ASSESMENT OF ROOFTOP SOLAR NETMETERING CONCEPT:
CONSUMER AND UTILTY POINT OF VIEW

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Degree of Master of Science

Department of Electrical Engineering

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The above candidate has carried out research for the Masters thesis under our supervision.

Prof.H.Y.R Perera :……………… Date :…………………

Dr. Asanka Rodrigo :……………… Date :………………..

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ABSTRACT

Global energy needs continue to grow, whilst fossil fuels still outstrip renewable energy in terms of supportive policies and subsidies. With growing concern towards climate change, many countries across the world are rethinking their energy strategy and incorporation alternative methods of energy generation. Of all the different modes of renewable energy technologies, Solar PV technology has caught the most attention.

With environmental concerns and energy needs increasing, the world is promoting renewable energy technologies. Today, the PV systems price is decreasing, which gives it a competitive edge. The aim of this study is to research the viability of rooftop solar PV systems under certain circumstances. The study performs a cost beneficial analysis for the lifetime of the solar PV system making use of economic analysis on residential consumer perspectives and avoided cost analysis on utility point of view.

The research concluded with several findings. Basically it concluded that the investment on Roof Top Solar is worthwhile when monthly consumption exceed 200 kWhs. Therefore, according to the present tariff structure and cost of solar PV Systems, Net Metering is not economical for monthly average consumption below 150 units. In utility point of view, it has been found that the reduction of avoided cost is rapidly increasing. But the rate at which the reduction of avoid cost increasing is decreasing and it becomes constant after 20 years. rooftop solar electricity generation cannot replace any marginal plant during the period of study concerned.

There is no detailed study has been conducted in Sri Lanka in this particular area of study. The outcome of the research provides important and useful information for consumers, electricity utilities as well as the policy makers in energy sector.

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TABLE OF CONTENTS

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

LIST OF FIGURES

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

LIST OF TABLES

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
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LIST OF ABBREVIATIONS

IEA	International Energy Agency
HFO	Heavy Fuel Oil
NREL	National Renewable Energy Laboratory
SEA	Sustainable Energy Authority
NOAA	National Oceanic and Atomic Administration
NGDC	National Geographical Data Centre
NPV	Net Present Value
IRR	Internal Rate of Return
DCF	Discounted Cash Flow
IPP	Independent Power Producers
LNG	Liquid Natural Gas
PUCSL	Public Utility Commission Sri Lanka
EPIA	European Photovoltaic Industry Association
NCRE	Non Conventional Renewable Energy
CEB	Ceylon Electricity Board
LECO	Lanka Electricity Company
PV	Photo Voltaic
LTGEP	Long Term Generation Expansion Plan
GWh	Gigawatt Hour
kWh	Kilowatt Hour
MW	Megawatt

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Chapter 1

INTRODUCTION

1.1 Global Energy Status and Challenges

Many countries depend on coal, oil and natural gas to supply most of their energy needs, but reliance on fossil fuels presents a big problem. Fossil fuels are a finite resource. Eventually, the world will run out of fossil fuels. It is becoming too expensive to retrieve the remaining. Fossil fuels also cause air, water and soil pollution, and produce greenhouse gases that contribute to global warming.

Due to the present situation of increasing energy demand, rising energy prices, and global warming, Non Conventional Renewable Energy (NCRE) sources playing a major role in global energy supply. NCRE sources, such as Wind, Solar and Hydro power are clean alternatives to fossil fuels. They produce little or no pollution or greenhouse gases, and they will never run out.

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1.2 Renewable Energy for Global Energy Demand

Renewable energy comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat. During 2013, modern renewables continued to grow strongly in all end-use sectors: power, heating and cooling, and transport. In the Power Sector, renewable sources accounted for almost half of the electricity capacity added globally during 2013.They have supplied 18% of global energy consumption in 2013 with 16% of global electricity coming from hydro electricity and 2% from new renewable sources [1].

Wind and Solar Photo Voltaic (PV) accounted for almost 40% and 30% of new renewable capacity, respectively. Hydro Power provided nearly 25% of the global energy requirement [1]. By the end of 2013, total renewable power capacity worldwide exceeded 1,370 GW, including Hydro Power. In summary, NCRE comprised more than 25% of total global power-generating capacity [1].

According to the International Energy Agency (IEA), Photovoltaic and solar-thermal plants may meet most of the world's demand for electricity by 2060 .It is half of all energy demand. Meantime, Wind, hydropower and biomass plants will supply much of the remaining generation. Photovoltaic and concentrated solar power together can become the major source of electricity.

Figure1.1 exhibits the Renewable Power Capacity (GW) added globally since 2004.

