic location of project site is very close to the equator, error in the calculation would be not significant.

Table 5: Annual Mean Monthly Total Solar Radiation for Sri Lanka [6]

Month	Mean Monthly Solar Radiation ($kWh/m^2.day$)
January	5.35
February	5.5
March	5.7
April	6
May	5
June	4.9
July	4.6
August	4.8
September	4.6
October	4.5
November	5
December	5.25

Energy Backup and Carrier System

Hydrogen is the suitable energy carrier and backup source as far as sustainability concern.

Modeling and Results

Design of the Thermal Energy System

Solar thermal technology is one of the economical options for thermal energy requirement. As this location is closer to the equator with good solar irradiance, solar thermal is the best renewable option for the thermal energy. The solar thermal system was designed and simulated using Polysun software provided by Vela Solaris AG.

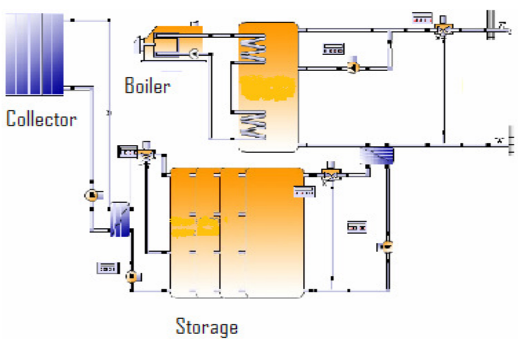
Hot Water System

The following parameters which were given in the Table 6 were assumed for requirements in system design.

Table 6: Design Parameters

Delivery Temperature	50 ^{0}C
Hot Water Consumption	60 litre/guest.day
No. of Rooms	400
Room Occupancy Rate in Season (Dec to Mar)	1.8
Room Occupancy Rate in Off-Season (Apr – Nov)	0.9

Figure 5: Schematic Diagram of Solar Thermal Hot Water System



Three loops were considered in this design, to achieve better efficiency and maintainability. Pure water can be used in the solar loop and the storage loop, which enables smooth heat transfer and longer life-time of the pipes and other accessories. Raw water is used only in the discharge loop. Electrical heater is considered to support when there is an energy deficiency and for quick temperature makeup in high demand case. All the loops and pumps will be controlled by sensing the temperature and flow rates. Considering operation and maintenance, it is assumed to assign one full-time person to carry out the operations and maintenance of the system. Further, 5% of the total investment is considered as the annual maintenance cost of the system. Figure 5 shows the schematic diagram of hot water system drawn using Polysun 5 and the Professional design report generated by Polysun 5.

The overview of the solar thermal annual values is given in Table 7. About 91% of energy demand is supplied by solar energy and the balance would be met with electricity.

The remaining fraction of heat demands has to be supplied by oil fired boiler or electric boiler. The unmet demand of 86,858 MJ of energy will be supplied by oil fired boiler. Electricity is an alternative option. Table 8 shows the basic details of oil fired boiler. Results of investment analysis are given in Table 9.

Table 7: Overview of Solar Thermal Energy

Collector Area (m^2)	**500 m^2**
Solar Fraction Total (%)	91.20
Total Annual Field Yield (MJ)	901,519
Collector Field Yield Relating to Gross Area (MJ/m^2.year)	1,803
Collector Field Yield Relating to Aperture Area (MJ/m^2.year)	2,003
Total Electrical Energy Consumption of the System [E_{tot}](MJ)	110,023
Total Energy Consumption [Q_{use}](MJ)	904,889
System Performance (Q_{use} / E_{tot})	8.22
Max. Fuel Savings (litre of diesel)	29,463
Max. Energy Savings (MJ)	1,060,611
Max. Reduction in CO_2 Emissions (Metric ton)	88

Table 8: Overview of Oil Fired Boiler

Power (kW)	50
Total Efficiency	82.5%
Energy to the System (MJ)	86,858
Diesel or Electrical Energy consumption (MJ)	105,255

Table 9: Cost Analysis of Hot Water System

Total Investment	$ 103,500
Operating Cost	$ 1,000
Life Time (Years)	30
Base Line price (Diesel)	$ 0.12/kWh
Annual Cost Saving	$ 35,350
Payback (Years)	4

Cooking Needs

Biogas and hydrogen energy options can be considered for cooking. Table 10 shows the annual heat demand for cooking for the 'business as usual' scenario.

Table 10: Business as Usual Scenario for LPG [11]

Consumption (kg/guest .day)	Demand (kg/year)	LHV (MJ/kg)	Total Heat Energy (GJ/year)
0.25	43,800	46.26	2026

Annual LPG gas demand is 43.8 ton which is equivalent to approximately 2026 GJ of heat energy. Table 11 shows the availability of biogas and its equivalent thermal energy. While biogas could meet approximately 10% of total demand, the remaining fraction of energy could be supplied either by Hydrogen or LPG. Hydrogen has been chosen since Hydrogen storage is available in the energy system. The storage will serve both the purposes i.e. both electricity and thermal requirements. About 15 ton of Hydrogen is required to meet the demand.

