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SUSTAINABLE ENERGY SOURCE FOR WATER PUMPING AT PUTTALAM SALT LIMITED

Mohammed Rizwan Kamaldeen

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Supervisor: Mr. Ershad Khan

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Mohammed Rizwan Kamaldeen

Approved Date	*Examiner* Professor Andrew Martin	*Supervisor* Mr. Ershad Khan
	Commissioner	*Contact person*

ABSTRACT

The cost of grid based electrical and diesel sea water pumping to salt fields is one of the major cost components out of the total production cost in Puttalam Salt Limited, situated in northern part of Sri Lanka. In order to explore ways and means to improve the energy efficiency and alternative resources to meet the energy requirement a feasibility study was conducted using power system simulation software, (HOMER) and also detailed technical, environmental and financial tools.

This research study is conducted to evaluate the performances and applicability and propose the most suitable sustainable renewable energy source and methodology for water pumping to salt fields instead of currently utilized grid based and fossil fueled energy supply.

Preliminary results obtained by simulation software shows that direct wind mill pumping and solar PV water pumping was found to be unfeasible due to its limited pumping capacity and high investment cost. More over solar PV does not seems much feasible due

to its high cost of energy (0.234 US $/kWh) compared to wind powered rivals in this type of applications.

Based on comparisons of the analysis it is seen that the wind/ grid combined configuration of 04 units of AOC15/50 model (50kW manufactured by AOC Renewable Energy - Canada) wind turbine units with 150kw inverter seems to be a logical supplement for water pumping energy requirement than using grid based electricity which costs 0.201 US $/ kWh. The solution in this research affords an attractive 60% annual average renewable fraction as well as an approximate 215.8 tCO2(eq) of annual Carbon Footprint saving. Also it assures a moderate Discounted Payback Period of 6 years and 5months with a 15% of Internal Rate of Return.

ACKNOWLEDGEMENT

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NOMENCLATURE

AC	Alternating Current
AR4	Fourth Assessment Report
CH_4	Methane
CE	European Conformity
CEB	Ceylon Electricity Board
CFP	Carbon Footprint
CO_2	Carbon Dioxide
CoE	Cost of Energy
DC	Direct Current
DPP	Discounted Payback Period
EIA	Energy Information Administration
GHG	Green House Gases
IC	Internal Combustion
IEC	International Electrotechnical Commission
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
ISO	International Organization for Standardization
MT	Metric Tonne
N_2O	Nitrous Oxide
OECD	Organization for Economic Co-operation and Development
PV	Photovoltaic
NASA	National Aeronautical & Space Administration
NPC	Net Present Cost
NREL	National Renewable Energy Laboratory

Appellation	sign	SI units
Density of Liquid	ρ	kg/ m^3
Drive efficiency	$\eta_{(drive)}$	%
Differential head	h	m
Electrical Power	$P_{(actual)}$	kW
Gravitational force	g	m/s^2
Hydraulic Power	$P_{(hydraulic)}$	kW
Pump efficiency	$\eta_{(pump)}$	%
Flow rate	Q	m^3/ h

1. BACKGROUND OF THE STUDY

Puttalam Salt Limited is one of the leading salt producers in Sri Lankan salt industry where the main production site is located at Puttalam next to Kalpitiya lagoon nearly 120km north of Colombo. Annual salt production exceeds 30,000 MT [1] utilizing an approximate 600 acre of land area. which provides living for nearly 750 local families. The cost of grid based electrical and diesel powered sea water pumping to salt fields is one of the major cost component out of the total production cost. More over the emissions and environmental impact due to diesel powered pumps was a major concern to the company management.

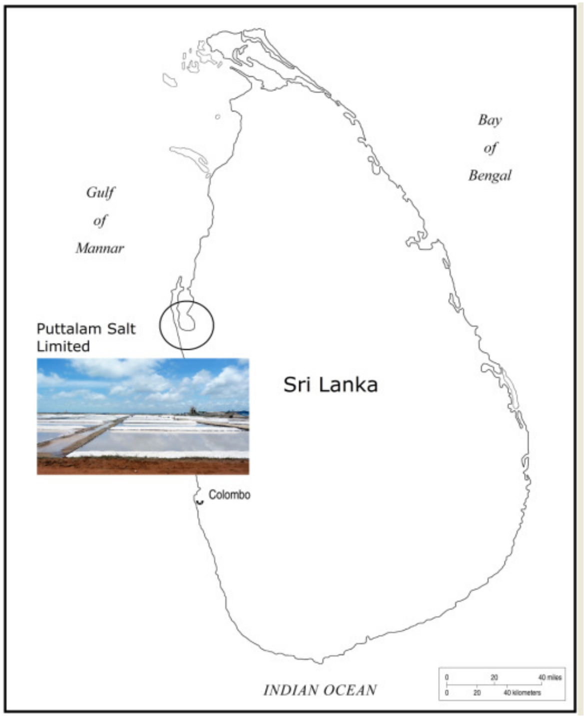


Figure 1-1: Location Map, Puttalam Salt Limited, Sri Lanka

In order to explore ways and means to improve the energy efficiency and alternative resources to meet the energy requirement the management wanted to commission a research study focused on to proposed the most suitable sustainable renewable energy source and methodology for water pumping to salt fields instead of currently utilized grid based and fossil fueled energy supply. So that would definitely enhance the performance as well as the image and recognition as the leading environmentally friendly organization in Sri Lanka.

As per the management the average production cost is US $ 155/MT [1]. The grid based electrical energy and fossil fueled diesel power for pumping sea water to salt fields is the major component which is nearly 80% of the total energy requirement [2]. Apart from the financial aspects current usage of diesel fueled water pumping causes innumerous emissions and environmental impacts. On the other hand as a responsible and well renowned company in Sri Lankan industry, Puttalam salt limited is willing to support the Sri Lankan government on their remarkable journey towards their motto to become the Wonder of Asia. According to the National energy policies and strategies established in 2008 is working on to uplift the renewable energy production at least 10% of the total energy production by 2016 [3, 4]. Also it is essential to positively contribute on environmental safeguard and take steps to move towards modern cleaner and green production concepts where it will be rewarded financially as well as social and international recognition [3– 6]. Financial value of carbon credits have made the industries to concentrate more and more on their renewable energy utilization rather than going for conventional fossil fuel energy. More over the rapid increase of energy cost will make it worst if correct proactive steps not taken on timely basis.

According to the research and surveys Puttalam area falls under the best locations with highest solar and wind power potential in Sri Lanka [7]. It is in the dry zone where the annual rain fall is below 1200mm [8]. Also the solar insolation is approximately 5.0 – 6.5 kWh/m^2/day [8-9] which is genuinely a high solar power potential. The other factor is the wind power potential. As per the survey data the location benefit from a strong wind stream with an average wind speed of 06 knots [6] throughout the year on both monsoon seasons and the government research has estimated a staggering 500 – 1000MW wind power potential around Puttalam/ Kalpitiya area where the salt production factory is located [7,10].

After considering all these aspects it is worthwhile to study the feasibility of sustainable energy sources such as solar power and wind power as alternatives replacing the current grid based electricity and diesel fuel for sea water pumping to salt fields which would benefit financially by chopping down the production cost by a fair margin. On the other hand the organization would be able to gain an added advantage by adopting the Green production concept which will definitely enhance the image in salt production industry.

2. OBJECTIVES & SCOPE

2.1 Objectives

The main objective would be to carry out a feasibility study for adopting sustainable renewable energy source for water pumping to salt fields instead of currently utilized grid based and fossil fueled energy supply.

Propose the most suitable energy source and methodology to be adopted mainly considering environmental aspects together with technical and economical feasibility.

2.1.1 Identification of total pumping requirement

Puttalam Salt Limited is one of the leading salt production companies in Sri Lanka where the annual salt production exceeds 30,000 MT [1]. The salt production site consists of nearly 600 acres [1] of seawater and the total water pumping requirement was an approximate 60,000 m3/day [2]. The water pumping is done by both electrical centrifugal and submersible pumps as well as mobile diesel powered pumps where the main sea water pumping from the lagoon is done using 03 nos. electrically powered centrifugal pumps.

As the pumping requirement is different from the production stage to the other it is essential to identify the complete information on pumping capacity, power requirement, daily usage and energy utilized to study the complete requirement of power required for total water pumping for the salt production.

2.1.2 Identification of sustainable energy sources available

The energy sources currently utilized for the water pumping is mainly concentrated on grid based electricity and fossil fueled diesel power. As per the findings the total electrical energy requirement for water pumping is nearly 80% of the total plant energy requirement [2].

Even though there are many sustainable renewable energy options such as bio-fuel energy, geothermal energy, tidal energy and ocean wave energy which utilized in various applications around the world they cannot be considered as sustainable energy sources for this particular water pumping application considering the specific pumping requirement, location and access for available energy resources. Therefore in this research study wind energy and solar energy was considered as the most suitable sustainable energy sources that can be utilized for this water pumping of salt production industry.

2.1.3 Study of solar and wind power generation and water pumping technology

The water pumping technology to be utilized was studied considering technical, financial and environmental feasibility under each of the available sustainable energy sources.

2.2 Scope

The scope will be limited to recommend and propose the most technically, financially feasible and environmentally attractive sustainable energy source and methodology that could be adopted to water pumping for salt fields that would enhance the performance as well as the image and recognition as an environmentally graciousness of Puttalam Salt Limited in Sri Lanka.

3. LITERATURE REVIEW

In this section the past research and literature on similar areas of study is discussed in detailed manner. There are many study works carried out on direct solar and wind powered water pumping specially utilized for irrigation and living water in remote areas.

In the article "Selection of Suitable Wind Turbine for Wind Farm Candidate Site Narakkaliya, Kalpitiya Peninsula, Sri Lanka" by C A Sandagiri, L R Peiris, L A A N Perera, K A P Siriwardena, W H I D Soysa of Department of Electrical Engineering, University of Moratuwa, Sri Lanka in 2003 have discussed about the feasibility of proposing a best site location as well as the most suited wind turbine for a utility scale wind farm in Kalpitiya peninsula, Sri Lanka.

M Young & R Vilhauer in " Sri Lanka Wind Farm Analysis and Site Selection Assistance" published by National Renewable Energy Laboratory (NREL), USA in August 2003 discussed about quantifying the Sri Lanka wind energy potential and ways to foster wind energy development. Also it included completion of NREL wind atlas for Sri Lanka. More ever it has discussed key policy, regulatory, business and infrastructural issues which affected the wind energy development in the country.

The final report "Feasibility Assessment of Replacement of Diesel Water Pumps with Solar Water Pumps" by Pankratius Kondjamba, Robert Schultz, Brita Emmermacher, Martin Heita and Matthias Metz of emCON Consulting Group, Namibia (September 2006) have discussed about the cost effectiveness of solar water pumps compared to diesel water pumps primarily for water pumping needs of rural areas through borehole water pumping sources.

Akihiro Oi of Department of Electrical Engineering, California Polytechnic State University had discussed in his thesis report (September 2005) "Design and Simulation of Photovoltaic Water Pumping System" discussed on design and simulation of a simple efficient photovoltaic water pumping system. Also it included theoretical studies on photovoltaic's and modeling techniques employing Maximum Power Point Tracking.

In the article “Solar Water Pump Studies for Small Scale Irrigation” by Erin Williamson of Department of Bioresource Engineering, McGill University, Montreal in august 2006 discussed about the feasibility of photovoltaic water pumps for small scale irrigation systems in Montreal Canada.

The report “Renewable Energy for Water Pumping Applications in Rural Villages” by R Foster and A Ellis of New Mexico State University, Mexico (July 2001) discussed on different options and methods of renewable energy water pumping that can be utilized under specific needs, conditions and locations.

4. METHODOLOGY & DATA COLLECTION

4.1 Methodology

Relevant data was collected such as water pumping requirement (quantity and time schedules), electricity and diesel fuel consumption for water pumping and financial statistics of complete salt production. More over data related to Solar and Wind energy potential assessment such as solar irradiation and insolation, wind speed and direction on hourly/ daily basis from recording facilities established by Meteorological Department of Sri Lanka for the concerned study area.

A comprehensive literature survey was carried out on available solar power and wind power technology utilized for water pumping and similar irrigation purposes locally and internationally.

A preliminary feasibility study was carried out considering technical, economical and environmental aspects to adopt a sustainable renewable energy source for water pumping concentrating on research objectives. After a detailed research study the most feasible renewable energy source and methodology was proposed that could be utilized for sea water pumping for salt production at Puttalam Salt Limited Sri Lanka.

4.2 Study Model & Power system simulation

In order to make the research project more realistic and reasonable all the available renewable water pumping options were studied while focusing on specific water pumping requirement for slat production industry, pumping capacity, location and access to modern sustainable technology as explain below. Therefore in this research study renewable energy sources other than solar and wind power was not considered for water pumping due to the practical difficulties adopting such sources for this particular salt production industry.

1. Grid based electricity

2. Wind powered Electrical pumping - Energy generated will drive a pump by directly generating AC supply

3. Direct Windmill Mechanical pumping - Either compressor charged from wind power or Piston pump lifts water through a snake rod arrangement that to lift water

4. Solar PV Electrical pumping - Electricity generated will drive a pump through a battery or directly through a converter

5. Direct solar water pumping systems - Solar PV kits including direct brushless DC drive submersible or centrifugal pumps

HOMER power system simulation software (HOMER 2.0 14days trial version) developed by National Renewable Energy Laboratory have been used for the modeling of selected wind/ Grid and Solar/ Grid powers systems.

4.3 Data Collection

All study data obtained after site inspection and data related to solar power and wind power collected from the sources which was available in previous similar projects carried out by different study groups on various discipline.

4.3.1 Water pumping requirement

Figure 4 – 1: Water Intake and pumping locations, Puttalam Salt Limited, Sri Lanka

As the pumping requirement is different from the production stage to the other it is essential to identify the complete information on pumping capacity, power requirement, daily usage and energy utilized to study the complete requirement of power required for total water pumping requirement for the salt production.

Sea water pumping from the Kalpitiya lagoon to the main concentration basin is done using 03 nos. of centrifugal diesel pumps with a capacity of 30 kW and a flow rate of 5 m^3/ min. Also 02 nos. of electrical submersible pumps have been utilized with flow rates 2.85 m^3/ min at the same area (data collected on site visits). Comparatively smaller capacity electrically driven pumps have been used for pumping concentrated water with higher density to the secondary concentration basins and crystallizing basins.

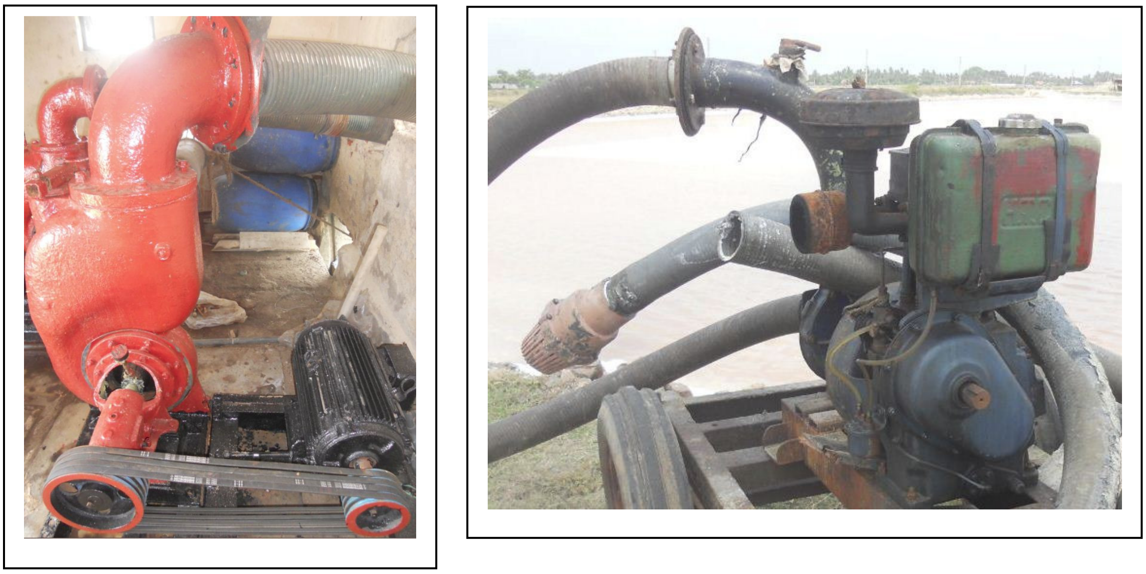


Figure 4 – 2: Centrifugal electrical and diesel pumps, Puttalam Salt Limited, Sri Lanka

The complete information and capacities were tabulated as follows.

Table 4 – 1: Pump capacities utilized at different locations, Puttalam Salt Limited, Sri Lanka

No of Pumps	Location	Type	Flow rate (m^3/ min)	Rated Power (kW)
03	Boat Channel	Centrifugal/ Electrical	5.0	30.0
02	Boat Channel	Submersible/Electrica	2.8	11.0
03	Combumune Station	Centrifugal/Electrical	4.2	22.5
02	Combumune Station	Submersible/Electrica	2.8	11.0
02	C – Area	Centrifugal/Electrical	3.0	18.5
03	C – Area	Centrifugal/Electrical	1.8	11.0
05	Mobile Pumping	Centrifugal/ Diesel	1.0	11.0

Apart from the electrically powered pumps there are 05nos of mobile diesel engine pumps where they are utilized for pumping works at different crystallizing basins located at different places. The average diesel fuel consumption is approximately 2 L/hour and the average monthly diesel fuel consumption is around 3000 L [2] which a considerable amount seeing the current trend in diesel fuel price inflation.

4.3.2 Wind Resource Data

The wind data recorded by Meteorological Department of Sri Lanka and National Renewable Energy Laboratory is useful to get a general understanding about the wind energy potential around Puttalam area where the salt production factory is located.

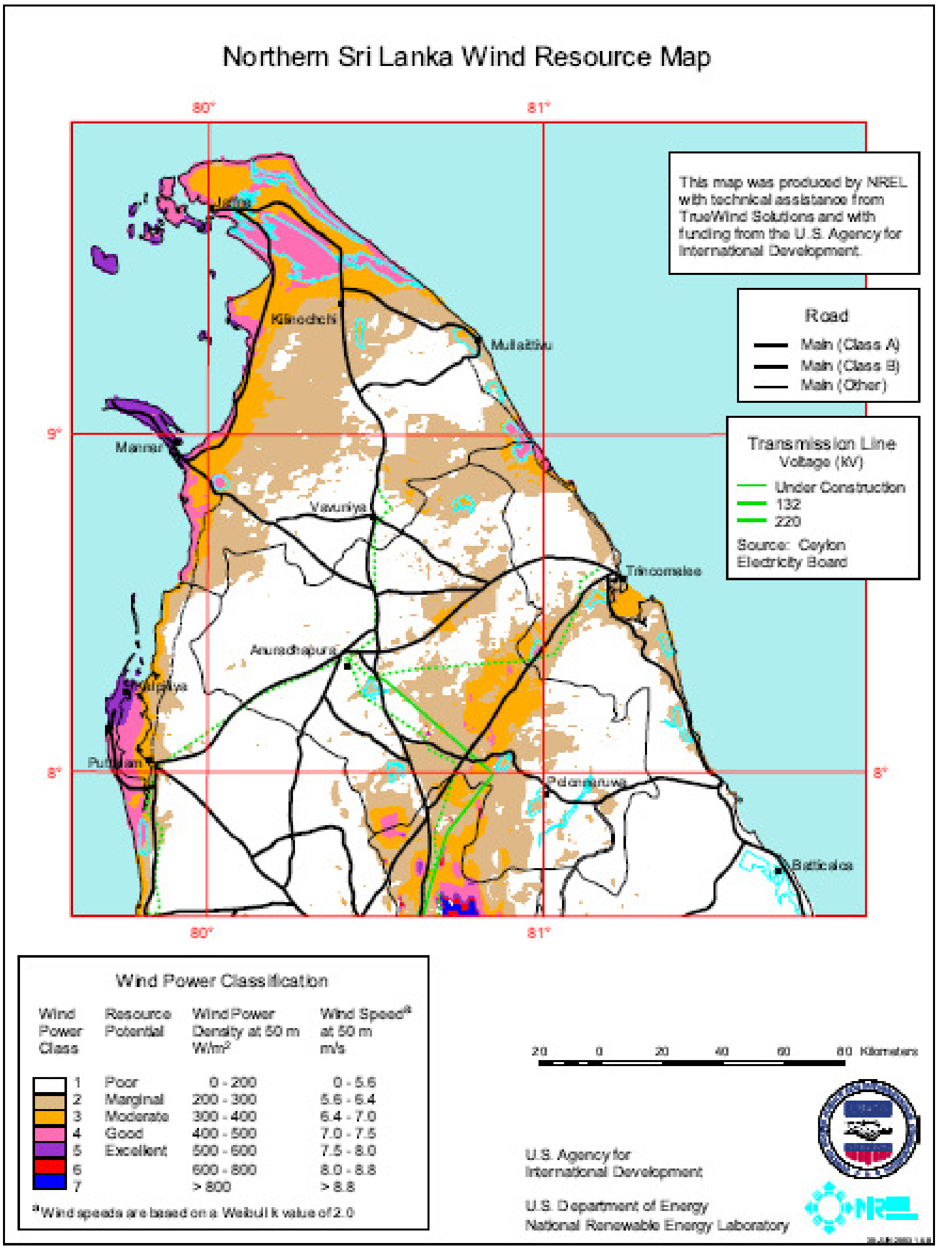


Figure 4 – 3: Wind Resource Map Sri Lanka [10]

As a general guide line wind resource map published by NREL for Sri Lanka could be handful and the subjected salt factory is located at the highest wind potential area 400 – 500 w/m^2 measured at 50m height [7, 10]. The problem with NREL data is the available data is more generalized for whole Sri Lanka and the published data is nearly a decade old.