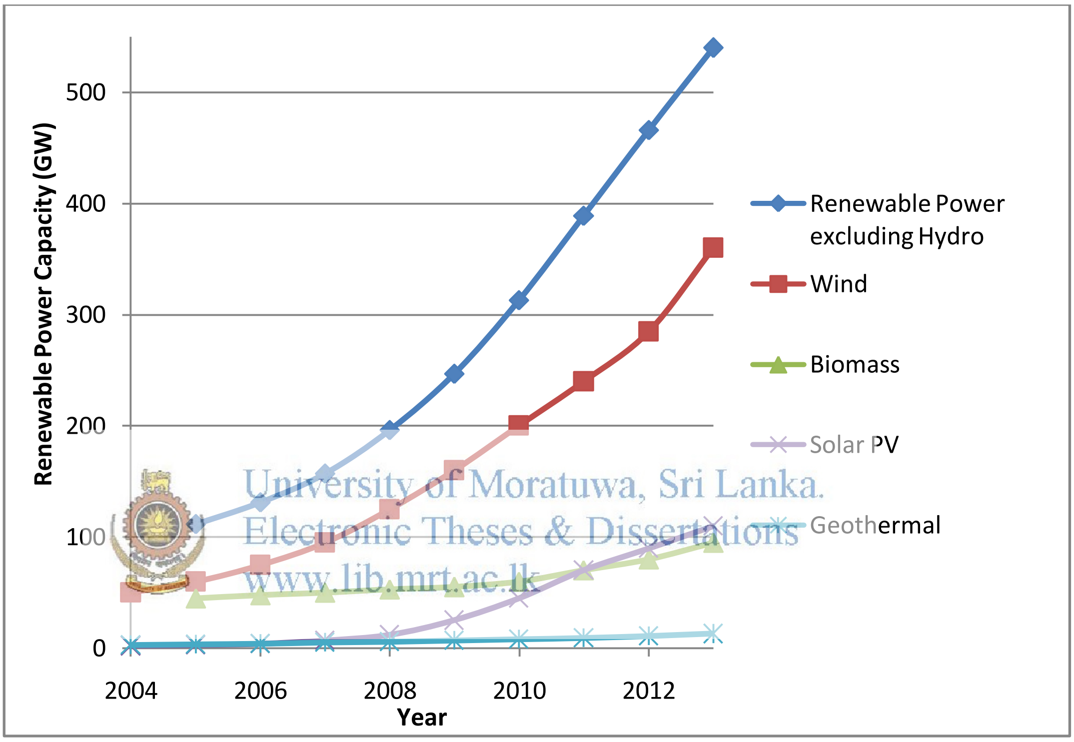

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Figure 1.1: Growth of Global Renewable Power Capacities (Excluding Hydro)
Source: REN 21, Renewable Global Status Report (2006-2013) [2]

1.3 Global Solar Status

The sun is our most powerful source of energy. Sunlight, or solar energy, can be used for heating, lighting, generating electricity and a variety of industrial processes. Most forms of NCRE come either directly or indirectly from the sun. For example, heat from the sun causes the wind to blow, contributes to the growth of trees and other plants that are used for biomass energy, and plays an essential role in the cycle of evaporation and precipitation that makes hydropower possible.

In Solar market, very large-scale ground-mounted systems and building integrated (rooftop) small-scale systems continued to play an important role. European Union is dominated the global solar market, led by Italy and Germany. Germany is currently the global leader in solar power. Germany has a goal to discontinue all nuclear power by the year 2020 and replace it with renewable resources. There are major PV feed-in-tariff programs in Italy, Japan and China. It can be seen that Solar Market has been expanded in other regions. China has rapidly emerged as the dominant player in Asia.

The following Figure shows Solar PV operating capacity of leading countries in the world as percentage.