Table 11: Availability of Biogas [7]

Type of Feed Stock	Gas Yield (m^3/kg)	Avail. (kg / guest.day)	Gas Yield* (m^3/yr)	Loss (%)	Calorific Value of Biogas (MJ/m^3)	Total Heat Energy (GJ/yr)
Human Excreta	0.07	0.4	4906	7%	19.72	90
Solid Waste	0.1	0.5	5256	7%	19.72	96
Total Heat Energy	-	-	-	-	-	**186**

Transportation

The automotive transport system is required for moving people and logistics. The maximum distance from the resort to the jetty would be 500 m. Hydrogen powdered cars (both hydrogen and electric) are considered for guest shuttle services. Consumption of the hydrogen of car is 0.8kg /100km [7]. Therefore, 11 tons of hydrogen is needed for operation per year. Diesel vehicles will be used for moving heavy loads. Within the island periphery, bicycles will be used as another mean of transport.

Water Supply

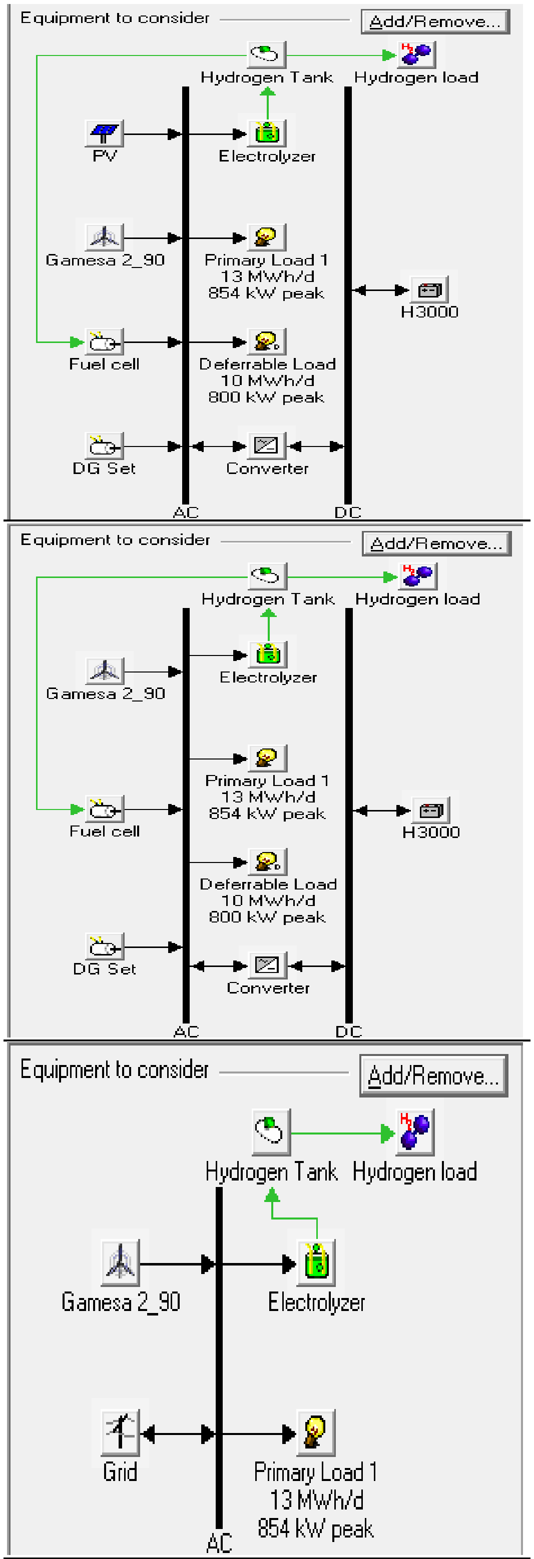
It was observed that ground water of good quality is available in Kalpitiya peninsula. Hence, water supply for the hotel operation is expected to be ground water. Electricity supply and energy demand for pumping and purification are included under demands for 'Auxiliary'.

Design of the Electrical Energy System

HOMER software was used for micro generation system modeling. The electric power system primarily consists of solar PV and wind turbines. As temporal variation of wind and solar is the biggest challenge for reliability of the system, an electrolyzer with a storage system is introduced to produce and store Hydrogen, the energy carrier of the system. Fuel cell is to supply the base load where as battery is to supply the peak demand. A standby DG set is connected to system to operate in case of emergency. As described above, the expected electrical load of the proposed hotel would be about 6 GWh/year with a maximum demand of 780 kVA. Three scenarios were considered for modeling, namely; wind only, wind-solar and wind-grid. For all three scenarios the results are quite different. The summary of the results are given in Table 12.