Therefore to make this research study more viable wind data was collected from the Meteorological Department of Sri Lanka at Puttalam base station nearly 5 km north east to the salt production factory where the recorded data (at 10 m height) for last three years. Monthly average wind speed and direction considering data for last three years were tabulated below (Please refer Appendix 1 for the complete wind data collected).

Table 4 – 2: Monthly averaged wind speed and direction (2009 – 2011) **[11]**

Month	Average wind Speed (m/s)	Direction (^{O})
Jan	5.40	82
Feb	5.10	95
Mar	4.80	139
Apr	4.30	176
May	8.30	195
Jun	9.20	212
Jul	9.70	211
Aug	9.00	208
Sep	8.70	210
Oct	7.00	179
Nov	4.70	138
Dec	5.50	97

When studying the wind data it was observed the best wind speeds are from May to October each year and the worst observed on April which is 4.5 m/s still able to produce nearly 5 kW of electricity with most of the wind turbines operated around the world [7, 10].

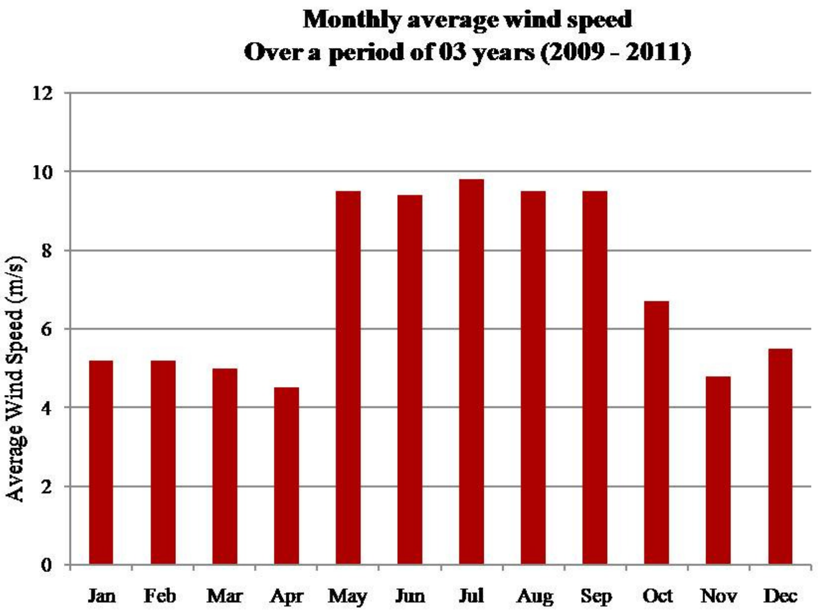


Figure 4 – 4: Monthly Average wind speed at Puttalam Base Station [11]

4.3.3 Solar Resource Data

Solar resources data for Sri Lanka is recorded mainly by the Meteorological Department of Sri Lanka as well as National Renewable Energy Laboratory (NREL). Also NASA has solar data for decades but usually the published data are nearly a decade old [9]. Solar irradiation and insolation records published by NREL and NASA are suitable to carry out any solar potential analysis similar to our research project.

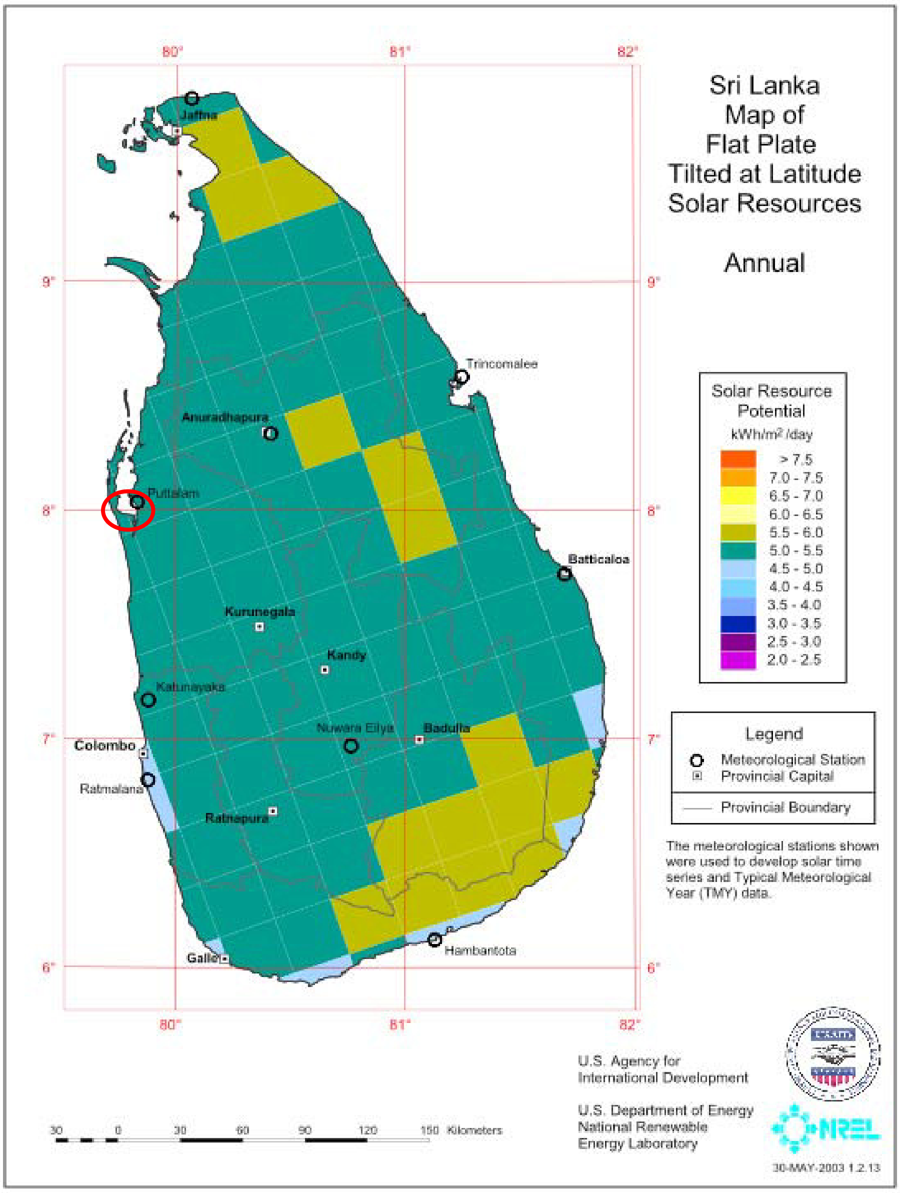


Figure 4 – 5: Sri Lanka Solar Resource Map of Flat Plate tilted at Latitude [9]

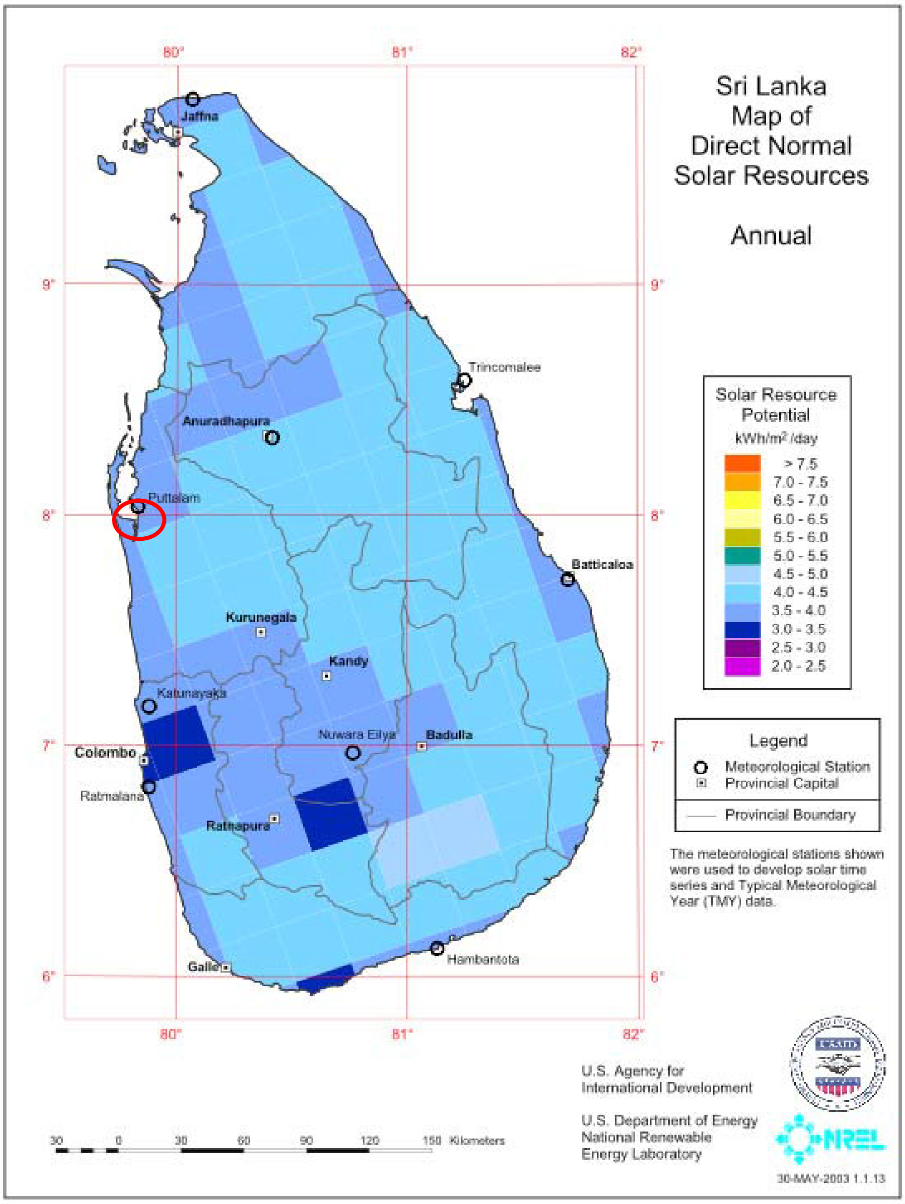


Figure 4 – 6: Sri Lanka Solar Resource Map of Direct Normal [9]

As Sri Lanka is geographically located closer to the equator receives an uninterrupted supply of sun light throughout the year. Also the solar radiation does not demonstrate any significant variation across the country except for the central highlands. According to the data the flat plate solar irradiation is approximately 5.0 – 5.5 kWh/m^2/day [8, 9] at the factory location which is considered as a best solar resource as rule of thumb for implementing a Solar PV project [8].

In order to make the feasibility analysis more reliable solar resource data such as hourly solar insolation and clearness index measured at Puttalam observation station by Meteorological Department of Sri Lanka which is some 5 km north to the factory location also taken in to consideration (please refer Appendix 2 for raw data).

Table 4 – 3: Monthly averaged Insolation Incident (2009 – 2011) [11]

Month	Monthly Average Insolation (kWh/m^2/day)	Average Clearness Index
Jan	4.86	0.532
Feb	5.62	0.576
Mar	6.41	0.622
Apr	6.20	0.592
May	5.59	0.543
Jun	5.37	0.532
Jul	5.27	0.519
Aug	5.57	0.539
Sep	5.54	0.537
Oct	4.98	0.505
Nov	4.66	0.504
Dec	4.28	0.481

5. FEASIBILITY STUDY

According to the geographical location of the Salt factory and available renewable energy sources it was decided to consider wind energy and solar energy as the best possible alternative renewable resources that could be considered considering the practical difficulties for adopting such sources for the production process at Puttalam Salt Limited.

5.1 Pumping Requirement

In this research the main parameter for determining the energy requirement depends on two factors. For Solar PV direct pumping and Windmill pumping the major variable is the water pumping capacity which needs to achieve per day or an hourly basis. On the other hand for Solar PV or wind power electrical pumping depends on the electrical load required. So the calculations were done based on flow rate for direct pumping and pumping power required for electrical pumping.

According to the studies the total water pumping capacity for the entire salt factory is around 60,000 m^3 per day [2]. Also the pumping requirement from each location should be taken in to consideration as they cannot be changed at will as the production method is solar evaporation so it will affect the salt manufacturing process.

Table 5 – 1: Pump capacities utilized at different locations [2]

Location	No of Pumps	Type	Flow rate (m^3/ min)	Rated power (kW)	Operating hours per day	Total Flow rate (m^3/ min)
Boat Channel	03	Centrifugal / Electrical	5.0	30.0	24	20.6
Boat Channel	02	Submersible / Electrical	2.8	11.0	24	
Combumune	03	Centrifugal / Electrical	4.2	22.5	16	18.2
Combumune	02	Submersible / Electrical	2.8	11.0	16	
C – Area	02	Centrifugal / Electrical	3.0	18.5	16	11.4
C – Area	03	Centrifugal / Electrical	1.8	11.0	16	
Mobile Pumping**	05	Centrifugal/ Diesel	1.0	11.0	8	1

** Mobile pumps are located in different places so pumping volume cannot add together

When considering the AC drive water pumping using wind/ solar resources the calculations are based on the required electrical load. Most of the currently utilized electrical pumps were either over designed or out dated. Therefore if the rated power considered for this electrical load calculation it will be an over design as the actual power requirement for pumping is far small than the rated powers. So the actual pumping power requirement for each pumping stage was re calculated (Appendix [3]).

Table 5 – 2: Pumping power requirement

Location	No of Pumps	Type	Flow rate (m^3/ min)	Rated Power (kW)	Actual Maximum power required (kW)
Boat Channel	03	Centrifugal / Electrical	5.0	30.0	10
Boat Channel	02	Submersible / Electrical	2.8	11.0	4.9
Combumune	03	Centrifugal / Electrical	4.2	22.5	7.9
Combumune	02	Submersible / Electrical	2.8	11.0	5.2
C – Area	02	Centrifugal / Electrical	3.0	18.5	6.1
C – Area	03	Centrifugal / Electrical	1.8	11.0	3.8
Mobile Pumping	05	Centrifugal/ Diesel	1.0	11.0	2.1

The electrical load potential for water pumping was calculated considering the calculated actual power and actual operating time for each pump. Accordingly the daily base load was 41.7 kWh and the peak demand was 102 kWh from 8:00 – 16:00 hours (Daily load profile for Puttalam salt limited for water pumping).

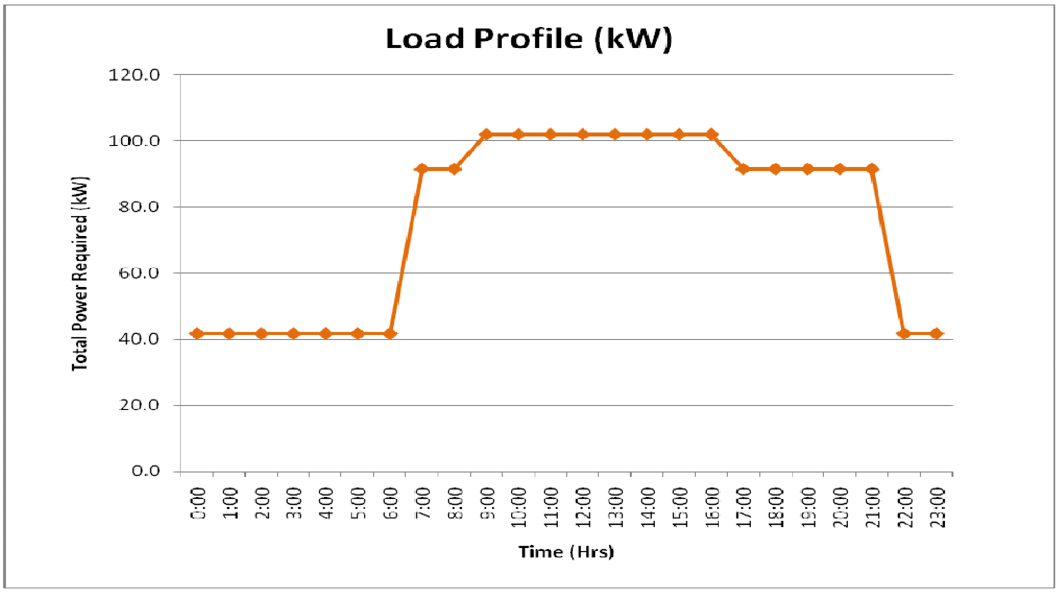


Figure 5 – 1: Daily load profile for Puttalam salt limited for water pumping

Monthly average electrical load was 53,928 kWh [2] and the annual average electricity requirement was 647,136 kWh [2]. The annual electricity and diesel bill was 14.7 million rupees (USD 117,353/=) [2].

5.2 Water Pumping Options

5.2.1 Direct Windmill water pumping

The direct wind mill pumping is very much popular in United States and European countries especially for farm houses and small/ medium scale irrigation works. The water is pumped by mechanical means either by air lifting technology or by piston pump technology. The advantages are the power transfer efficiency relatively high as the kinetic energy of wind power is directly transferred for pumping work.

For the research study windmill pumps by leading manufacturers considered together with the best possible available pumping capacity and capital cost of the equipments. No of pumps required was calculated considering the pumping capacity for each location.

Table 5 – 3: Windmill pump capacities and prices [12-13]

Item No.	Manufacturer	Windmill Diameter (m)	Flow rate (m^3/ min)	Head (m)	Unit Price (US $)
01	Ironman Windmill Co.	6.0	0.75	5.0	21,000
02	Ironman Windmill Co.	4.8	0.3	5.0	14,500
03	Aeromotor Windmill Co.	4.8	0.2	5.0	13,800

The pumping capacity (flow rate) relevant to the annual average wind speed and pumping head was calculated according to the manufacturer's performance curve (refer Appendix [4] for performance curves).

Table 5 – 4: Total Windmill pump requirement and total capital cost

Location	No of Pumps	Type	Flow rate (m^3/ min)	Total capacity required (m^3/ min)	No of pumps required		
					Ironman 6m	Ironman 4.8m	Aeromotor 4.8m
Boat Channel	03	Centrifugal / Electrical	5.0	20.6	28	69	103
	02	Submersible / Electrical	2.8				
Combumune Station	03	Centrifugal / Electrical	4.2	18.2	25	61	91
	02	Submersible / Electrical	2.8				
C – Area	02	Centrifugal / Electrical	3.0	12	16	40	60
	03	Centrifugal / Electrical	1.8				
Mobile Pumping	05	Centrifugal/ Diesel	1.0	1	10	20	25
Total no of Pumps					79	190	279
Total Cost (US $ Million)					1.66	2.75	3.85

By considering the annual average wind speed and average windmill pumping capacity the total number of windmill pump requirement for each pumping location and initial investment cost for each model was calculated and tabulated as above.

5.2.2 Direct Solar PV pumping systems

Figure 5 – 2: Solar PV pumping unit

The direct solar PV pumping kits are very popular in United States, Africa and European countries and they are more feasible in small/ medium scale irrigation, farm houses and dairy industry. The major advantage is low cost pumping, stand alone systems and very little maintenance requirements while the main disadvantage is limited pumping capacity [14, 15].

For this project most feasible DC drive submersible and centrifugal type pumps with integrated PV kits was considered after collecting and going through the price lists and product brochures published by the world renowned manufacturers.

Table 5 – 5: Direct Solar PV pump capacities and prices [16-18]

Item No.	Model	Manufacturer	Flow rate (m^3/ min)	DC Power (W)	Head (m)	Unit Price (US $)
01	PS4000C	Lorentz	0.85	3000	5.0	4,600
02	PS9K	Lorentz	2.0	7000	5.0	14,700
03	SunCentric 7526	Dankoff	0.25	952	5.0	1,482
04	4SP8 – 5A	Xintong Solar	0.32	2880	5.0	3,800

Cost for PV array/ Battery bank/ inverter and other switch/fuse & wiring were calculated according to the world market prices and solar PV cost estimation thumb rules. Cost of PV array is approximately 5$ per watt and 1$ per amp hour for the battery bank [19, 20]. Also the cost of inverter is approximately 1 $ per rated watt [19, 20] and for other system components such as switch/ fuse/ wire etc will cost nearly 20% of the sub total [19, 20].

Accordingly total unit cost of the above models of solar PV pumping units has been calculated (See Appendix [5] for a specimen calculation).

Table 5 – 6: Cost of Direct Solar PV pumping units

Item No.	Model	Manufacturer	Total cost of PV pumping unit (US $)
01	PS4000C	Lorentz	51,120
02	PS9K	Lorentz Windmill Co.	121,020
03	SunCentric 7526	Dankoff	15,952
04	4SP8 – 5A	Xintong Solar	47,096

Total number of direct solar PV pump requirement for each pumping location and initial investment cost for each model was tabulated below.