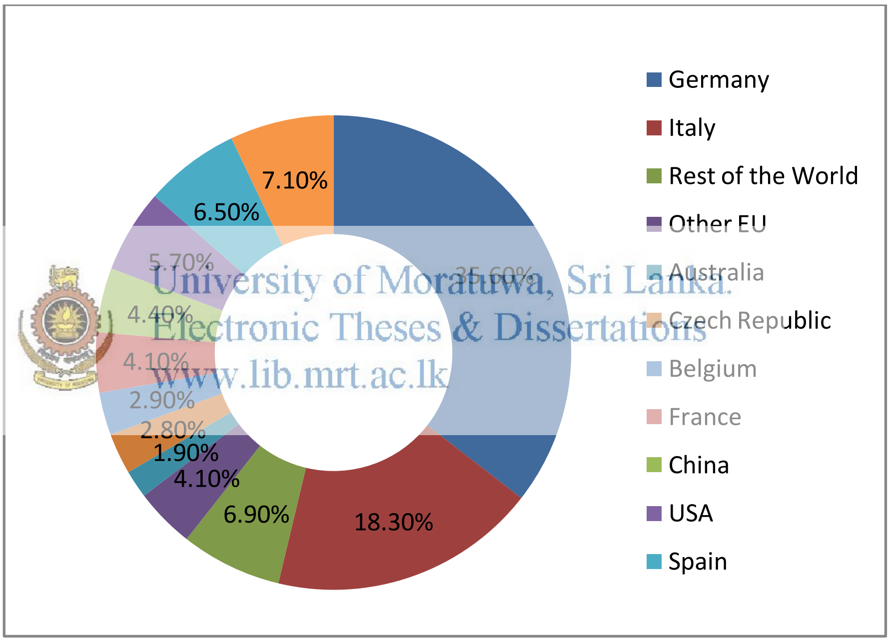

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Figure 1.2: Solar PV operating capacity as percentages
Source: REN 21, Renewable Global Status Report (2006-2013) [2]

During 2013, Solar PV experienced extraordinary market growth. The capacity was increased by 30 GW, increasing total global capacity by 74%.The total installed Solar PV capacity at the end of 2012 is about 98 GW. The seven year growth rate from 2007 to 2013 was approximately 70% per year [2].

The Figure 1.3 shows the actual annual installed capacity of solar PV systems worldwide from 1995.

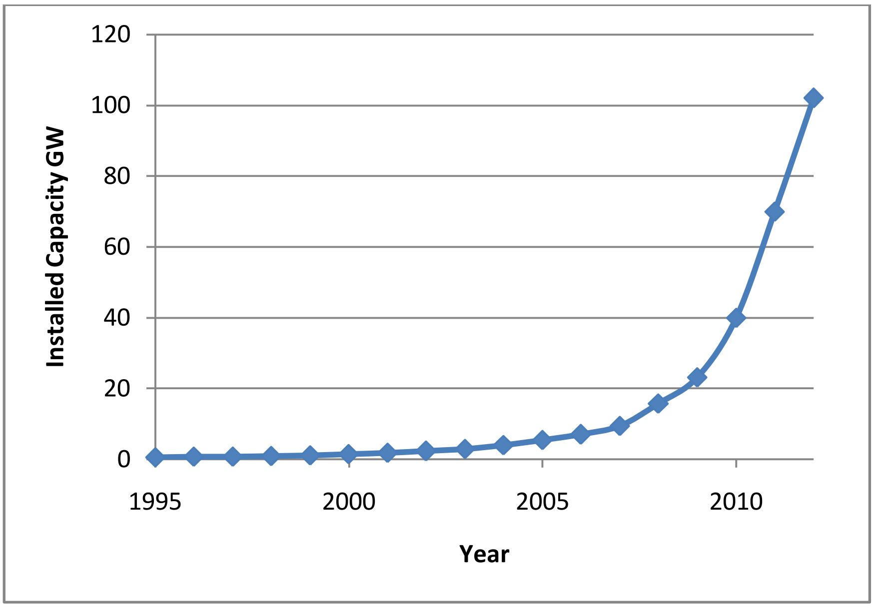

Figure 1.3: Growth of installed capacity of solar PV
Source: REN 21, Renewable Global Status Report (2006-2013) [2]

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1.4 Sri Lanka Energy Picture

With steady economic growth, the demand for energy is of paramount importance especially for a developing country like Sri Lanka.

Sri Lanka's energy sources consist primarily of biomass, hydro-electricity and petroleum that contribute to 47%, 8% and 45% of total energy respectively [2]. In the power sector, the installed capacity for electricity generation receives from hydro, thermal and wind power.

Electricity generation increased by 7.5% to 11,521 GWh in 2013 reflecting the dry weather conditions which prevailed during the second half of the year. As a result, thermal power generation increased by 36% to 6,785 GWh. The Coal power plant at Norechchole provides 300MW to the electricity demand of Sri Lanka since 2012. The second phase of coal power plant at Norachchole added 600 MW to the system capacity in 2014. The Coal fired plant in Sampur will add 500 MW to the installed capacity [2].

At present the annual electricity requirement in Sri Lanka is about 11,000 GWh and the installed power plant capacity is about 3141 MW. This installed capacity consists of 1401 MW of hydro power, 1690 MW of thermal power and 50 MW from other renewables. The thermal power plants generate electricity by firing coal, Heavy Fuel Oil (HFO) and diesel. The cheapest option for power generation is hydropower as it has no fuel cost involved. The most expensive option is diesel and the costs of HFO & coal are in between these two.