The island power system, shown in Figure 6, is a mixed one, with both AC and DC buses present in the system. All the loads are assumed to be AC in nature and the converter is a cyclic one acting as an interface between the two buses.

Figure 6: Single Line Diagrams of the Power Systems; Wind-Solar, Wind only, Wind-Grid



Results indicate that model 'Solar PV + wind and no grid connectivity' has the highest cost. Also it yields the highest energy cost, 0.15 US$/kWh. Hence compared with 'Wind only' model, Solar PV + wind and no Grid connectivity' is not an option for further study and could be disregarded. High cost of the solar PV system, low efficiency and high storage cost could be the reasons for lower economic performance of this combination.

Table 12: Summary of Rating and Details of Power System Components

Component	Wind Only	Wind & Solar	Grid Connected
Wind Turbines (2 MW)	6	6	8
PV (kW)	0	300	0
Fuel Cell (kW)	70	70	0
DG set (kW)	500	500	0
Batteries (6 kWh)	200	100	0
Converter (kW)	400	250	0
Electrolyzer (kW)	1,000	1,000	200
H_2 Tank(kg)	500	500	300
Grid Capacity Million (kWh)	0	0	900
Initial Capital US$	$2,806,500	$3,752,500	$847,500
Operating Cost US$/Yr	$304,873	$315,254	-$12,030,764
Total NPC using 10% DR US$	$5,573,844	$6,614,075	-$108,356,224
Cost of Energy US$/kWh	0.1250	0.1480	-2.43
Cost of H_2 US$/kg	10.760	12.796	-447.3
Renewable Fraction	0.95	0.95	0.95
Fuel Cell (h)	2,415	2,416	0
DG (h)	605	874	0
CO_2 Emission (tone/yr)	241	284	-34,735

Note: + ve values represent the costs and -ve values represent the income.
NPC = Net present cost, DR = discount rate

Conclusions

The study was to identify the feasible renewable energy technologies for sustainable operation of tourism services. Considering all the factors required to develop an island energy system, wind energy system is found to be feasible for the business operation. Wind energy projects can be put into operation within a very short period of time. However, at present, there are barriers at the infrastructural, economic, regulatory, political and administrative level.

Further studies are required to address the barriers given above. Complexity of these barriers will make the implementation a tough task.

References

[1] National Renewable Energy Laboratory (NREL), Technical Report- Sri Lanka and the Maldives Wind Energy Resource Assessment (Updated 21st Aug 2006), Available at: http://www.nrel.gov/docs/fy03osti/34518.pdf [Accessed on 10th Feb 2010].

[2] Ceylon Electricity Board, Kalpitiya Integrated Tourism Resort Project, Requirement of Electricity Supply. Published on 20th Sep 2010.

[3] Pam Baldinger, USAID, Energy and Sustainable Tourism: Energy Supply and Use in Off-Grid Ecotourism Facilities (Updated 26th of February 2006), Available at: http://www.pdf.usaid.gov/pdf_docs [Accessed on 10th Feb 2010].

[4] Sri Lanka Tourism Development Board, 2008. Annual statistical report 2008. [Online] Available at: http://www.sltda.lk/statistics [Accessed 4th Feb 2010]

[5] Tourism Development Project Proposal Kalpitiya (Updated 2010), Available at: http://www.sltda.lk/kalpitiya [Accessed on 10th Feb 2010]

[6] Dave Renné, Ray George, Bill Marion and Donna Heimiller (NREL) and Chris Gueymard (Solar Consulting Services), Solar Resource Assessment for Sri Lanka and Maldives with the Collaboration of Ceylon Electricity Board and National Renewable Energy Laboratory, USA.

[7] F. N. Büchi et al, Consumption and Efficiency of a Passenger Car with a Hydrogen/Oxygen PEFC based Hybrid Electric Drive train, Fuel Cells, 2007(04), pp 329-335.

[8] Sri Lanka Tourism Development Board, Master Plan for Kalpitiya Integrated Tourism Resort Project (KITRP), Published on 13th Aug 2008.

[9] Statistical Digest– 2009, Ceylon Electricity Board.

[10] Neven Duic, Maria da Grac Carvalho, Increasing renewable energy sources in island energy supply: case study Porto Santo, Renewable and Sustainable Energy Reviews (2004) pp 383–399.

[11] National Institute of Industrial Research, India, Handbook on Biogas and its applications, published by Ajey Kr. Gupta. Date unavailable.

[12] Rohit. H, Discussion on unit energy consumption of hotels managed by Aitken Spence (Pvt.) Ltd. [Telephone] (Personal Communication 5th Feb 2010)