Table 5 – 7: Total Cost of Direct Solar PV pumping system

Location	No of Pumps	Type	Flow rate (m^3/ min)	Total capacity required (m^3/ min)	No of pumps required			
					Lorentz PS9K	**Lorentz PS4000C**	**Xintong 4SP14 -5A**	**Dankoff SunCentric 7526**
Boat Channel	03	Centrifugal / Electrical	5.0	20.6	11	25	65	83
	02	Submersible / Electrical	2.8					
Combumune Station	03	Centrifugal / Electrical	4.2					
	02	Submersible / Electrical	2.8	18.2	9	22	57	73
C – Area	02	Centrifugal / Electrical	3.0					
	03	Centrifugal / Electrical	1.8	12	6	15	38	48
Mobile Pumping	05	Centrifugal/ Diesel	1.0	1	5	8	15	20
Total no of Pumps					31	70	175	224
Total Cost (US $ Millions)					3.75	3.58	8.24	3.57

5.2.3 Solar PV powered AC electrical system

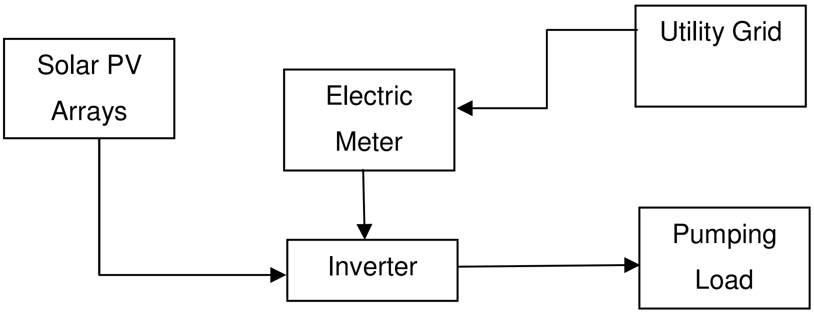


Figure 5 – 3: Schematic diagram of conceptual design for Solar PV grid tied system

The system contains a series of solar PV arrays connected to the electrical pumping load through an inverter and tied to the utility grid to accommodate the solar power short falls.

As the system is tied with utility grid the battery storage facility was not considered. Due to the availability of other electrical loads in the factory a dump load was not considered either.

When selecting a solar PV system the main component is the PV panel. Even there are so many PV panel/ array manufacturers over the world the PV panels are the heart of a PV power system. So for this research study world renowned brands of PV panels were considered to increase the reliability of the study data.

According to the peak demand/ base load and load profile PV panels ranging from 5 – 200 W were considered.

Table 5 – 8: Price and data of selected PV panels in the market [21-24]

Item No.	Model	Manufacturer	Country of Origin	Watt Rating (W)	Certifications	Unit Cost (US $)	Unit Cost per kW (US $)
01	STP190S	Suntech Power	USA	190	IEC 61215/ 61730 CE ISO 9001:2008	628	3,305.00
02	NU – 180R1H	Sharp	Germany	180	IEC 61215/ 61730 CE ISO 9001:2008	447	2,483.00
03	KD140	Kyocera	UK	140	IEC 61215/ 61730 CE ISO 9001:2008	412	2,943.00
04	LC120	Lorentz	Germany	120	IEC 61215/ 61730 CE ISO 9001:2008	666	5,500.00
05	UP – M190M	Upsolar	China	190	IEC 61215/ 61730 CE ISO 9001:2008	418	2,200.00

When comparing the unit price per kW rated power the Upsolar make UP-M190M is the most cost effective and could be selected for further modeling and cost analysis.

Different sizes of branded converter/ rectifier units were considered and that usually will cost 1,000 US$ per kW according to the market survey [19, 20]. According to the cost estimation standards cost components related to labour/ wiring/ fuses/ fixtures & lightning arrests etc. will cost approximately 1,000 US$ per kW [19, 20]. Operation & maintenance cost adhered with solar PV power systems generally split in to Preventive/ Corrective and Conditioned based maintenance elements and will cost approximately 60 $/ kW – yr. [19, 20] as described in international standards.

5.2.4 Wind powered electrical system

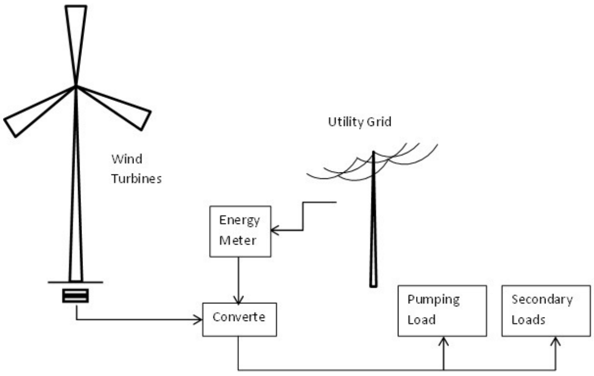


Figure 5 – 4: Schematic diagram of conceptual design for wind power grid tied system

The system contains a series of wind turbines connected to the electrical pumping load through an inverter and tied to the utility grid to accommodate the solar power short falls. As the system is tied with utility grid the battery storage facility was not considered. Also a dump load was not included to the system due to the availability of secondary electrical loads in the factory.

Table 5 – 9: Price and data of selected wind turbines in the market [25-30]

Item No.	Model	Manufacturer	Capacity (kW)	Rated Speed (m/s)	Annual power generation at 6.5m/s (kWh)	Unit Cost (US $)
01	AOC 15/50	AOC Renewable Energy (Canada)	50 (3ph AC 480V 50Hz)	13.0	95,400	120,000
02	WES 18	Wind Energy Solutions (Netherland)	80 (3ph AC 400V 50Hz)	12.5	141,500	350,000
03	NW 100	Northern Power (USA)	100 (3ph AC 480V 50Hz)	14.5	174,250	553,000
04**	Windmatic 17S	Remanufactured by Repowering Solutions (Spain)	95 (3ph AC 400V 50Hz)	15	175,000	169,000
05**	Vestas V27	Remanufactured by Repowering Solutions (Spain)	225 (3ph AC 400V 50Hz)	15.5	488,000	418,500

(Wind turbine prices are approximate value referred from manufacturer web sites and product brochures as well as from WindTurbines-MarketPlace.com)

According to the peak demand/ base load/ load profile/annual average wind speed and annual power generated at available average wind speed following world branded wind turbines ranging from 50 – 250 kW were considered.

When considering a small size wind turbine the remanufactured wind turbines are very cost effective and generally cost half the price of a new one and provide a popular alternative having the same warranty coverage as well as the life expectancy. Repowering Solutions (Spain), Matrix wind solutions (USA), Talk incorporation (USA) are few of the leading remanufacturers.

Branded converter/ rectifier units were considered and the usually will cost 1,000 US$ per kW [31] and the O&M cost in wind power generation units are generally considered as 1 cent/ kWh per annual rated generation [31].

5.3 Modeling of Power system

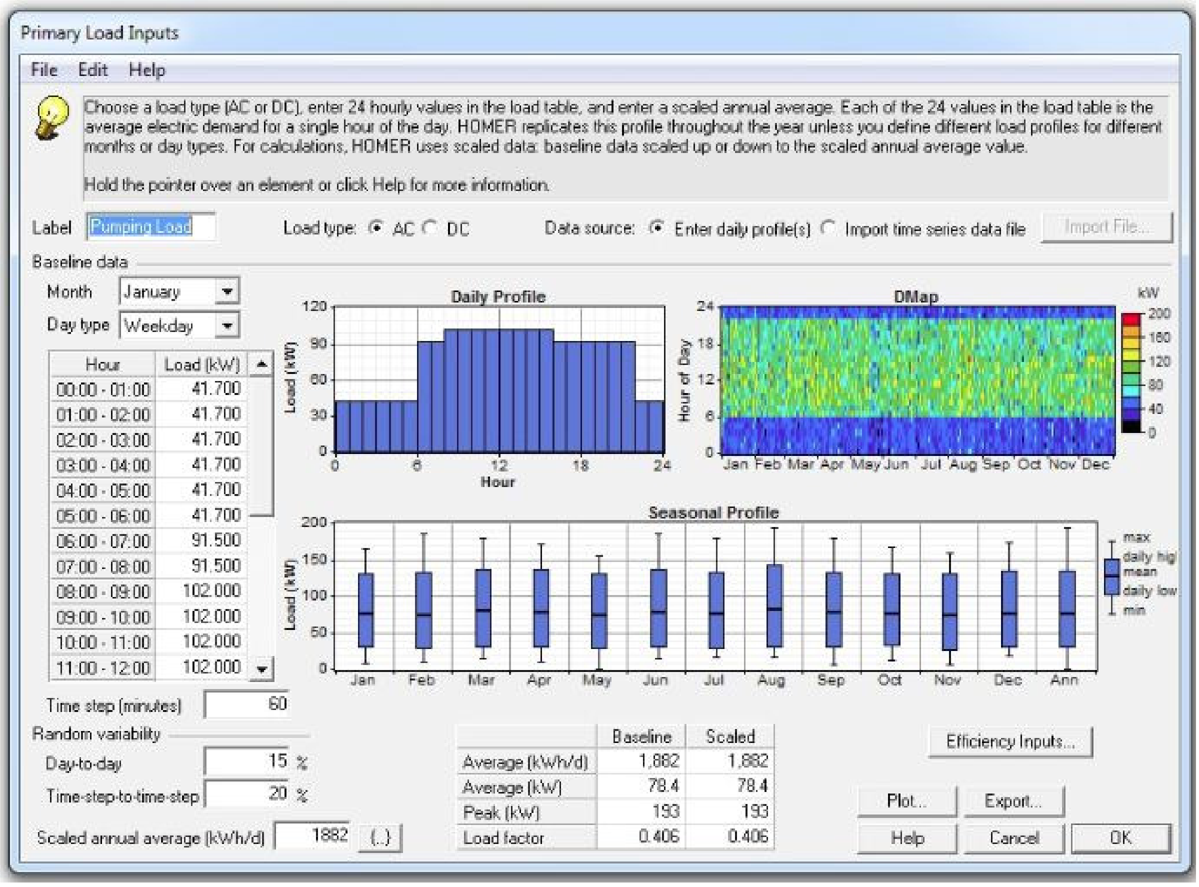
HOMER power system simulation software (HOMER 2.0 trial version) developed by National Renewable Energy Laboratory have been used for the modeling of selected wind/ Grid and Solar/ Grid powers systems [32].

5.3.1 Data for HOMER

For simulation the power systems using HOMER, data related to electrical load/ wind resource/ solar resource/ solar PV system and selected wind turbine provided as required.

- Electrical Load

  Hourly load profile was generated from the calculated actual pumping electrical power (Table 6-2) and 10% of daily variation was considered as pumping requirement is generally constant.



Choose a load type (AC or DC), enter 24 hourly values in the load table, and enter a scaled annual average. Each of the 24 values in the load table is the average electric demand for a single hour of the day. HOMER replicates this profile throughout the year unless you define different load profiles for different months or day types. For calculations, HOMER uses scaled data: baseline data scaled up or down to the scaled annual average value.

Hold the pointer over an element or click Help for more information.

Label: Pumping Load
Load type: ● AC ○ DC
Data source: ● Enter daily profile(s) ○ Import time series data file

Baseline data
Month: January
Day type: Weekday

Hour	Load (kW)
00:00 - 01:00	41.700
01:00 - 02:00	41.700
02:00 - 03:00	41.700
03:00 - 04:00	41.700
04:00 - 05:00	41.700
05:00 - 06:00	41.700
06:00 - 07:00	91.500
07:00 - 08:00	91.500
08:00 - 09:00	102.000
09:00 - 10:00	102.000
10:00 - 11:00	102.000
11:00 - 12:00	102.000

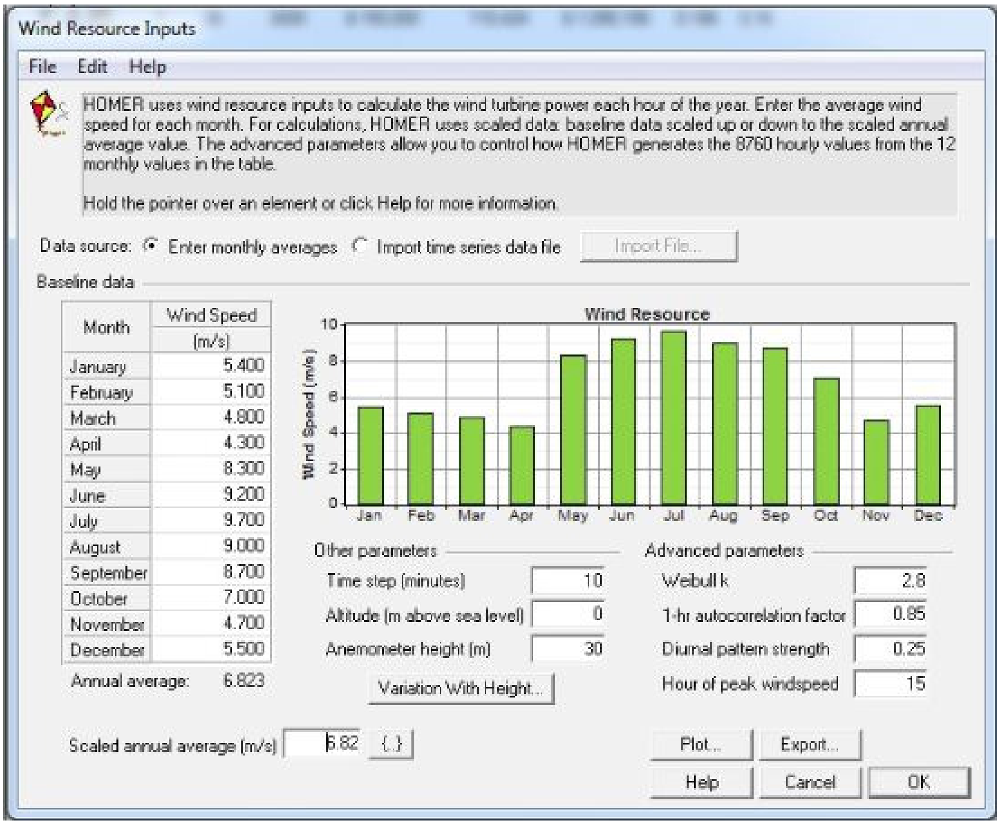
Time step (minutes): 60
Random variability
Day-to-day: 15 %
Time-step-to-time-step: 20 %
Scaled annual average (kWh/d): 1882 (...)

	Baseline	Scaled
Average (kWh/d)	1,882	1,882
Average (kW)	78.4	78.4
Peak (kW)	193	193
Load factor	0.406	0.406

Figure 5 – 5: Primary pumping load at the production facility for HOMER simulation

- Wind and Solar Resource

Monthly average wind speed tabulated in Table 4-2 calculated from recorded wind data at 30m height was inserted and Weibull shape factor (k) = 2.8 [7] and the surface roughness as 0.1m as per the geographical factors of the location [7, 11]. For other parameters such as 1hr autocorrelation factor and Diurnal pattern strength default values provided by HOMER was considered as sufficient [32].



HOMER uses wind resource inputs to calculate the wind turbine power each hour of the year. Enter the average wind speed for each month. For calculations, HOMER uses scaled data: baseline data scaled up or down to the scaled annual average value. The advanced parameters allow you to control how HOMER generates the 8760 hourly values from the 12 monthly values in the table.

Hold the pointer over an element or click Help for more information.

Data source: ● Enter monthly averages ○ Import time series data file

Baseline data

Month	Wind Speed (m/s)
January	5.400
February	5.100
March	4.800
April	4.300
May	8.300
June	9.200
July	9.700
August	9.000
September	8.700
October	7.000
November	4.700
December	5.500
Annual average:	6.823

Other parameters

Time step (minutes) 10

Altitude (m above sea level) 0

Anemometer height (m) 30

Advanced parameters

Weibull k 2.8

1-hr autocorrelation factor 0.85

Diurnal pattern strength 0.25

Hour of peak windspeed 15

Scaled annual average (m/s) 6.82

Figure 5 – 6: Wind resource data for HOMER simulation

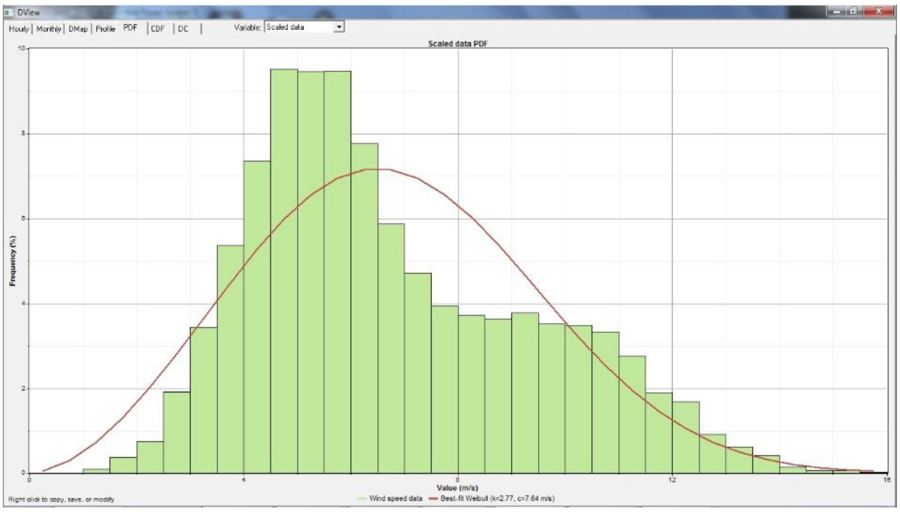
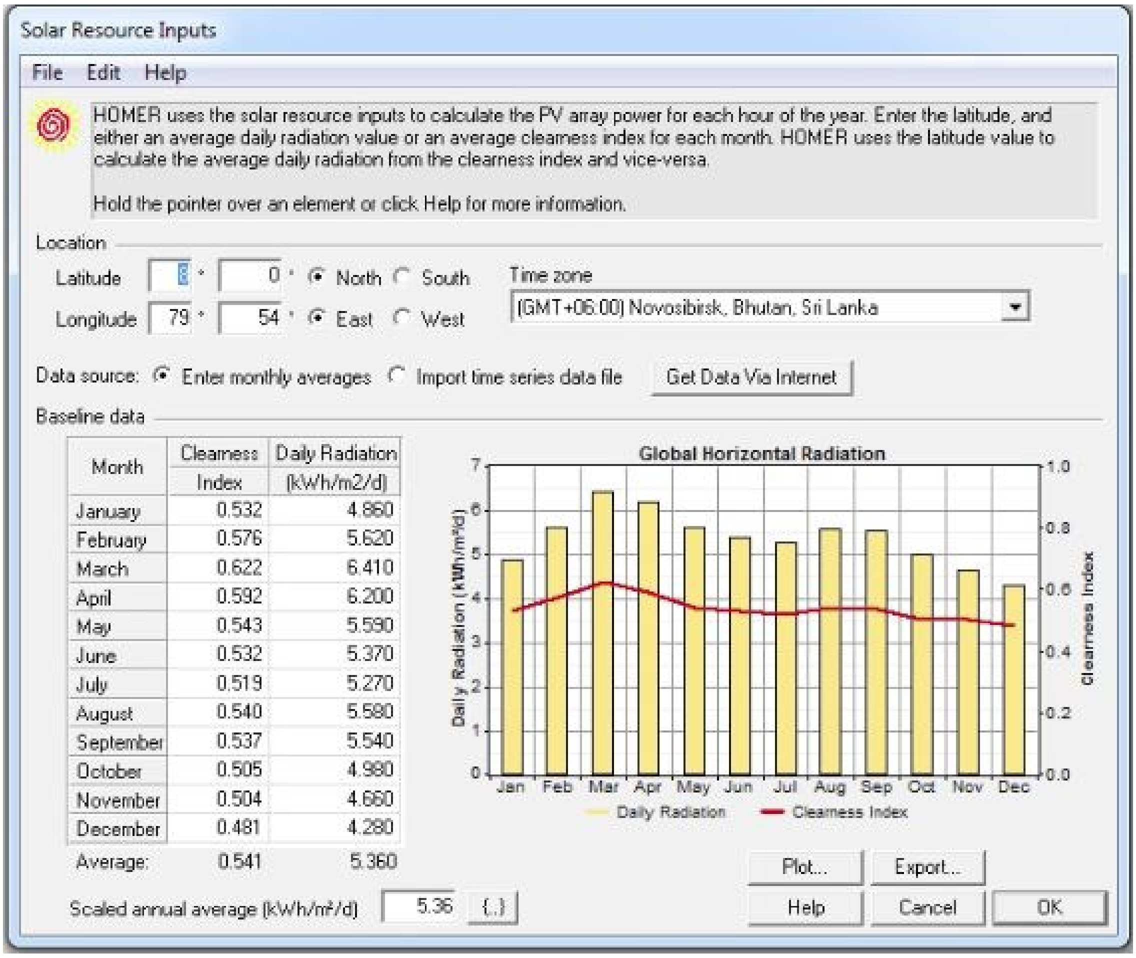


Figure 5 – 7: Weibull distribution generated by HOMER

The geographical location as Latitude 8° North and Longitude 79° 54' East [9]. The monthly average clearness index and monthly average insolation tabulated in Table 4-3 was considered [7, 33].



HOMER uses the solar resource inputs to calculate the PV array power for each hour of the year. Enter the latitude, and either an average daily radiation value or an average clearness index for each month. HOMER uses the latitude value to calculate the average daily radiation from the clearness index and vice-versa.

Hold the pointer over an element or click Help for more information.