The total electricity requirement in the country is about 33 GWh/day at present. The power requirement varies during the day time (from 6.30 am – 6.30 pm).The day time demand is about 1200-1400 MW. The demand increases and reaches a peak of about 2000 MW during the night from 6.30 pm to 9.30 pm. Again it drops to about 800 MW from 9.30 pm to6.30 am. Ceylon Electricity Board (CEB) has the responsibility of providing uninterrupted power supply to this varying daily demand.

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The hydro power generation is mainly dependent on the water in reservoirs basically under the multipurpose Mahaweli project. The following table shows the availability and total production of Energy in 2013.

Table 1.1: Availability and total production of Electricity by category
Source: Generation Performance in Sri Lanka-2013 prepared by Public Utilities Commission of Sri Lanka [3]

Source	MW	GWh
Hydro power	1,401	4,622
Thermal	1,690	6,785
Other Renewables	50	121
Total	**3,141**	**11,528**

97% of the households are enjoying the grid connected electricity while another 2% of households are provided with basic electricity connection through off-grid systems. The demand for electricity is estimated to rise at an annual rate of 8% - 10%. Per capita consumption of electricity meanwhile reflected 460 kWh / person per annum in 2013.

1.5 Potential for NCRE in Sri Lanka

In order to meet the increasing demand the electricity, generation capacity needs to be doubled every ten years. This exponential growth cannot be sustained forever as the fossil fuel era has reached its ultimate dead-end. Therefore NCRE is emerging as the energy supply solution for the 21st century. Sri Lanka, a small island located south of the Indian subcontinent, has embraced NCRE in electricity generation.

Renewable sources of energy including solar power, small scale hydro power and wind power have emerged as an economical and sustainable alternative source to promote medium term electricity generation in Sri Lanka. NCRE resources have received great attention in recent times for generating electricity in Sri Lanka for meeting the targets of 100% electrification. Electrification of rural areas is a challenge due to high capital investment, operational costs and the difficulties associated with extending grid connected electricity lines to remote areas.

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The National Energy Policy of Sri Lanka clearly highlights the importance of promoting indigenous energy resources. And the government has the target to reach a minimum level of 10% of the gird electricity using non-conventional NCRE by 2016.

On the way to achieve this target, power generation through NCRE sources has contributed 7.9% of the total electricity generation of the national grid in 2013. In the Sri Lankan power sector, the grid connected installed capacity for electricity generation from NCRE sources was 320.628 MW. However, when comparing electricity generation from conventional energy sources, the total contribution from the NCRE sector to the national grid still remains small.

The Figure: 1.4 shows the existed installed capacity in MW of each type of Renewable Energy power plants by the end of 2013.

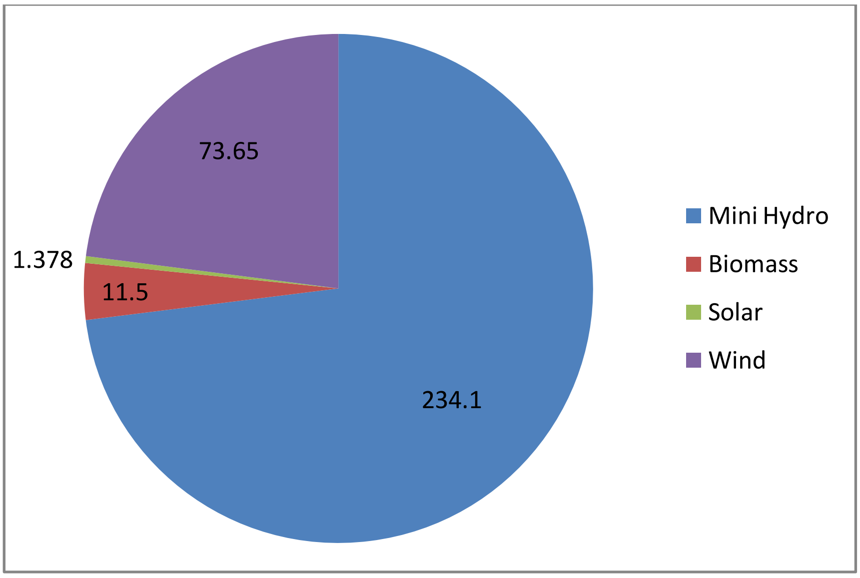

Figure: 1.4 Installed capacities of NCRE Sources in Sri Lanka

Source: Generation Performance in Sri Lanka-2013 prepared by Public Utilities Commission of Sri Lanka [3].