Location

Latitude 8 ° 0 ° ● North ○ South

Longitude 79 ° 54 ° ● East ○ West

Time zone: (GMT+06:00) Novosibirsk, Bhutan, Sri Lanka

Data source: ● Enter monthly averages ○ Import time series data file

Baseline data

Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.532	4.860
February	0.576	5.620
March	0.622	6.410
April	0.592	6.200
May	0.543	5.590
June	0.532	5.370
July	0.519	5.270
August	0.540	5.580
September	0.537	5.540
October	0.505	4.980
November	0.504	4.660
December	0.481	4.280
Average:	0.541	5.360

Scaled annual average (kWh/m²/d) 5.36

Figure 5 – 8: Solar resource data for HOMER simulation

- <u>Wind turbine & Solar PV data</u>

  Turbine specifications related to the selected wind turbines (Table 5-8) was considered and the power curves for each turbine was taken from the data sheets (Appendix [6]) provided by the manufacturers. O & M cost considered as discussed earlier while the expected lifetime for turbine and converter was considered as 15 years and 10 years respectively [31].

  Solar PV panel data considered relevant to UPsolar UP-M190M (Table 5-7) and horizontal axis monthly tracking was considered. Also temperature effect assumed negligible. O & M cost considered as discussed earlier while the expected lifetime for PV system and converter was considered as 20 years and 10 years respectively [19].

- Utility Grid & Project Economics

A strong utility grid with unlimited purchase capacity and a 0.18 US$/kWh fixed rate was considered [34-36]. Project lifetime considered as 20 years and the Annual real interest rate as 10% [37].

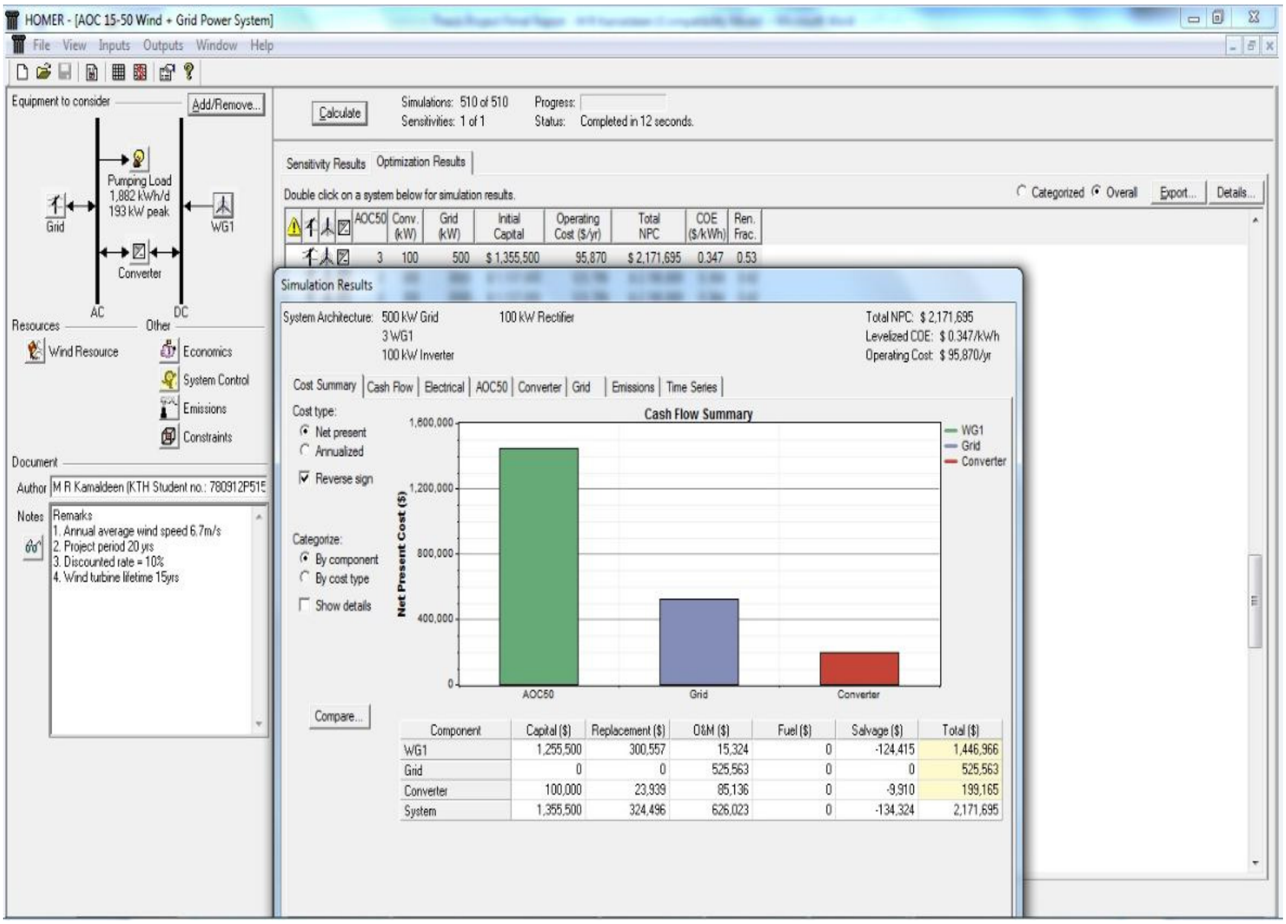
- Emission

Emission factors by the grid based power generation was set for standard values as CO_2 – 384 g/kWh, Methane – 0.027 g/kWh and NO_2 – 0.005 g/kWh for carbon footprint calculation [38, 39]. The electricity emission factors for Sri Lanka was referred from the EIA report 2007 published by US Department of Energy (Appendix [8]).

5.3.2 Modeling

Following configurations were simulated using HOMER to obtain an optimum set of configuration.

Wind turbines	AOC15/50	0, 1, 2, 3, 4 nos. of units
	WES 18	0, 1, 2, 3 nos. of units
	NW 100	0, 1, 2, 3 nos. of units
	Windmatic 17S	0, 1, 2, 3 nos. of units
	Vestas V27	0, 1, 2 nos. of units
Solar PV	UP – M190M	0, 10, 50, 100 kW systems
Converter		0, 10, 30, 50, 80, 100, 150, 200, 250 kW



Pumping Load
1,882 kWh/d
193 kW peak

Author: M R Kamaldeen (KTH Student no.: 780912P515

Notes:
Remarks
1. Annual average wind speed 6.7m/s
2. Project period 20 yrs
3. Discounted rate = 10%
4. Wind turbine lifetime 15yrs

Simulations: 510 of 510
Sensitivities: 1 of 1
Progress:
Status: Completed in 12 seconds.

Double click on a system below for simulation results.

AOC50	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
3	100	500	$ 1,355,500	95,870	$ 2,171,695	0.347	0.53

System Architecture: 500 kW Grid
3 WG1
100 kW Inverter
100 kW Rectifier

Total NPC: $ 2,171,695
Levelized COE: $ 0.347/kWh
Operating Cost: $ 95,870/yr

Cost type:
● Net present
○ Annualized
☑ Reverse sign

Categorize:
● By component
○ By cost type
☐ Show details

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
WG1	1,255,500	300,557	15,324	0	-124,415	1,446,966
Grid	0	0	525,563	0	0	525,563
Converter	100,000	23,939	85,136	0	-9,910	199,165
System	1,355,500	324,496	626,023	0	-134,324	2,171,695

Figure 5 – 9: HOMER simulation result window snapshot

Above mentioned each configuration was simulated separately and the results have been attached to Appendix [11].

5.4 Carbon footprint

Carbon footprint (CFP) is a modern global index which used to estimate the environmental impacts originated due to human activities. It is defined as the amount of Green House Gases (GHG) emitted by an activity directly or indirectly and measured in tons of carbon dioxide equivalents (tkg$CO_{2(eq)}$). The total CFP for an organization such as the salt production industry would be the accumulation of direct and indirect CFP of each and every activity of the complete salt production process.

For the research study contribution to CFP was considered only the major emission forms inherent to the concerned salt production system.

- Direct GHG emission by current diesel engine water pumping
- Indirect emission due to consumption of grid based electricity (water pumping).

Other direct and indirect GHG emissions related to packaging, office staff, welfare, salt & staff transportation and diesel transportation from Colombo to factory premises was not considered due to practical difficulties to quantifying such emissions accurately.

Table 5 – 10: Green House Gases and Global Warming Potential [38, 39]

Item No.	Name of Green House Gas	Global Warming Potential (AR4[2])
01	Carbon dioxide (CO_2)	1
02	Methane (CH_4)	25
03	Nitrous Oxide (N_2O)	298
04	Hydroflourocarbons (HFCs)	12 – 14,800
05	Perflourocarbons (PFCs)	7,390 – 12,200
06	Sulfur Hexafluoride (SF_6)	22,800

AR4[2] – GWPs review as per the Fourth Assessment Report, Intergovernmental Panel on Climate Change (IPCC)

Table 5 – 11: Emission factors for diesel industrial engines [39]

Item No.	Pollutant	Emission factor (kg/L)
01	Carbon dioxide (CO_2)	2.697
02	Methane (CH4)	3.80×10^{-4}
03	Nitrous Oxide (N_2O)	5.82×10^{-5}

According to the survey data the annual diesel fuel consumption for diesel engine water pumps were about 33,000 L [2]. There were 05nos of centrifugal mobile diesel pumps (11kW) in operation for approximately 8hours per day throughout the year.

According to the calculations annual Carbon footprint due to diesel engine water pumping is approximately 89.8 t $CO_{2(eq)}$ (Refer Appendix [9] for calculations).

Current annual grid electricity consumption for water pumping activities was 647.1MWh [2] as mentioned earlier chapters. Average grid electricity emission factor for Sri Lanka 386.3 kg $CO_{2(eq)}$/ MWh as per the EIA regulations 2007 [39].

Table 5 – 12: Emission factors for grid based electricity Sri Lanka [39]

Item No.	Pollutant	Emission factor
01	Carbon dioxide (CO_2)	384
02	Methane (CH4)	2.72×10^{-2}
03	Nitrous Oxide (N_2O)	5.43×10^{-3}

CFP for annual grid based electricity (water pumping) = 386.3 x 647.1

= 249.9 t $CO_{2(eq)}$

The annual carbon footprint for the salt production organization (considering direct GHG emission by current diesel engine pumps and indirect emission due to consumption of grid based electricity) was a staggering 339.7 t $CO_{2(eq)}$ [40].

5.6 Financial Assessment

Economical feasibility of this project was assessed more precisely as any proposal that would be made should be financially viable to sustain the organization in competitive market. Therefore most reliable and common financial analytical tools such as Internal Rate of Return (IRR) and Discounted Payback Period adopted to assess the financial aspects.

5.6.1 Internal Rate of Return & Discounted Payback Period

By definition Internal Rate of Return (IRR) is the discounted interest rate that makes the Net Present Value of all the cash flows of a project equal to zero and if the IRR value of a project is greater than the general interest rate of organization it is considered as profitable.

Discounted payback period (DPP) is the period for a breakeven point of a cash flow of a particular project in years. The discounted cash flow figures were used so that the time value of money would be enhanced and more realistic payback period could be assessed.

IRR and Payback period calculation for this research study was done using simple excel calculation sheet and the relevant figures such as energy units generated, saved and sold for a particular power system configuration was introduced from the results of HOMER power system simulation software [41].

For this project the discounted interest rate has been take as 10% which was higher than the stipulated value by Central Bank of Sri Lanka for year 2011 [37]. More over grid electricity purchase cost was considered as 0.18 US $/ kWh [33].

The economic assessment results for selected options are shown in the below figure. For other IRR and DPP calculations please refer the Appendix [10].

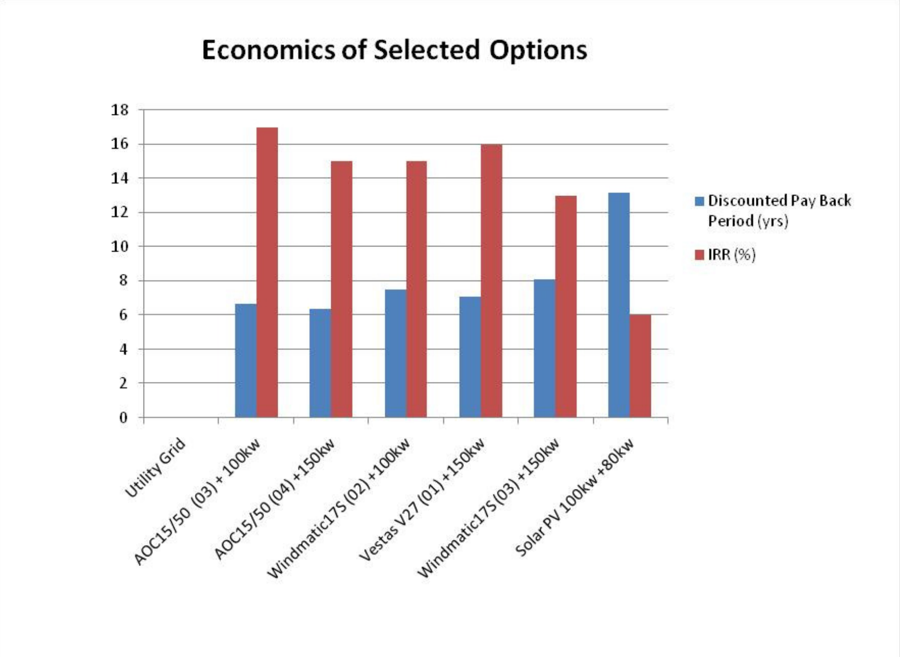


Figure 5 – 10: Discounted payback period and IRR for the selected options

6. ANALYSIS

6.1 Homer simulation results

HOMER simulates each of the configurations for optimum size and combinations comparing technical and economical feasibility according to the norms introduced.

A summary of top 15 simulation results sorted on the Cost of Energy (CoE) is tabulated below.

Table 6 – 1: Summary of simulation results sorted on the Cost of Energy (CoE)

No.	Pumping Energy Option	Solar PV/ Wind Turbine Size & no of units	Usage of Utility Grid	Converter (kW)	Initial Capital Cost (US $)	Operating Cost (US $)	NPC (US $)	Coe $/kWh	Renewable percentage
01	Utility Grid	-	YES	-	-	123,647	1,052,680	0.180	0%
02	Wind/Grid	AOC15/50 x 03	YES	100	460,000	89,193	1,219,349	0.197	48%
03	Wind/Grid	AOC15/50 x 04	YES	150	630,000	88,537	1,383,762	0.201	60%
04	Wind/Grid	Windmatic17S x 02	YES	100	438,000	93,840	1,236,911	0.203	45%
05	Wind/Grid	Vestas V27 x 01	YES	150	568,500	92,3114	1,354,423	0.204	57%
06	Wind/Grid	AOC15/50 x 03	YES	150	510,000	93,684	1,307,586	0.206	51%
07	Wind/Grid	AOC15/50 x 05	YES	150	750,000	85,900	1,481,312	0.206	66%
08	Wind/Grid	Windmatic17S x 03	YES	150	657,000	91,780	1,438,374	0.211	60%
09	Wind/Grid	Windmatic17S x 02	YES	150	488,000	98,665	1,327,987	0.213	47%
10	Wind/Grid	Vestas V27 x 01	YES	200	618,500	98,123	1,453,875	0.215	58%
11	Wind/Grid	Windmatic17S x 03	YES	100	607,000	88,493	1,360,393	0.216	54%
12	Wind/Grid	Vestas V27 x 02	YES	150	987,000	86,612	1,724,378	0.227	75%
13	PV/Grid	100	YES	50	370,000	112,906	1,331,234	0.228	18%
14	PV/Grid	100	YES	80	400,000	113,761	1,368,513	0.234	21%
15	Wind/Grid	WES18 x 02	YES	100	800,000	97,920	1,633,649	0.268	45%

6.2 Analysis

Selecting the most suitable sustainable renewable energy source for water pumping cannot be done just analyzing solely the cost of electricity. In addition to CoE it is essential to consider initial capital investment and total Net present cost (NPC) of the project.

Further selections from the above selected combinations were carried out considering total NPC of the project below USD 1.4 million/ initial capital cost below USD 700,000/ Renewable energy fraction above 40% (except for solar PV) and the CoE below USD 0.211 (except for Solar PV). Special attention was given to solar PV to access the level of unfeasibility adopting such system in this kind of pumping application.

Table 6 – 2: Selected simulation results sorted on the Cost of Energy (CoE)/ NPC/ Capital cost and Renewable fraction

No.	Pumping Energy Option	Solar PV/ Wind Turbine Size & no of units	Usage of Utility Grid	Initial Capital Cost (US $)	Operating Cost (US $)	NPC (US $)	CoE $/kWh	Renewable percentage
01	Utility Grid	-	YES	-	123,647	1,052,680	0.180	0%
02	Wind/Grid	AOC15/50 x 03	YES	460,000	89,193	1,219,349	0.197	48%
03	Wind/Grid	AOC15/50 x 04	YES	630,000	88,537	1,383,762	0.201	60%
04	Wind/Grid	Windmatic17S x 02	YES	438,000	93,840	1,236,911	0.203	45%
05	Wind/Grid	Vestas V27 x 01	YES	568,500	92,3114	1,354,423	0.204	57%
06	Wind/Grid	Windmatic17S x 03	YES	657,000	91,780	1,438,374	0.211	60%
07	PV/ Grid	100	YES	400,000	113,761	1,368,513	0.234	21%

More over as this projects concentrate on the positive contribution to the national energy policies it is important to consider the renewable energy contribution in both annual average as well as the lowest percentage contribution.

Also to assess the environmental impact of each option the annual Carbon Footprints were calculated emphasizing only the direct grid based electricity emission factors.

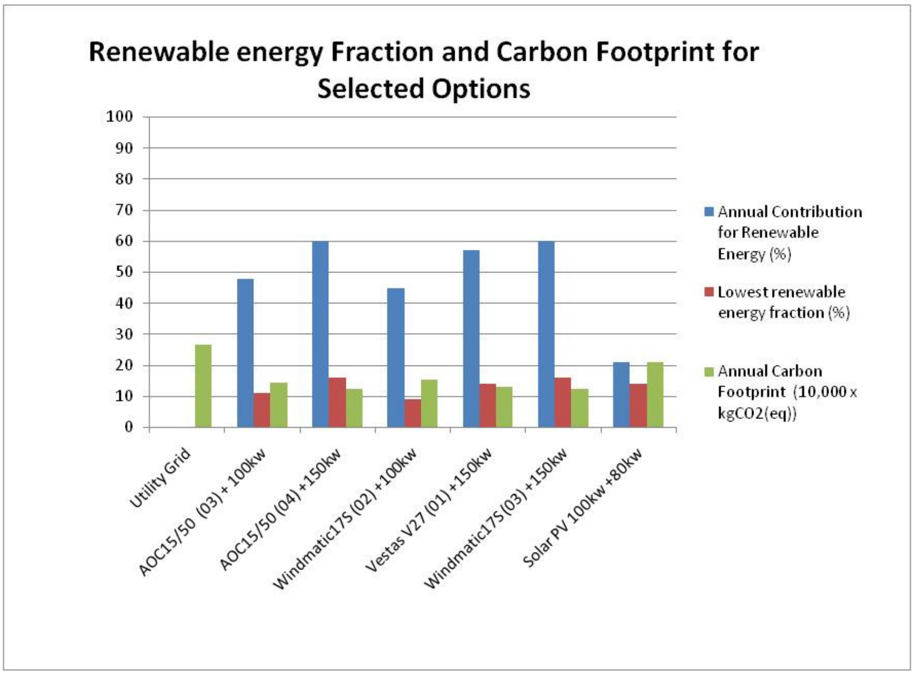


Figure 6 – 1: Renewable energy fraction and Carbon Footprint for the selected pumping options (Lowest renewable fraction considering the worst month)

The annual energy sold and annual energy savings were calculated to evaluate the energy savings that will be available for different options if implemented. For further analysis the economical feasibility of selected pumping solutions economic analyzing tools such as Internal Rate of Return (IRR) and DPP were taken into consideration so the evaluation of the options will be more accurate.

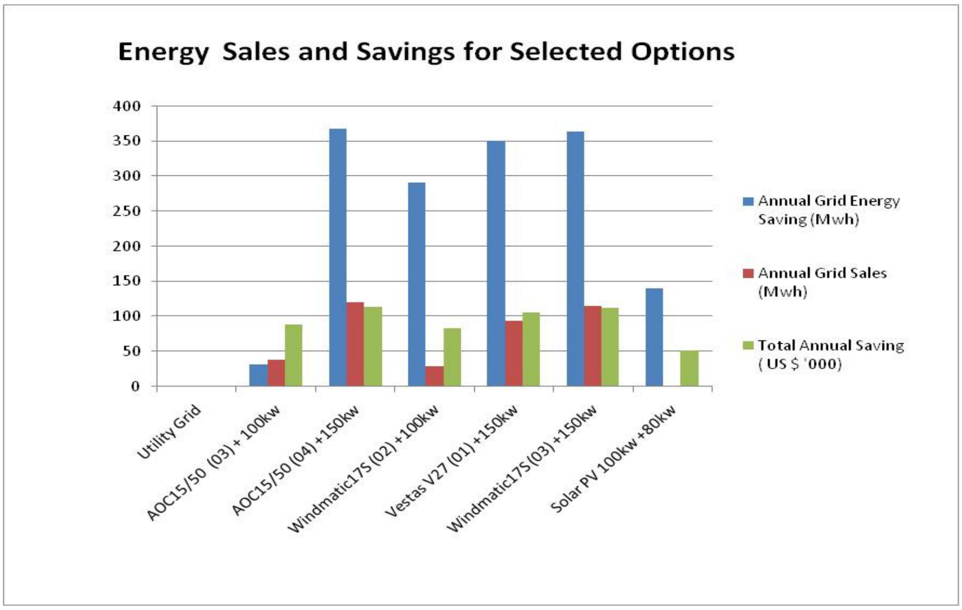


Figure 6 – 2: Annual Energy sales and savings for the selected options

For easy and more transparent analysis of most attractive sustainable energy source and configurations for this research study was tabulated considering the results using HOMER power system simulation software and financial analyzing tools.

Table 6 – 3: Selected simulation results sorted on the Environmental and Financial aspects

No.	**Solar PV/ Wind Turbine Size & no of units + Converter (kW)**	**Initial Capital Cost (US $ in Millions)**	**Annual Operating Cost (US $ in Millions)**	**NPC (US $ in Millions)**	**Coe (US $/kWh)**	**Renewable percentage**	**Annual Carbon Footprint ($kgCO_{2(eq)}$)**	**Annual Grid Energy Saving (kWh)**	**Annual Grid Sales (kWh)**	**Total Annual Saving (US $)**	**Discounted Pay Back Period (yrs/months)**	**IRR**
01	-	-	0.12	1.05	0.180	0%	265,268	-	-	-	-	-
02	AOC15/ 50 x 03 + 100	0.46	0.089	1.22	0.197	48%	144,431	312,916	38,554	88,742	6/8	17%
03	AOC15/ 50 x 04 +150	0.63	0.088	1.38	0.201	60%	123,218	367,848	120,056	113,300	6/5	15%
04	Windmatic17S x 02 +100	0.43	0.094	1.24	0.203	45%	153,119	290,419	28,704	82,919	7/6	15%
05	Vestas V27 x 01 +150	0.56	0.092	1.35	0.204	57%	130,064	350,120	93,627	105,352	7/1	16%
06	Windmatic17S x 03 +150	0.66	0.092	1.44	0.211	60%	124,598	364,274	114,411	111,640	8/1	13%
07	PV/ Grid 100 +80	0.40	0.114	1.37	0.234	21%	211,196	140,025	1,146	50,888	13/2	6%

7. DISCUSSION

Even though there are many sustainable renewable energy options such as bio-fuel energy, geothermal energy, tidal energy and ocean wave energy which were utilized in various applications around the world they cannot be considered as sustainable energy sources for this particular water pumping application considering the specific pumping requirement, location and access for available energy resources. Therefore in this research study wind energy and solar energy was considered as the most suitable sustainable energy sources that can be utilized for this water pumping of salt production industry.

When considering direct wind mill pumping and solar PV water pumping was found to be unfeasible due to its limited pumping capacity and very high investment cost. Also the requirement of large number of pumps (a total of either 79 windmill pumps or 31 solar PV pumps) have made it even more unfeasible due to its huge area of installation as well as practicability of maintaining such large no of pumping units. On the other hand water pumping through wind power electricity generation and solar PV electricity generation seems more viable at a glance.

Selection of most suitable sustainable energy source and configuration for this research study (see Table 6 – 3) was analyzed according to the simulation results using HOMER power system simulation software (HOMER 2.0 14days trial version) considering Initial capital cost, Cost of energy, Net present project cost, Annual operating cost, Renewable energy fraction, Annual grid energy sales, Annual grid energy sales and Annual carbon footprint. More over financial aspects were analyzed using discounted payback period and internal rate of return. Though the sub selection components such as Initial investment cost, NPC, Annual grid energy saving, Annual grid sales and total annual saving were illustrated under analysis they were weighted less as these components were interpret under financial and environmental analytical tools such as IRR, Discounted payback period, renewable energy fraction and annual carbon footprint saving.

100% grid utilizing will offer the lowest Cost of energy 0.18 US$/kwh but worst in terms of emissions and contradicts with the project Also wind/ grid combinations 04nos. of AOC15/50 wind turbines including 150kw converter and Vestas V27 turbine together with

150kw converter gives second and third best cost of energy values 0.201 US $/kWh and 0.203US $/ kWh respectively. Even thought total grid based electrical pumping is clearly out of our research objectives it still remained as the best configuration under cost of energy (only 0.180US $/kWh) and highlights the most common financial barrier which prevents adopting renewable energy in local industrial energy related applications. More over the solar PV/ grid combination was merely introduced to the selected list to emphasis that solar PV has to climb some distance due to its high cost of energy (0.234 US $/kWh) compared to wind powered rivals in this type of applications.

Even though the study objectives mainly focuses on promoting the local government energy targets on renewable energy utilization and green production concepts the economical feasibility has imposed some strong attitudes when introducing this kind of projects in reality as the customers of its end product are highly price sensitive. Therefore financial analytical tools such as IRR and Discounted Payback Period have some significant strength in feasibility analysis. As presented earlier (Table 6-3) wind/ grid combination of 04nos of AOC15/50 turbines and 01 unit of Vestas V27 turbine provides the best IRR values (17% and 16%) respectively. Out of the selected configurations wind/ grid combination of 03nos of remanufactured Windmatic 17S turbines displays the worst IRR rating (13%) which lead that to withdraw from the remaining four best contenders.

More over when considering the discounted payback period for the project the wind/ grid combination of 02nos of Windmatic 17S turbines revealed the worst scenario which was seven and half years out of the best four configurations. The wind/ grid combinations 04nos. of AOC15/50 wind turbines including 150kw converter was the best configuration having a moderate six years and 5months DPBP when considering the financial feasibility analysis.

Annual average renewable energy fraction and the Annual carbon footprint was considered as the most significant selection parameters and given the highest weighted merely our research study objective was to propose the most suitable energy source and methodology to be adopted for water pumping mainly considering the environmental viability. When considering the remaining best three options) wind/ grid combination of 04nos of AOC15/50 turbines and 01 unit of Vestas V27 turbine was the best two options having an annual average renewable energy fractions of 60% and 57% respectively. The wind/ grid combination of 03nos of AOC15/50 turbines just managed to contribute with a moderate 48% out of the total annual average energy requirement utilizing wind energy.

When considering the most important annual carbon footprint the wind/ grid combination of 04nos of AOC15/50 turbines with 150kw inverter was the best of all having a saving of 215.8 $tCO_{2(eq)}$. Wind/ grid combination 01 unit of Vestas V27 turbine saves 209 $tCO_{2(eq)}$ carbon foot print annually.

Contribution to Carbon Foot Print (CFP) for the research study was considered under major emission forms inherent to the concerned salt production system. They were direct GHG emission by current diesel engine water pumping and indirect emission due to consumption of grid based electricity for pumping activities in the salt production process. The annual carbon footprint for the salt production organization was a staggering 339.7 t $CO_{2(eq)}$.

IRR and Payback period calculation for this research study was done using simple excel calculation sheet and the relevant figures such as energy units generated, saved and sold for a particular power system configuration was introduced from the results of HOMER power system simulation software. Discounted interest rate was taken as 10% [34] and grid electricity unit cost was considered as 0.18 US $/ kWh [31, 32].

Cost estimations including operation & maintenance costs for PV systems and wind power systems were calculated referring “Estimating PV System Size & Cost” SECO fact sheet #24, published by State Energy Conservative Office, USA and “ Wind Energy Cost” published by National Wind Coordinating Committee Wind Energy Series #11 , USA (1997) [28].

Furthermore when calculating the initial capital cost the cost incurred for shipping/ insurance and other related national and international taxes have not been considered due to its complexity to estimate such cost components accurately for the equipment considered in this project.

8. CONCLUSION

Wind power is the most feasible sustainable energy source that could be utilized for this water pumping project considering specific pumping requirement, location and access for available energy resources.

The most technically, financially feasible and environmentally attractive sustainable water pumping methodology would be a Wind/ grid combined configuration of 04nos of model AOC15/50 (50kW manufactured by AOC Renewable Energy - Canada) wind turbine units with 150kw inverter while utilizing the already employed water pumps in the salt production process.

Following characteristics of the selected pumping configuration would enhance the performance as well as the image and recognition as an environmentally graciousness of Puttalam Salt Limited in Sri Lanka.

Table 8 – 1: Performance evaluation of the selected configuration

Configuration : Wind/ Grid Combined
Wind Turbine Model : AOC 15/ 50
Manufacturer : AOC Renewable Energy - Canada
Power Rating : 50 kW
No of Units : 04

Annual Carbon Footprint Saving	215.8 t $CO_{2(eq)}$.
Renewable percentage	60%
Cost of Energy	0.201 US $/kWh
Annual Grid Sales	120.1 MWh
Total Annual Saving	113,000 US $
Initial Capital Cost	0.46 US $ in Millions
Discounted Pay Back Period	06 years and 05months
IRR	15%

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Appendix [1] Wind Resource Data for Puttalam

1. Monthly Average Wind speed and Direction at Puttalam Station (Year 2009)
   (Source: Meteorological Department of Sri Lanka)

Month	January	February	March	April	May	June	July	August	September	October	November	December
Monthly Average Wind Speed (m/s)	4.80	4.80	4.50	4.00	9.10	9.50	9.90	9.40	9.10	7.60	5.50	5.80
Wind Direction (degree)	81	92	135	176	198	208	213	205	210	178	111	95

2. Monthly Average Wind speed and Direction at Puttalam Station (Year 2010)
   (Source: Meteorological Department of Sri Lanka)

Month	January	February	March	April	May	June	July	August	September	October	November	December
Monthly Average Wind Speed (m/s)	5.70	5.40	5.00	4.50	7.70	8.50	9.30	8.20	8.10	7.80	4.20	5.30
Wind Direction (degree)	83	90	150	175	195	212	211	208	200	209	159	108

3. Monthly Average Wind speed and Direction at Puttalam Station (Year 2011)
   (Source: Meteorological Department of Sri Lanka)

Month	January	February	March	April	May	June	July	August	September	October	November	December
Monthly Average Wind Speed (m/s)	5.40	5.10	4.90	4.40	8.20	9.60	9.80	9.40	9.00	5.70	4.50	5.30
Wind Direction (degree)	81	109	139	176	206	217	210	208	210	179	126	98

Appendix [2] Solar Insolation Data for Puttalam

1. Monthly Average Solar Insolation for Puttalam Area (Year 2009)
(Source: Meteorological Department of Sri Lanka)

Month	January	February	March	April	May	June	July	August	September	October	November	December
Monthly Average Soral Radiation (MJ/m^2)	418.35	549.15	584.65	542.37	467.53	450.27	432.72	467.85	478.93	424.45	403.44	384.59
Monthly Average Soral Radiation (kWh/m^2/day)	4.842	6.356	6.767	6.277	5.411	5.211	5.008	5.415	5.543	4.913	4.669	4.451
Clearness Index	0.53	0.652	0.656	0.599	0.526	0.516	0.493	0.524	0.538	0.498	0.505	0.5

2. Monthly Average Solar Insolation for Puttalam Area (Year 2010)
(Source: Meteorological Department of Sri Lanka)

Month	January	February	March	April	May	June	July	August	September	October	November	December
Monthly Average Soral Radiation (MJ/m^2)	435.13	558.29	567.85	539.4	507.28	482.94	488.19	514.67	420.56	413.16	391.28	355.54
Monthly Average Soral Radiation (kWh/m^2/day)	5.036	6.462	6.572	6.243	5.871	5.590	5.650	5.957	4.868	4.782	4.529	4.115
Clearness Index	0.551	0.663	0.637	0.596	0.571	0.554	0.557	0.576	0.472	0.485	0.49	0.462

3. Monthly Average Solar Insolation for Puttalam Area (Year 2011)
(Source: Meteorological Department of Sri Lanka)

Month	January	February	March	April	May	June	July	August	September	October	November	December
Monthly Average Soral Radiation (MJ/m^2)	405.19	349.28	509.27	526.16	474.68	459.52	445.97	460.96	536.92	453.03	413.64	382.38
Monthly Average Soral Radiation (kWh/m^2/day)	4.690	4.043	5.894	6.090	5.494	5.319	5.162	5.335	6.214	5.243	4.788	4.426
Clearness Index	0.513	0.415	0.572	0.581	0.534	0.527	0.509	0.516	0.603	0.531	0.518	0.497

Appendix [3] Calculation for Pump Power

Specimen calculation to get the actual pump power of the Boat Channel centrifugal pump.

$P_{(actual)} = P_{(hydraulic)} / (\eta_{(drive)} \times \eta_{(pump)})$ Eq. 1

Where: $P_{(hydraulic)} = Q \times \rho \times g \times h / (3.6 \times 10^6)$

$P_{(actual)}$ – Actual electrical pumping power (kW)

$P_{(hydraulic)}$ – Hydraulic power

$\eta_{(drive)}$ – Drive efficiency

$\eta_{(pump)}$ – Pump efficiency

Q – Flow rate (m^3/ h)

ρ – Density of liquid (kg/m^3)

g – Gravitational force (m/s^2)

h – Differential head (m)

$Q = 5\ m^3/\ min$, $\rho = 1030\ kg/m^3$ for sea water, $h = 5m$
(Approximate elevation difference is nearly 2 m at site)
$g = 9.81\ m/s^2$, $\eta_{(pump)} = 0.6$, $\eta_{(drive)} = 0.7$

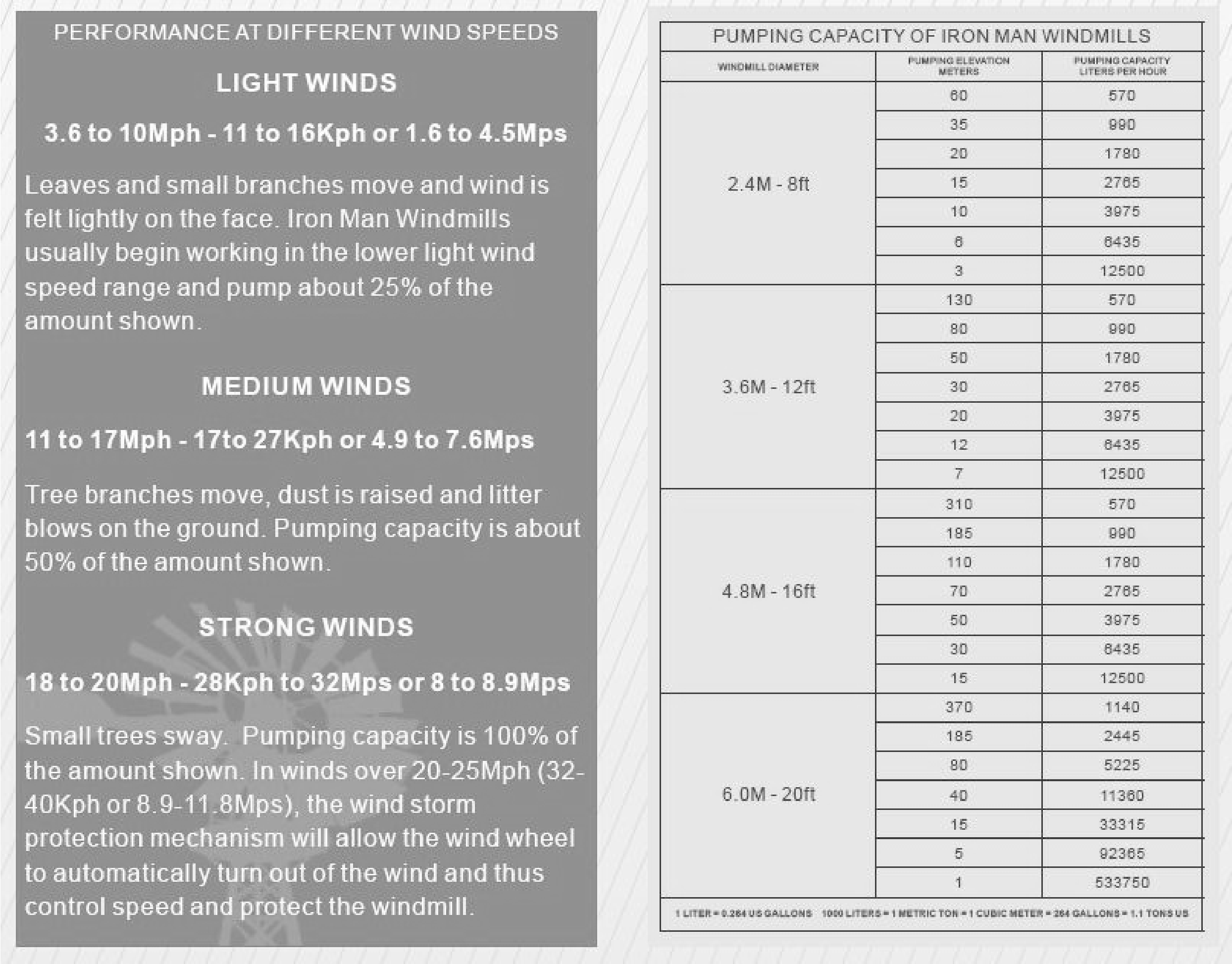
Applying the data on Eq.1 the actual pumping power can b calculated.
$P_{(actual)} = 5 \times 60 \times 1030 \times 5 \times 9.81 / (3.6 \times 10^6)$ kW = 10.02 kW ≈ 10kW

Table: Each pumping power requirement according to the above calculations

Location	No of Pumps	Type	Flow rate (m^3/ min)	Rated Power (kW)	Actual Maximum power required (kW)
Boat Channel	03	Centrifugal / Electrical	5.0	30.0	10
Boat Channel	02	Submersible / Electrical	2.8	11.0	4.9
Combumune	03	Centrifugal / Electrical	4.2	22.5	7.9
Combumune	02	Submersible / Electrical	2.8	11.0	5.2
C – Area	02	Centrifugal / Electrical	3.0	18.5	6.1
C – Area	03	Centrifugal / Electrical	1.8	11.0	3.8
Mobile Pumping	05	Centrifugal/ Diesel	1.0	11.0	2.1

Appendix [4] Windmill Pump Data Sheets

1. Ironman windmill pumps performance sheet
   Source: IRONMAN WINDMILL Co.



PERFORMANCE AT DIFFERENT WIND SPEEDS

LIGHT WINDS

3.6 to 10Mph - 11 to 16Kph or 1.6 to 4.5Mps

Leaves and small branches move and wind is felt lightly on the face. Iron Man Windmills usually begin working in the lower light wind speed range and pump about 25% of the amount shown.

MEDIUM WINDS

11 to 17Mph - 17to 27Kph or 4.9 to 7.6Mps

Tree branches move, dust is raised and litter blows on the ground. Pumping capacity is about 50% of the amount shown.

STRONG WINDS

18 to 20Mph - 28Kph to 32Mps or 8 to 8.9Mps

Small trees sway. Pumping capacity is 100% of the amount shown. In winds over 20-25Mph (32-40Kph or 8.9-11.8Mps), the wind storm protection mechanism will allow the wind wheel to automatically turn out of the wind and thus control speed and protect the windmill.

PUMPING CAPACITY OF IRON MAN WINDMILLS

WINDMILL DIAMETER	PUMPING ELEVATION METERS	PUMPING CAPACITY LITERS PER HOUR
2.4M - 8ft	60	570
	35	990
	20	1780
	15	2765
	10	3975
	6	6435
	3	12500
3.6M - 12ft	130	570
	80	990
	50	1780
	30	2765
	20	3975
	12	6435
	7	12500
4.8M - 16ft	310	570
	185	990
	110	1780
	70	2765
	50	3975
	30	6435
	15	12500
6.0M - 20ft	370	1140
	185	2445
	80	5225
	40	11360
	15	33315
	5	92365
	1	533750

1 LITER = 0.264 US GALLONS 1000 LITERS = 1 METRIC TON = 1 CUBIC METER = 264 GALLONS = 1.1 TONS US

2. Aeromotor windmill pump performance sheet
   Source: Aermotor Windmill Co.

Size of Cylinder, Inches	**Capacity per Hour, Gallons**		**Elevation in Feet to Which Water Can Be Raised**					
			Size of Aermotor Windmill					
	X (6')	**A (8')-F(16')**	**X (6')**	**A (8')**	**B (10')**	**D (12')**	**E (14')**	**F (16')**
1 7/8"	125	180	120	175	260	390	560	920
2"	130	190	95	140	215	320	460	750
2 1/4"	180	260	77	112	170	250	360	590
2 1/2"	225	325	65	94	140	210	300	490
2 3/4"	265	385	56	80	120	180	260	425
3"	320	470	47	68	100	155	220	360
3 1/2"	440	640	35	50	76	115	160	265
3 3/4"		730			65	98	143	230
4"	570	830	27	37	58	86	125	200
5"	900	1300	17	25	37	55	80	130
6"		1875		17	25	38	55	85

3. Aeromotor windmill pump price list
   Source: Aermotor Windmill Co.

Aermotor Complete Windmills (For 4 Post Towers)

(Complete Windmills do not include a tower or stub tower)

Wheel Diameter (Feet)		**Strokes (inches)**	**Price**	**Weight (Pounds)**
X	(6')	5" & 3 3/4"	$2,880.00	200
A	(8')	7 1/8" & 5 1/2"	$2,980.00	350
B	(10')	9 1/4" & 7 1/4"	$4,350.00	640
D	(12')	11 1/2" & 8 1/4"	$7,320.00	1090
E	(14')	13 1/2" & 9 3/4"	$10,550.00	1735
F	(16')	14 7/8" & 11 3/8"	$13,820.00	2380

* PRICES SUBJECT TO CHANGE WITHOUT NOTICE. PRICES DO NOT INCLUDE SHIPPING.

Appendix [5] Specimen Calculation for Lorentz PS4000C unit

Specimen calculation for Lorentz PS4000C unit integrated with PV array and battery bank. Cost for PV array/ Battery bank/ inverter and other switch/fuse & wiring were calculated according to the world market prices and solar PV cost estimation thumb rules. Cost of PV array is approximately 5$ per watt and 1$ per amp hour for the battery bank [19, 20]. Also the cost of inverter is approximately 1 $ per rated watt [19, 20] and for other system components such as switch/ fuse/ wire etc will cost nearly 20% of the sub total [19, 20].

Lorentz PS4000C unit

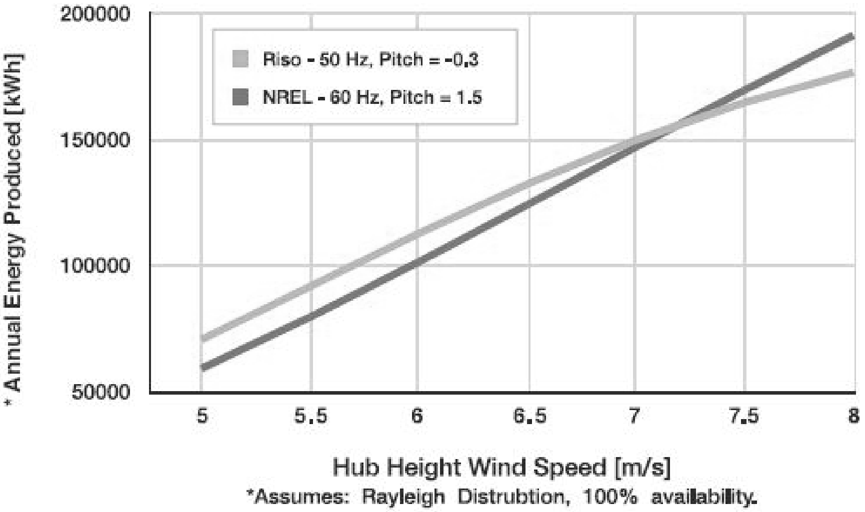
PV array size = 3000W
Size of battery bank = 3000 x 16 x 5/12
= 20,000Ah (Consider the battery cyclic discharge as 20% and
running hours of the pump as 16 hrs)

Cost of Pump & controller = 4,600 $
Cost of PV array = 3000 x 5 = 15,000$
Cost of battery bank = 20000 x 1 = 20,000$
Cost of inverter = 3000 x x1 = 3,000$
Sub Total = 4,600+15,000+20,000+3,000 = 42,600$
Cost of system components (Breaker/ Fuses/ Lightning arrests/ wiring & labour)
= 2% of the total equipment cost
= 42,600 x 0.2 = 8,520$

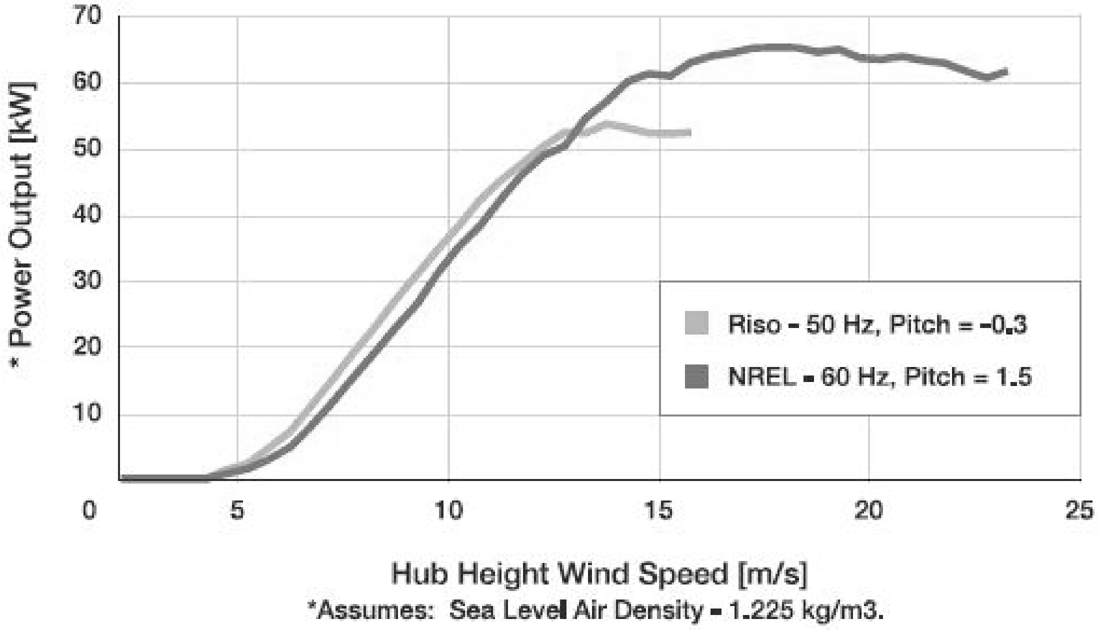
Total cost = 42600+8520 = 51,120$

Appendix [6] Wind Turbine Data Sheet

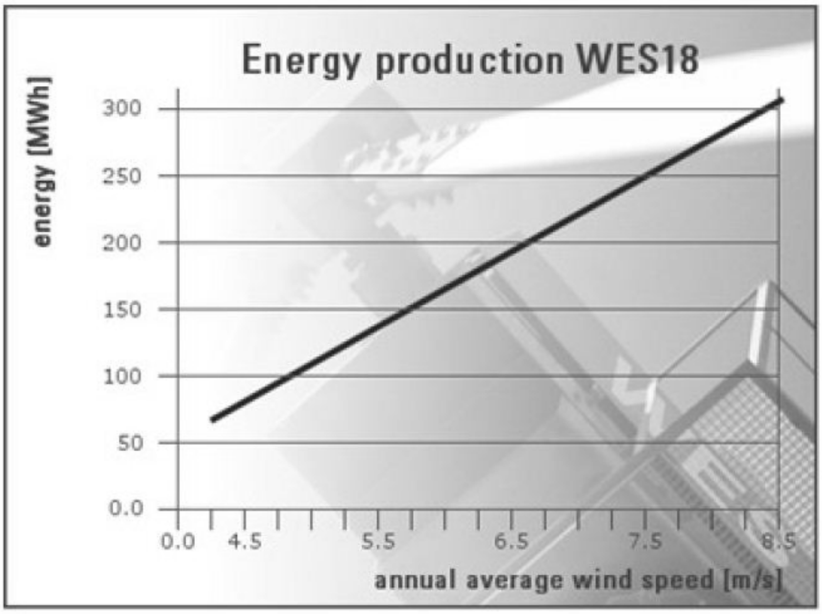
1. AOC 15/50 wind turbine Annual Energy Output
   Source: Seaforth Energy



2. AOC 15/50 wind turbine Power Curve
   Source: Seaforth Energy

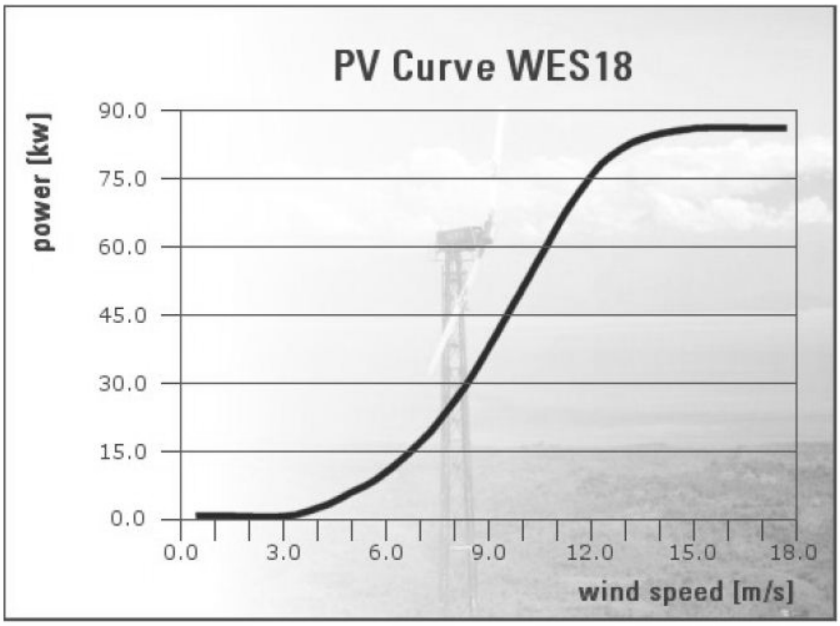


3. WES 18 wind turbine Annual Energy Production
   Source: Wind Energy Solutions



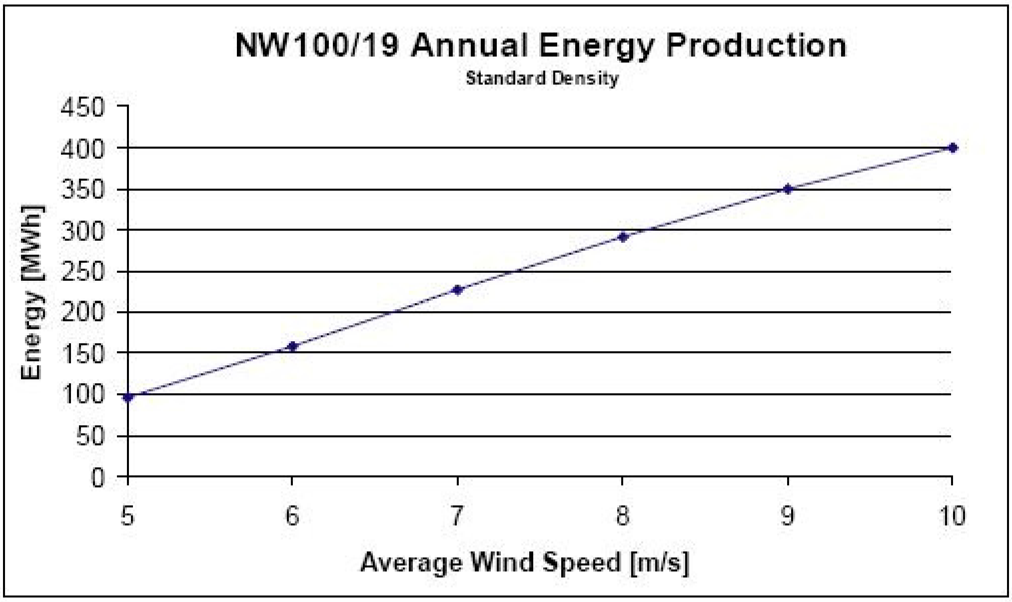
Wind speed [m / s]	Energy [MWh]
4	52
5	102
6	161
7	224
8	284
9	341
more than 9	more than 341

4. WES 18 wind turbine Power Curve
   Source: Wind Energy Solutions

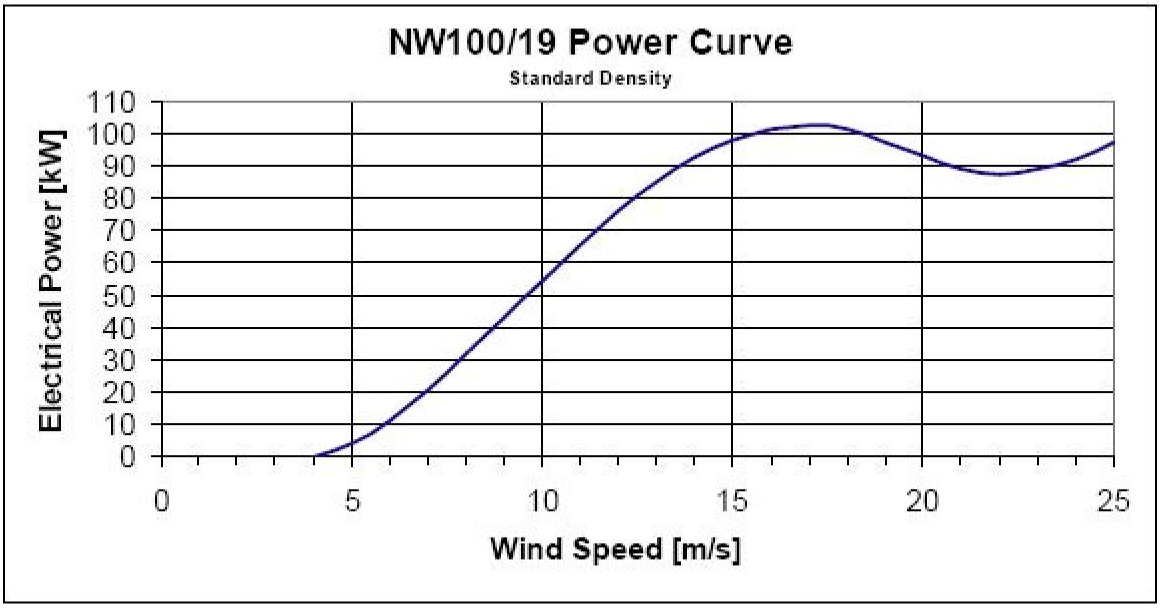


Wind speed [m / s]	Power [kW]
2,7	cut - in
3	0,8
4	2,9
5	6
6	11
7	17,7
8	27,7
9	39,2
10	51,4
11	63,8
12	74,2
13	79,9
14	82,2
15 - 25	83

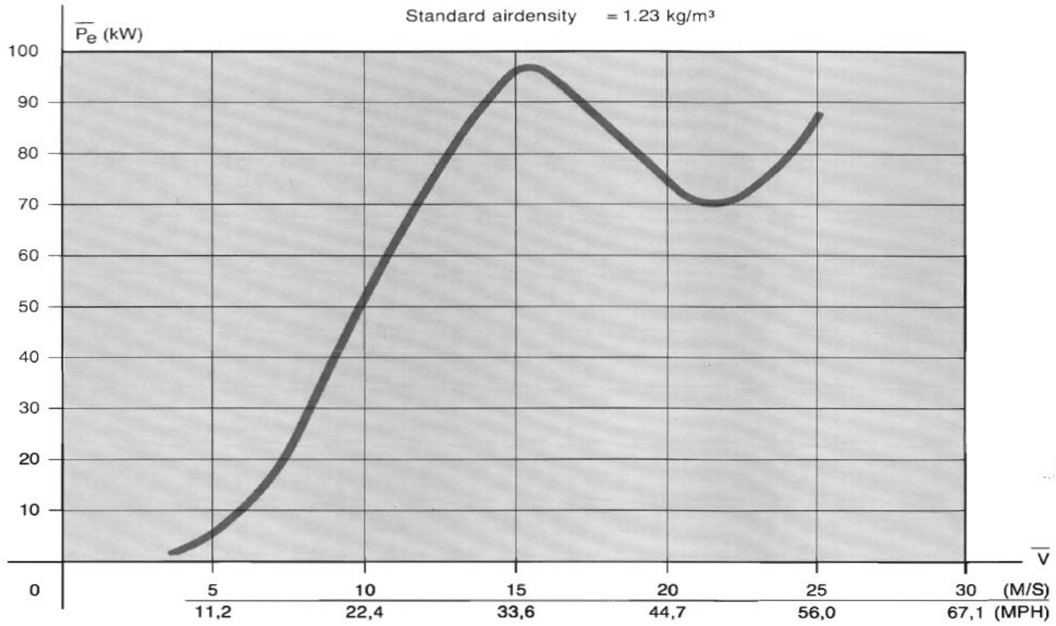
5. NW100 wind turbine Annual Energy Production
   Source: Northern Power



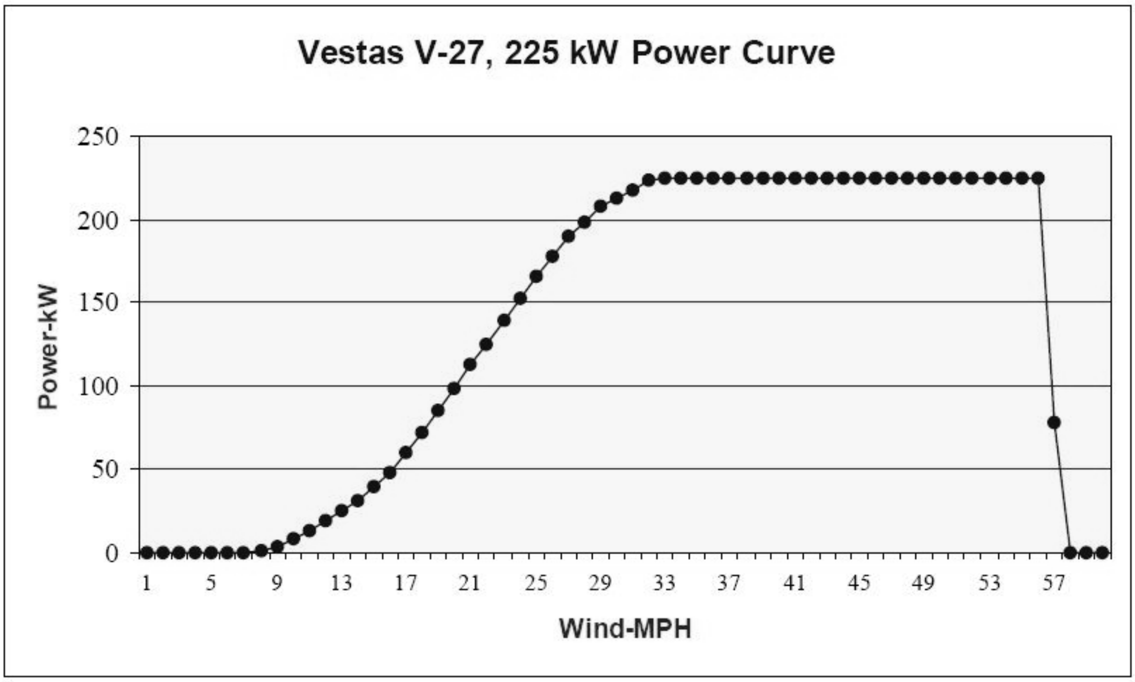
6. NW100 wind turbine Power Curve
   Source: Northern Power

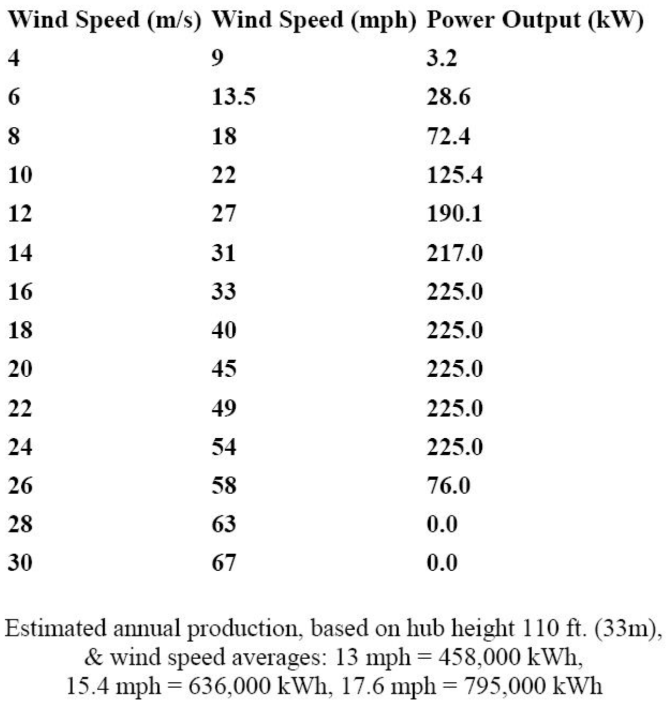


7. Remanufactured Windmatic WM 17S wind turbine Power curve
   Source: Repowering Solutions, Spain



8. Remanufactured Vestas V27 wind turbine Power Curve
   Source: Repowering Solutions, Spain



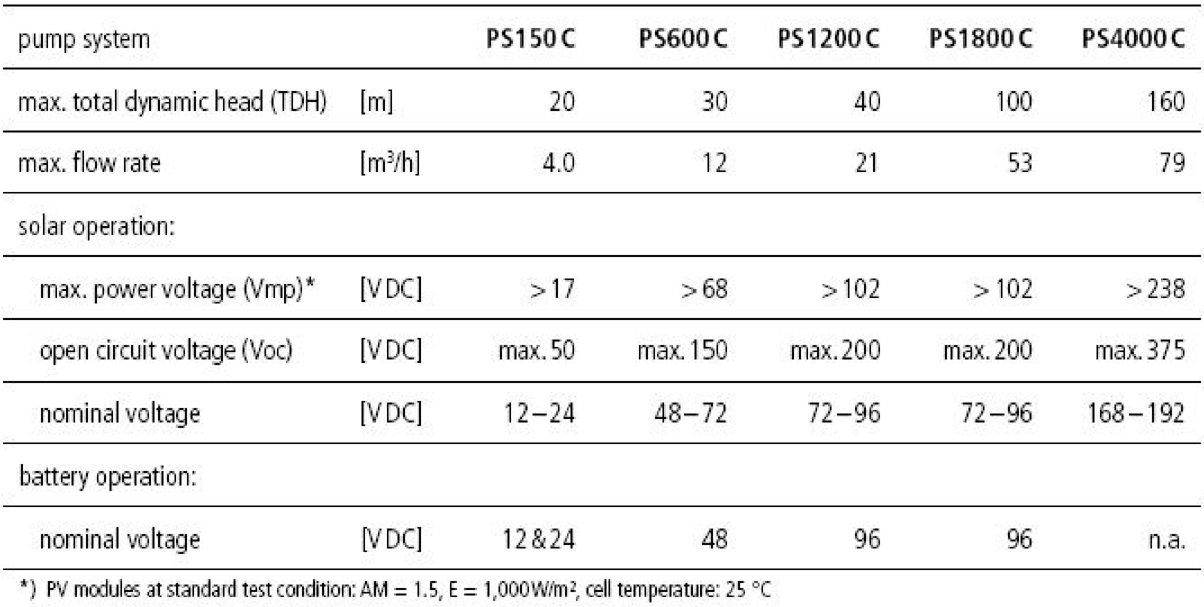


Wind Speed (m/s)	Wind Speed (mph)	Power Output (kW)
4	9	3.2
6	13.5	28.6
8	18	72.4
10	22	125.4
12	27	190.1
14	31	217.0
16	33	225.0
18	40	225.0
20	45	225.0
22	49	225.0
24	54	225.0
26	58	76.0
28	63	0.0
30	67	0.0

Estimated annual production, based on hub height 110 ft. (33m),
& wind speed averages: 13 mph = 458,000 kWh,
15.4 mph = 636,000 kWh, 17.6 mph = 795,000 kWh

Appendix [7] Direct Solar Water Pump Data Sheets

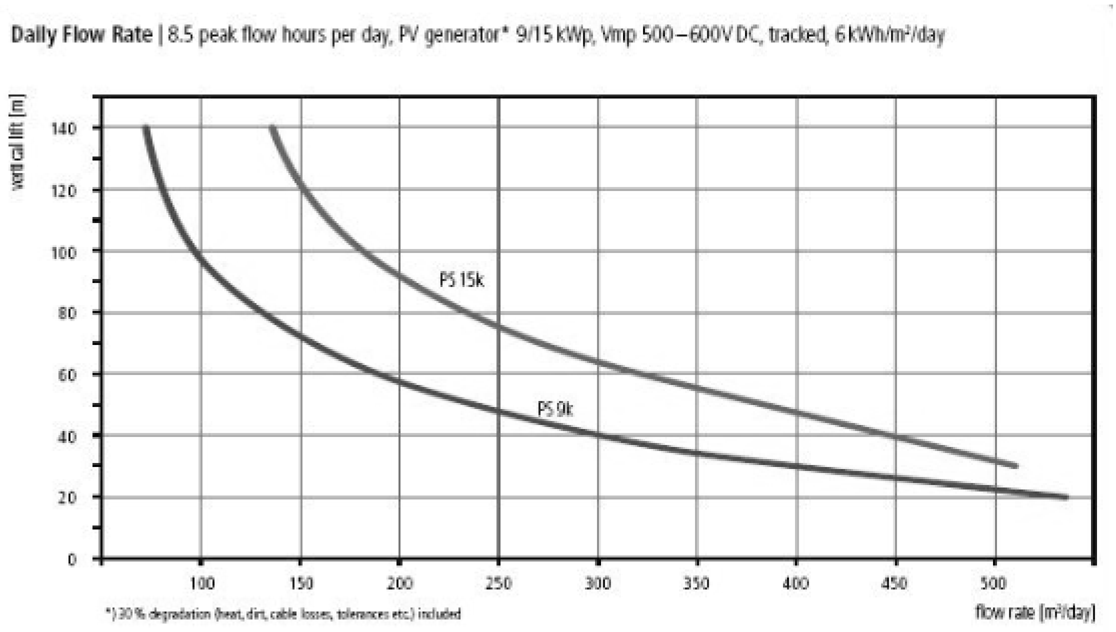
1. Lorentz PS4000C Data Sheet
   Source: Bernt Lorentz GmbH & Co.



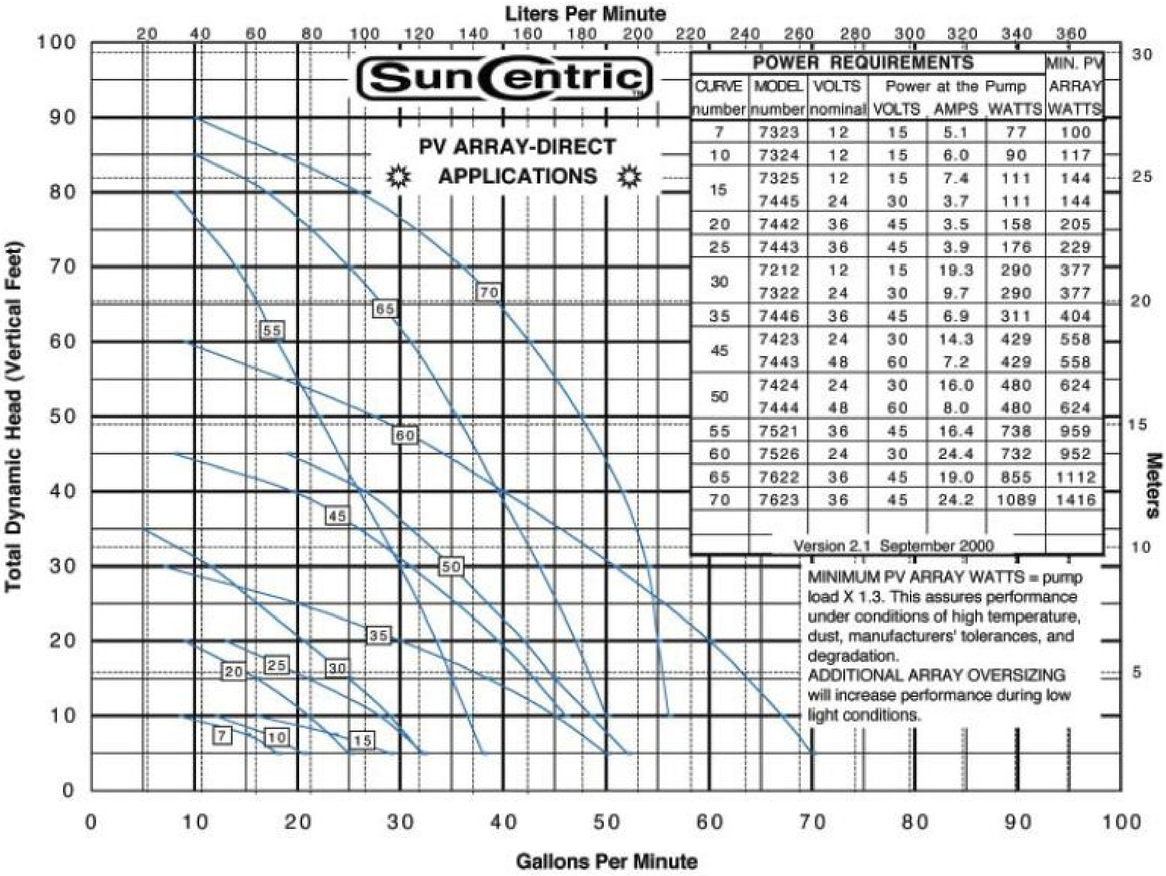
pump system		PS150 C	PS600 C	PS1200 C	PS1800 C	PS4000 C
max. total dynamic head (TDH)	[m]	20	30	40	100	160
max. flow rate	[m³/h]	4.0	12	21	53	79
solar operation:						
max. power voltage (Vmp)*	[V DC]	> 17	> 68	> 102	> 102	> 238
open circuit voltage (Voc)	[V DC]	max. 50	max. 150	max. 200	max. 200	max. 375
nominal voltage	[V DC]	12 – 24	48 – 72	72 – 96	72 – 96	168 – 192
battery operation:						
nominal voltage	[V DC]	12 & 24	48	96	96	n.a.

*) PV modules at standard test condition: AM = 1.5, E = 1,000 W/m², cell temperature: 25 °C

2. Lorentz PS9K Performance Curve
   Source: Bernt Lorentz GmbH & Co.



3. Dankoff SunCentric 7526 Performance Curve
   Source: Dankoff Solar water pumps



POWER REQUIREMENTS						MIN. PV
CURVE number	MODEL number	VOLTS nominal	Power at the Pump			ARRAY WATTS
			VOLTS	AMPS	WATTS	
7	7323	12	15	5.1	77	100
10	7324	12	15	6.0	90	117
15	7325	12	15	7.4	111	144
	7445	24	30	3.7	111	144
20	7442	36	45	3.5	158	205
25	7443	36	45	3.9	176	229
30	7212	12	15	19.3	290	377
	7322	24	30	9.7	290	377
35	7446	36	45	6.9	311	404
45	7423	24	30	14.3	429	558
	7443	48	60	7.2	429	558
50	7424	24	30	16.0	480	624
	7444	48	60	8.0	480	624
55	7521	36	45	16.4	738	959
60	7526	24	30	24.4	732	952
65	7622	36	45	19.0	855	1112
70	7623	36	45	24.2	1089	1416

Version 2.1 September 2000

MINIMUM PV ARRAY WATTS = pump load X 1.3. This assures performance under conditions of high temperature, dust, manufacturers' tolerances, and degradation.
ADDITIONAL ARRAY OVERSIZING will increase performance during low light conditions.

Appendix [8] Emission Factors and Global Warming Potential of GHGs

1. Fuel Emission Factors for Stationary IC Engines
   Source: Energy Information Administration Report – 2011 (EIA – 1605)

Fuel	Emission Factor	Units
Coal[2]		
Anthracite	103.69	kg CO_2 / MMBtu
Bituminous	93.28	kg CO_2 / MMBtu
Sub-bituminous	97.17	kg CO_2 / MMBtu
Lignite	97.72	kg CO_2 / MMBtu
Electric Power Sector	95.52	kg CO_2 / MMBtu
Industrial Coking	93.71	kg CO_2 / MMBtu
Other Industrial	93.98	kg CO_2 / MMBtu
Residential/Commercial	95.35	kg CO_2 / MMBtu
Natural Gas[3]		
Pipeline Natural Gas		
HHV of 975 - 1000 Btu/scf	54.01	kg CO_2 / MMBtu
	5.401	kg CO_2 / therm
HHV of 1000 - 1025 Btu/scf	52.91	kg CO_2 / MMBtu
	5.291	kg CO_2 / therm
HHV of 1025 - 1050 Btu/scf	53.06	kg CO_2 / MMBtu
	5.306	kg CO_2 / therm
HHV of 1050 - 1075 Btu/scf	53.46	kg CO_2 / MMBtu
	5.346	kg CO_2 / therm
HHV of 1075 - 1100 Btu/scf	53.72	kg CO_2 / MMBtu
	5.372	kg CO_2 / therm
Weighted National Average (1029 Btu/scf)	53.06	kg CO_2 / MMBtu
	5.306	kg CO_2 / therm
Flared Natural Gas	54.71	kg CO_2 / MMBtu
	5.471	kg CO_2 / therm
Petroleum Fuels[3]		
Middle Distillate Fuels (No. 1, No. 2, No. 4 fuel oil, diesel, home heating oil)	73.15	kg CO_2 / MMBtu
	10.15	kg CO_2 / gallon
Jet Fuel (Jet A, JP-8)	70.88	kg CO_2 / MMBtu
	9.57	kg CO_2 / gallon
Kerosene	72.31	kg CO_2 / MMBtu
	9.76	kg CO_2 / gallon
Heavy Fuel Oil (No. 5, 6 fuel oil), bunker fuel	78.80	kg CO_2 / MMBtu
	11.80	kg CO_2 / gallon
Ethane	59.59	kg CO_2 / MMBtu
	4.14	kg CO_2 / gallon
Propane	63.07	kg CO_2 / MMBtu
	5.74	kg CO_2 / gallon
Isobutane	65.07	kg CO_2 / MMBtu
	6.45	kg CO_2 / gallon

n-Butane	64.95	kg CO_2 / MMBtu
	6.69	kg CO_2 / gallon
Unspecified LPG	62.28	kg CO_2 / MMBtu
	-	kg CO_2 / gallon
Refinery (Still) Gas	64.20	kg CO_2 / MMBtu
	9.17	kg CO_2 / gallon
Crude Oil	74.54	kg CO_2 / MMBtu
	10.29	kg CO_2 / gallon
Petroleum Coke	102.12	kg CO_2 / MMBtu
	14.65	kg CO_2 / gallon
Other Fuels		
Tires/Tire Derived Fuel[4]	85.97	kg CO_2 / MMBtu
Waste Oil[5,6]	9.98	kg CO_2 / gallon
Waste Oil Blended with Residual Fuel Oil[5]	66.53	kg CO_2 / MMBtu
Waste Oil Blended with Distillate Fuel Oil[5]	71.28	kg CO_2 / MMBtu
Municipal Solid Waste (MSW)[7,8]	417.04	kg CO_2 / short ton MSW
Municipal Solid Waste (MSW)[7,8]	41.70	kg CO_2 / MMBtu MSW
Plastics Portion of MSW7	2,617.50	kg CO_2 / short ton plastics

[1] All factors assume 100 percent combustion except those for MSW, which assume 98 percent combustion.

[2] U. S. Energy Information Administration, Documentation for Emissions of Greenhouse Gases in the United States 2008, DOE/EIA-0638 (2006), October 2008,Table 6-2, p. 183.

[3] Energy Information Administration, Documentation for Emissions of Greenhouse Gases in the United States 2005, DOE/EIA-0638 (2005), October 2007, Tables 6-1, 6-2, 6-4, and 6-5.

[4] U.S. Department of Energy, Technical Guidelines Voluntary Reporting of Greenhouse Gases (1605(b)) Program, Chapter 1, Part C, Stationary Source Combustion, January 2007.

[5] U.S. EPA, AP 42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s11.pdf.

[6] To convert to an energy basis (kg/MMBtu), divide by the heating value of the oil in units of MMBtu/gal, if known. If the heating value is not known, use the default values below depending on whether the waste oil is blended with residual or distillate fuel oil.

2. Methane and Nitrous Oxide Emission Factors for Stationary IC Engines Source: Energy Information Administration Report – 2011 (EIA – 1605)

Source	**Methane (g /MMBtu)**	**Nitrous Oxide (g/MMBtu)**
Coal		
Residential	301	1.5
Commercial	10	1.5
Industry	10	1.5
Electricity Generation	1	1.5
Petroleum		
Residential	10	0.6
Commercial	10	0.6
Industry	3	0.6
Electricity Generation	3	0.6
Natural Gas		
Residential	5	0.1
Commercial	5	0.1

Industry	1	0.1
Electricity Generation	1	0.1
Wood		
Residential	253	3.2
Commercial	253	3.2
Industry	25	3.2
Electricity Generation	25	3.2

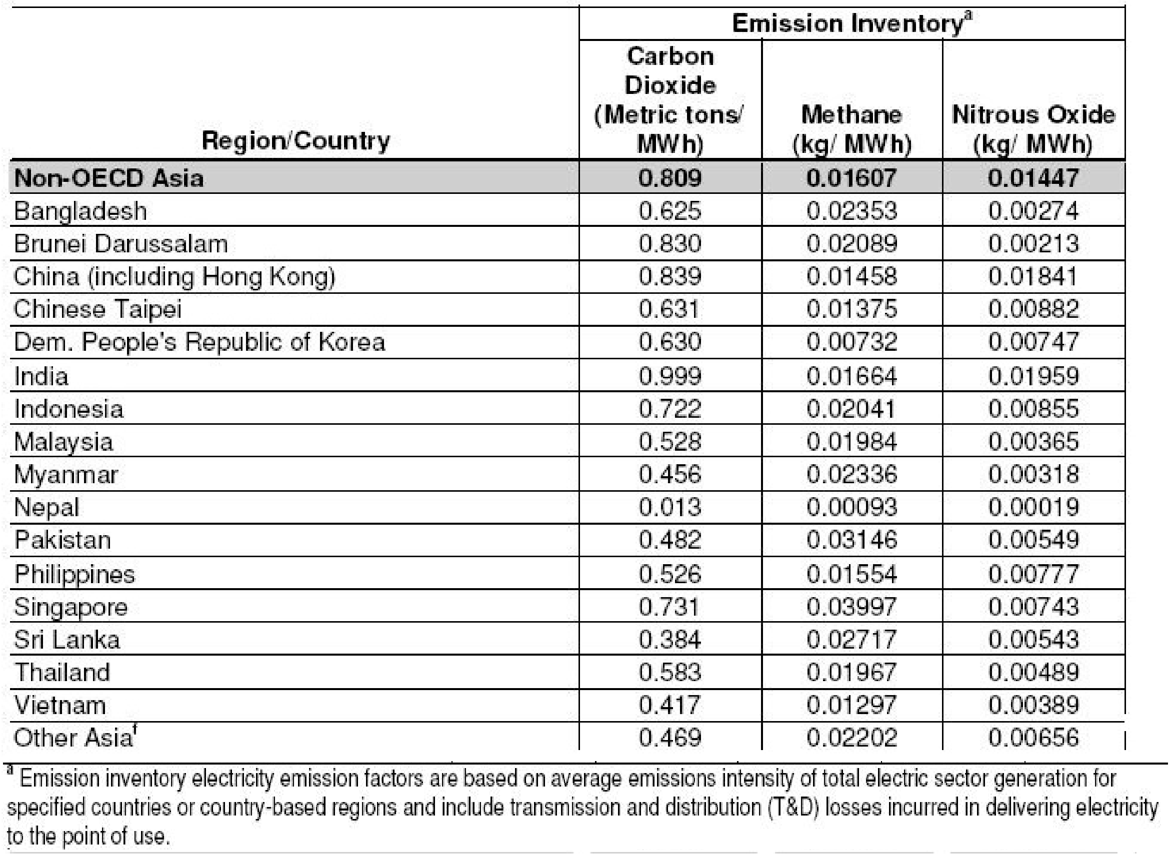
Source: Intergovernmental Panel on Climate Change (IPCC), 2006 IPCC Guidelines for National Greenhouse Gas Inventories, pp. 2.16 - 2.23, Tables 2.2, 2.3, 2.4 and 2.5 (Revised April 2007).

Note: Energy units are in higher heating value (HHV). Lower heating value (LHV) assumed to be 5 percent lower than HHV for coal and petroleum, 10 percent lower for natural gas, and 20 percent lower for wood.

3. Indirect Emission Factors for Grid based Electricity – Sri Lanka

Source: Voluntary Reporting of Greenhouse Gases, Energy Information Administration Report

– 2007 (EIA – 1605)



Region/Country	Emission Inventory[a]		
	Carbon Dioxide (Metric tons/ MWh)	Methane (kg/ MWh)	Nitrous Oxide (kg/ MWh)
Non-OECD Asia	**0.809**	**0.01607**	**0.01447**
Bangladesh	0.625	0.02353	0.00274
Brunei Darussalam	0.830	0.02089	0.00213
China (including Hong Kong)	0.839	0.01458	0.01841
Chinese Taipei	0.631	0.01375	0.00882
Dem. People's Republic of Korea	0.630	0.00732	0.00747
India	0.999	0.01664	0.01959
Indonesia	0.722	0.02041	0.00855
Malaysia	0.528	0.01984	0.00365
Myanmar	0.456	0.02336	0.00318
Nepal	0.013	0.00093	0.00019
Pakistan	0.482	0.03146	0.00549
Philippines	0.526	0.01554	0.00777
Singapore	0.731	0.03997	0.00743
Sri Lanka	0.384	0.02717	0.00543
Thailand	0.583	0.01967	0.00489
Vietnam	0.417	0.01297	0.00389
Other Asia[f]	0.469	0.02202	0.00656

[a] Emission inventory electricity emission factors are based on average emissions intensity of total electric sector generation for specified countries or country-based regions and include transmission and distribution (T&D) losses incurred in delivering electricity to the point of use.

4. Indirect Emission Factors for Grid based Electricity – Sri Lanka
Source: Energy Information Administration Report – 2011 (EIA – 1605)

GREENHOUSE GAS NAME	GREENHOUSE GAS CODE	FORMULA	GWP	
			TAR[1]	AR4[2]
(1) Carbon Dioxide	CO2	CO_2	1	1
(2) Methane	CH4	CH_4	23	25
(3) Nitrous Oxide	N2O	N_2O	296	298
(4) Hydroflourocarbons				
HFC-23 (trifluoromethane)	15	CHF_3	12000	14800
HFC-32 (difluoromethane)	16	CH_2F_2	550	675
HFC-41 (monofluoromethane)	43	CH_3F	97	92
HFC-125 (pentafluoroethane)	17	CHF_2CF_3	3400	3500
HFC-134 (1,1,2,2-tetrafluoroethane)	44	CHF_2CHF_2	1100	1100
HFC-134a (1,1,1,2-tetrafluoroethane)	18	CH_2FCF_3	1300	1430
HFC-143 (1,1,2-trifluorethane)	45	CHF_2CH_2F	330	353
HFC-143a (1,1,1-trifluoroethane)	46	CF_3CH_3	4300	4470
HFC-152 (1,2-difluorethane)	47	CH_2FCH_2F	43	53
HFC-152a (1,1-difluoroethane)	19	CH_3CHF_2	120	124
HFC-161 (ethyl fluoride)	48	CH_3CH_2F	12	12
HFC-227ea (heptafluoropropane)	20	CF_3CHFCF_3	3500	3220
HFC-236cb (1,1,1,2,2,3-hexafluoropropane)	49	$CH_2FCF_2CF_3$	1300	1340
HFC-236ea (1,1,1,2,3,3-hexafluoropropane)	50	CHF_2CHFCF_3	1200	1370
HFC-236fa (1,1,1,3,3,3-hexafluoropropane)	41	$CF_3CH_2CF_3$	9400	9810
HFC-245ca (1,1,2,2,3-pentafluoropropane)	21	$CH_2FCF_2CHF_2$	640	693
HFC-245fa (1,1,1,3,3-pentafluoropropane)	51	$CHF_2CH_2CF_3$	950	1030
HFC-365mfc (pentafluorobutane)	52	$CF_3CH_2CF_2CH_3$	890	794
HFC-43-10mee (decafluoropentane)	53	$CF_3CHFCHFCF_2CF_3$	1500	1640
(5) Perfluorcarbons				
PFC-14 (perfluoromethane)	22	CF_4	5700	7390
PFC-116 (perfluoroethane)	23	C_2F_6	11900	12200
PFC-218 (perfluoropropane)	42	C_3F_8	8600	8830
PFC 3-1-10 (perfluorobutane)	30	C_4F_{10}	8600	8860
PFC-318 (perfluorocyclobutane)	54	$c\text{-}C_4F_8$	10000	10300
PFC- 4-1-12 (perfluoropentane)	51	C_5F_{12}	8900	9160
PFC 5-1-14 (perfluorohexane)	31	C_6F_{14}	9000	9300
(6) Sulfur Hexafluoride	SF6	SF_6	22200	22800
(7) Chlorofluorocarbons[3]				
CFC-11 (trichlorofluoromethane)	1	CCl_3F	-	-
CFC-12 (dichlorodifluoromethane)	2	CCl_2F_2	-	-
CFC-13 (monochlorotrifluoromethane)	56	$CClF_3$	-	-
CFC-113 (Freon 113)	3	CCl_2FCClF_2	-	-
CFC-114 (dichlorotetrafluoroethane)	4	$CClF_2CClF_2$	-	-
CFC-115 (monochloropentafluoroethane)	5	CF_3CClF_2	-	-
(8) Other Gases				
Nitrogen Trifluoride	NF3	NF_3	10800	17200

[1] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001). This document was part of the Intergovernmental Panel on Climate Change's (IPCC's) Third Assessment Report (TAR).

[2] The IPCC developed revised GWPs for the Fourth Assessment Report (AR4). A complete list of revised GWPs were published in the errata to Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp., (http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-

[3] The reporting of CFC emissions on Form EIA-1605 is optional. CFC emissions cannot be included in total inventory emissions since reliable net global warming potentials are not available for these gases. Reductions in CFC emissions may be *reported but not registered*.

Appendix [9] Calculation for Direct Carbon footprint for Diesel fuel consumption

Calculation of direct carbon footprints can be done as follows.

Carbon footprint = $[(W_{CO_2} \times GWP_{CO_2}) + (W_{CH_4} \times GWP_{CH_4}) + (W_{N_2O} \times GWP_{N_2O})] \times (V_{diesel})$ Eq. 2

W_{CO_2} Weight of CO_2 emitted for 1L of diesel fuel for stationary diesel engines

W_{CH_4} Weight of CH_4 emitted for 1L of diesel fuel for stationary diesel engines

W_{N_2O} Weight of N_2O emitted for 1L of diesel fuel for stationary diesel engines

GWP_{CO_2} Global Warming Potential for CO_2

GWP_{CH_4}` Global Warming Potential for CH_4

GWP_{N_2O} Global Warming Potential for N_2O

V_{diesel} Quantity of diesel fuel consumed

Annual diesel consumption (V_{diesel}) = 33,000 L

Emission factors for diesel fuel

W_{CO_2}= 2.697 kg (CO_2)/L	W_{CH_4} = 3.80 x 10^{-4}kg (CH_4)/L	W_{N_2O} = 5.82 x 10^{-5}kg (NO_2)/L
GWP_{CO_2}= 1 $CO_{2(eq)}$	GWP_{CH_4}= 25 $CO_{2(eq)}$	GWP_{N_2O} = 298 $CO_{2(eq)}$

Annual Carbon footprint due to diesel engine water pumping can be calculated applying above data in to equation (2)

$$= [(2.697 \times 1) + (3.80 \times 10^{-4} \times 25) + (5.82 \times 10^{-5} \times 298)] \times 33{,}000$$

$$= 89.8\ t\ CO_{2(eq)}$$

Appendix [10] IRR and Payback Calculations

1. AOC 15/50 x 03 units (100kW inverter)

Internal rate of returen and Discounted Payback Period Calculation				
AOC 15/50 x 03 units and 100kw inverter				
Energy require if Total Grid	686,930.00			
Unit Purchased from Grid	374,014.00			
units saved	312,916.00			
Saving in US$	56,324.88			
Units Sold	38,554.00			
Earning on units sold US$	6,939.72			
Diesel Saving in US$	25,476.92			
Total Annual Cash in flow US$	88,741.52			
Capital expenditure	460,000.00			
Discount rate	0.10			
Project Life	20 yrs			
Year	Annual Cash Flow	Discounted Cash flow		
0	-460,000.00			
1	88,741.52	88741.52	88741.52	
2	88,741.52	80674.11	169415.63	
3	88,741.52	73340.10	242755.73	
4	88,741.52	66672.82	309428.55	
5	88,741.52	60611.65	370040.20	
6	88,741.52	55101.50	425141.70	
7	88,741.52	50092.27	475233.97	**(Break even point)**
8	88,741.52	45538.43	520772.41	
9	88,741.52	41398.57	562170.98	
10	88,741.52	37635.07	599806.05	
11	88,741.52	34213.70	634019.74	
12	88,741.52	31103.36		
13	88,741.52			
14	88,741.52			
15	-371,258.48			
16	88,741.52			
17	88,741.52			
18	88,741.52			
19	88,741.52			
IRR	17%			
Pay Back Period (Discounted cash Flow)		6 yrs & 8months		

2. Windmatic WM17S x 03 units (150kW inverter)

Internal rate of returen and Discounted Payback Period Calculation				
17S x 03 units and 150kw inverter				
Energy require if Total Grid	686,930			
Unit Purchased from Grid	322,656			
units saved	364,274			
Saving in US$	65,569			
Units Sold	114,411			
Earning on units sold US$	20,594			
Diesel Saving in US$	25,477			
Total Annual Cash in flow US$	111,640			
Capital expenditure	657,000			
Discount rate	10%			
Project Life	20 yrs			
Year	Annual Cash Flow	Discounted Cash flow		
0	-657000			
1	111,640	111640.2	111640.22	
2	111,640	101491.1	213131.3291	
3	111,640	92264.64	305395.9737	
4	111,640	83876.95	389272.9234	
5	111,640	76251.77	465524.6958	
6	111,640	69319.79	534844.4889	
7	111,640	63017.99	597862.4826	
8	111,640	57289.09	655151.5679	
9	111,640	52080.99	707232.5544	**(Break even)**
10	111,640	47346.35	754578.9058	
11	111,640	43042.14	797621.0435	
12	111,640	39129.22		
13	111,640			
14	111,640			
15	-545,360			
16	111,640			
17	111,640			
18	111,640			
19	111,640			
IRR	13%			
Pay Back Period (Discounted cash Flow)		8yrs & 1months		

3. Windmatic WM17S x 02 units (100kW inverter)

Internal rate of returen and Discounted Payback Period Calculation				
17S x 02 units and 100kw inverter				
Energy require if Total Grid	686,930			
Unit Purchased from Grid	396,511			
units saved	290,419			
Saving in US$	52,275			
Units Sold	28,704			
Earning on units sold US$	5,167			
Diesel Saving in US$	25,477			
Total Annual Cash in flow US$	82,919			
Capital expenditure	438,000			
Discount rate	10%			
Project Life	20 yrs			
Year	Annual Cash Flow	Discounted Cash flow		
0	-438000			
1	82,919	82919.06	82919.06	
2	82,919	75380.96	158300.02	
3	82,919	68528.15	226828.17	
4	82,919	62298.32	289126.49	
5	82,919	56634.83	345761.32	
6	82,919	51486.21	397247.54	
7	82,919	46805.65	444053.18	**(Break even)**
8	82,919	42550.59	486603.77	
9	82,919	38682.35	525286.13	
10	82,919	35165.78	560451.90	
11	82,919	31968.89	592420.79	
12	82,919	29062.62		
13	82,919			
14	82,919			
15	-355,081			
16	82,919			
17	82,919			
18	82,919			
19	82,919			
IRR	16%			
Pay Back Period (Discounted cash Flow)		7yrs & 6months		

4. Vestas V27 x 01 units (150kW inverter)

Internal rate of returen and Discounted Payback Period Calculation				
V27 x 01 unit and 150kW inverter				
Energy require if Total Grid	686,930			
Unit Purchased from Grid	336,810			
units saved	350,120			
Saving in US$	63,022			
Units Sold	93,627			
Earning on units sold US$	16,853			
Diesel Saving in US$	25,477			
Total Annual Cash in flow US$	105,351			
Capital expenditure	568,000			
Discount rate	10%			
Project Life	20 yrs			
Year	Annual Cash Flow	Discounted Cash flow		
0	-568000			
1	105,351	105351.38	105351.38	
2	105,351	95773.98	201125.36	
3	105,351	87067.26	288192.62	
4	105,351	79152.05	367344.67	
5	105,351	71956.41	439301.08	
6	105,351	65414.92	504716.00	
7	105,351	59468.11	564184.10	
8	105,351	54061.92	618246.02	**(Break even)**
9	105,351	49147.20	667393.22	
10	105,351	44679.27	712072.49	
11	105,351	40617.52	752690.00	
12	105,351	36925.02		
13	105,351			
14	105,351			
15	-462,649			
16	105,351			
17	105,351			
18	105,351			
19	105,351			
IRR	16%			
Pay Back Period (Discounted cash Flow)		7yrs & 1month		

5. Solar PV 100kW (80kW inverter)

Internal rate of returen and Discounted Payback Period Calculation				
Solar Pv 100kW and 80kW inverter				
Energy require if Total Grid	686,930			
Unit Purchased from Grid	546,905			
units saved	140,025			
Saving in US$	25,205			
Units Sold	1,146			
Earning on units sold US$	206			
Diesel Saving in US$	25,477			
Total Annual Cash in flow US$	50,888			
Capital expenditure	400,000			
Discount rate	10%			
Project Life	20 yrs			
Year	Annual Cash Flow	Discounted Cash flow		
0	-400000			
1	50,888	50887.70	50887.70	
2	50,888	46261.55	97149.25	
3	50,888	42055.95	139205.20	
4	50,888	38232.68	177437.88	
5	50,888	34756.98	212194.86	
6	50,888	31597.26	243792.12	
7	50,888	28724.78	272516.90	
8	50,888	26113.44	298630.34	
9	50,888	23739.49	322369.82	
10	50,888	21581.35	343951.18	
11	50,888	19619.41	363570.59	
12	50,888	17835.83	381406.42	
13	50,888	16214.39	397620.81	
14	50,888	14740.35	412361.16	**(Break even)**
15	-349,112			
16	50,888			
17	50,888			
18	50,888			
19	50,888			
IRR	6%			
Pay Back Period (Discounted cash Flow)		13yrs & 02months		

Appendix [11] HOMER Simulation Results

1. HOMER simulation result

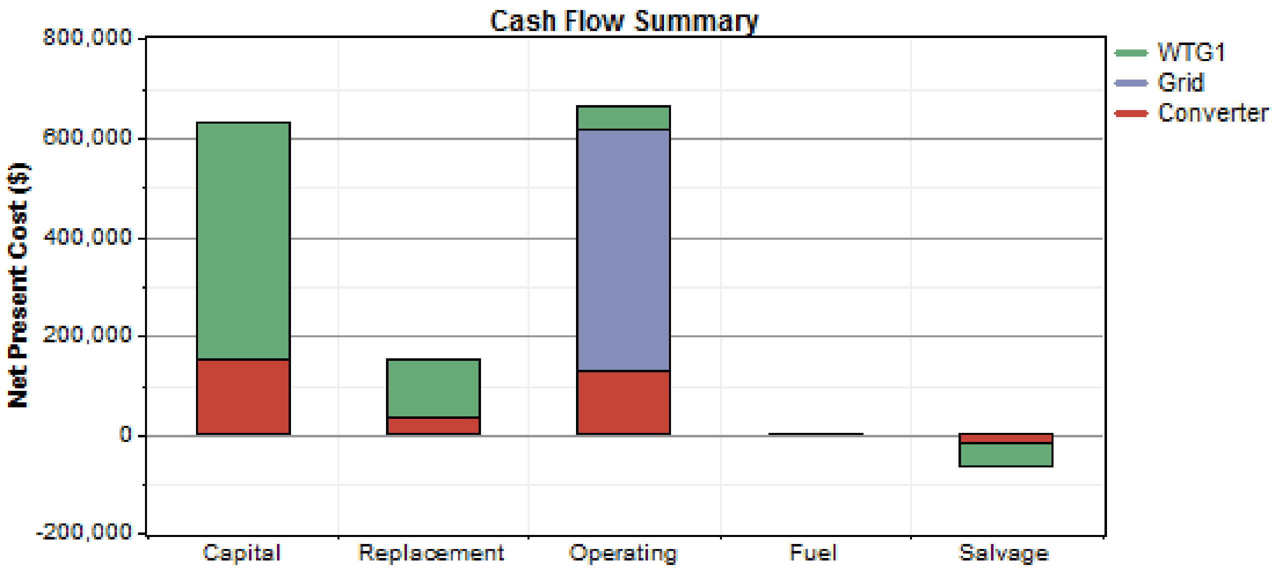
Wind Turbine/ Solar PV	Rated Array size or Capacity (kW)	No. of Units	Inverter (kW)	Initial capital (USD $)	Operating cost (USD $/ Yr)	Total NPC (USD $)	COE (USD $/kWh)	Renewable fraction (%)
AOC 15/50	50	1	50	170,000.00	110,195.00	1,108,154.00	0.189	18%
AOC 15/50	50	2	80	320,000.00	97,054.00	1,146,279.00	0.193	36%
AOC 15/50	50	3	100	460,000.00	89,193.00	1,219,349.00	0.197	48%
AOC 15/50	50	2	100	340,000.00	98,771.00	1,180,893.00	0.198	36%
WM 17S	95	1	80	249,000.00	107,910.00	1,167,696.00	0.199	25%
AOC 15/50	50	4	150	630,000.00	88,537.00	1,383,762.00	0.201	60%
WM 17S	95	2	100	438,000.00	93,840.00	1,236,911.00	0.203	45%
V27	225	1	150	568,500.00	92,314.00	1,354,423.00	0.204	57%
AOC 15/50	50	3	150	510,000.00	93,684.00	1,307,586.00	0.206	51%
AOC 15/50	50	5	150	750,000.00	85,900.00	1,481,312.00	0.206	66%
Solar PV	50	1	50	210,000.00	119,748.00	1,229,479.00	0.210	10%
WM 17S	95	3	150	657,000.00	91,780.00	1,438,374.00	0.211	60%
V27	225	2	250	1,087,000.00	98,192.00	1,922,965.00	0.212	79%
WM 17S	95	2	150	488,000.00	98,665.00	1,327,987.00	0.213	47%
V27	225	1	200	618,500.00	98,123.00	1,453,875.00	0.215	58%
WM 17S	95	3	100	607,000.00	88,493.00	1,360,393.00	0.216	54%
WES18	80	1	50	400,000.00	108,330.00	1,322,270.00	0.226	24%
Solar PV	50	1	100	260,000.00	125,572.00	1,329,062.00	0.227	10%
V27	225	2	150	987,000.00	86,612.00	1,724,378.00	0.227	75%
Solar PV	100	1	50	370,000.00	112,906.00	1,331,234.00	0.228	18%
Solar PV	100	1	80	400,000.00	113,761.00	1,368,513.00	0.234	21%
WES18	80	2	100	800,000.00	97,920.00	1,633,649.00	0.268	45%
WES18	80	2	80	780,000.00	98,664.00	1,619,980.00	0.270	42%
NW100	100	1	80	633,000.00	112,428.00	1,590,164.00	0.271	26%
WES18	80	2	150	850,000.00	102,589.00	1,723,401.00	0.275	48%
WES18	80	3	150	1,200,000.00	98,214.00	2,036,151.00	0.297	61%
WES18	80	3	100	1,150,000.00	95,040.00	1,959,127.00	0.311	55%
NW100	100	2	100	1,206,000.00	105,694.00	2,105,835.00	0.342	46%
NW100	100	2	150	1,256,000.00	110,110.00	2,193,432.00	0.344	49%
NW100	100	2	80	1,186,000.00	106,858.00	2,095,741.00	0.347	42%
NW100	100	3	150	1,809,000.00	111,249.00	2,756,125.00	0.394	60%
NW100	100	3	100	1,759,000.00	108,367.00	2,681,591.00	0.422	54%

2. AOC 15/50 x 03 units (100kW inverter) summary of complete HOMER analysis

Cost summary

Total net present cost	$ 1,383,762
Levelized cost of energy	$ 0.201/kWh
Operating cost	$ 88,537/yr

Cash flow summary



Net Present Cost

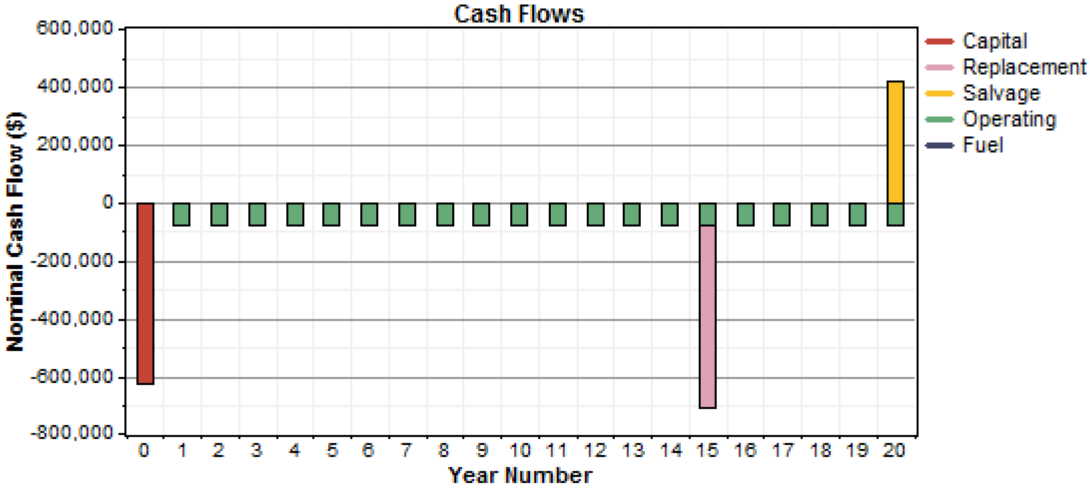
Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	($)	($)	($)	($)	($)	($)
WTG1	480,000	114,908	48,698	0	-47,566	596,040
Grid	0	0	488,974	0	0	488,974
Converter	150,000	35,909	127,703	0	-14,864	298,748
System	630,000	150,817	665,375	0	-62,430	1,383,762

Annualized Cost

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	($/yr)	($/yr)	($/yr)	($/yr)	($/yr)	($/yr)
WTG1	56,381	13,497	5,720	0	-5,587	70,011
Grid	0	0	57,435	0	0	57,435
Converter	17,619	4,218	15,000	0	-1,746	35,091

System	74,000	17,715	78,155	0	-7,333	162,536

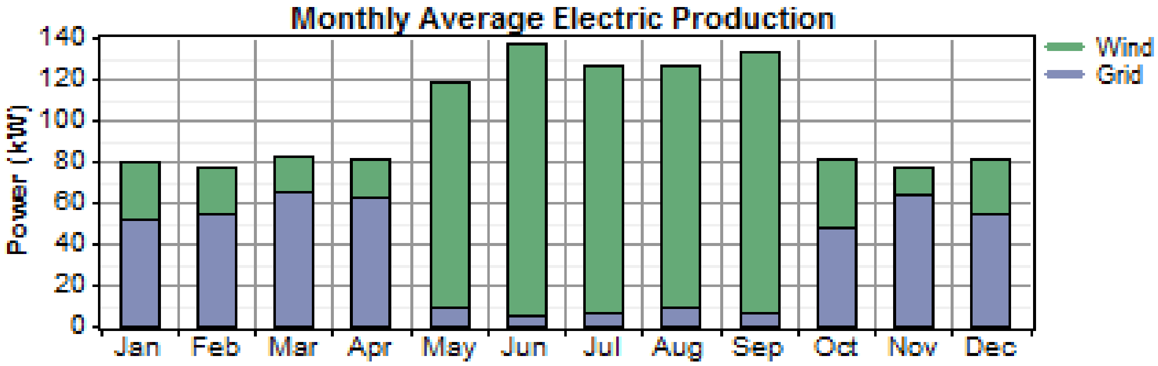
Cash Flow



Electricity Generation

Component	Production	Fraction
	(kWh/yr)	
Wind turbines	561,916	64%
Grid purchases	319,082	36%
Total	880,998	100%

Monthly Average Electricity Production



Annual Average Electricity Production

Month	Energy Purchased	Energy Sold	Net Purchases	Peak Demand	Energy Charge	Demand Charge
	(kWh)	(kWh)	(kWh)	(kW)	($)	($)
Jan	39,053	229	38,825	150	7,030	0
Feb	36,980	22	36,958	164	6,656	0
Mar	48,303	0	48,303	164	8,695	0
Apr	45,264	0	45,264	146	8,148	0
May	6,553	21,796	-15,243	99	1,180	0
Jun	3,946	26,886	-22,939	157	710	0
Jul	4,891	24,301	-19,410	148	880	0
Aug	6,541	20,789	-14,249	123	1,177	0
Sep	4,458	25,375	-20,917	105	803	0
Oct	35,846	426	35,420	132	6,452	0
Nov	46,138	0	46,138	143	8,305	0
Dec	41,107	232	40,875	156	7,399	0
Annual	319,082	120,056	199,025	164	57,435	0

Annual Average Emission

Pollutant	Emissions (kg/yr)
Carbon dioxide	125,784
Carbon monoxide	0
Unburned carbons	0
Particulate matter	0
Sulfur dioxide	545
Nitrogen oxides	267