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The growth of the grid connected installed capacity of NCRE power plants from year 1999 is depicted in Figure: 1.5.

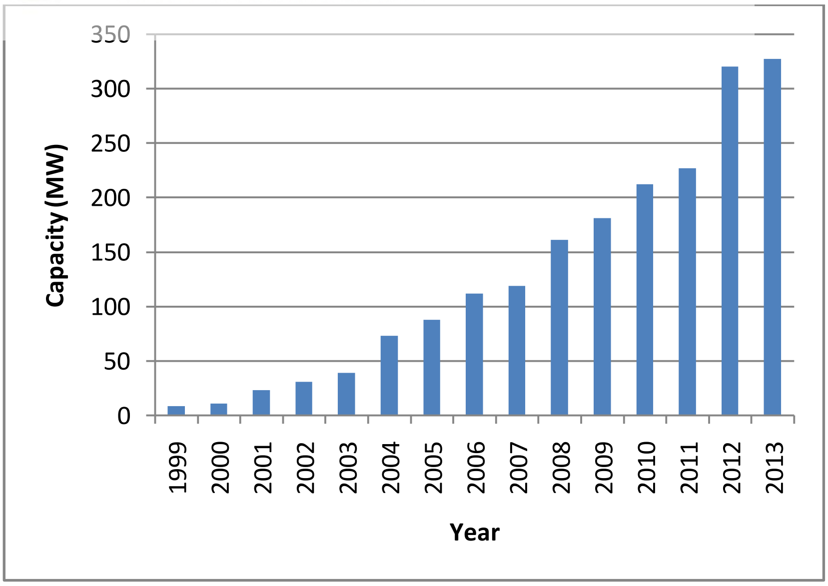

Figure: 1.5 Growth of installed capacity of NCRE sources

Source: Generation Performance in Sri Lanka-2013 prepared by Public Utilities Commission of Sri Lanka [3].

The percentage share of NCRE sources from total Energy has been increased exponentially over last 13 years.

Year	Energy (GWh)	Percentage from Total Energy
2000	43.3	0.6
2001	64.8	1
2002	103	1.5
2003	120	1.6
2004	206	2.6
2005	280	3.2
2006	346	3.7
2007	344	3.5
2008	433	4.4
2009	546	5.5
2010	724	6.8
2011	722	6.3
2012	730	6.9

Table 1.2: Percentage share of NCRE sources
Source: Generation Performance in Sri Lanka-2013 prepared by Public Utilities Commission of Sri Lanka [3].

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The growth of energy generated by the grid connected NCRE plants over past 12 years is depicted below.

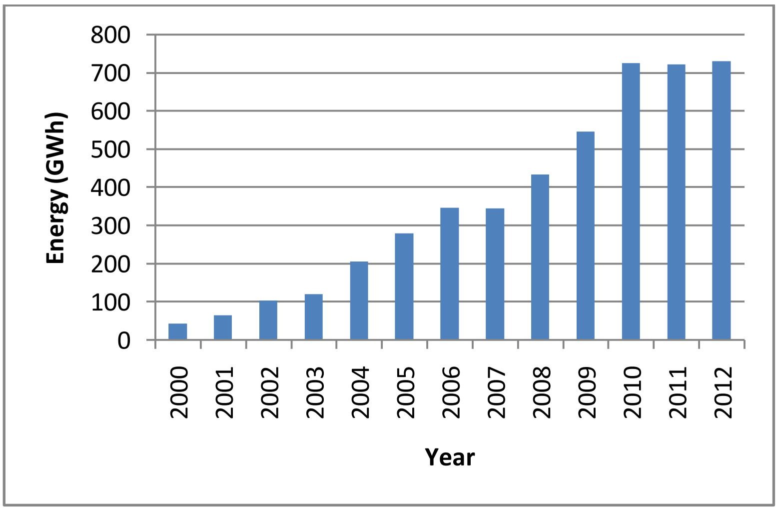

Figure 1.6: Generation from NCRE Sources
Source: Generation Performance in Sri Lanka-2013 prepared by Public Utilities Commission of Sri Lanka [3].

1.6 Solar Resource of Sri Lanka

Sri Lanka is located near the equator and has a great potential for solar radiation year around. The average radiation is 4-6 kWh/m^2/day. The Solar radiation over the island does not show a seasonal variation. According to the solar resource map developed by the National Renewable Energy Laboratory (NREL) of USA, solar radiation over the flat dry zone of Sri Lanka varies from 4.0 – 4.5 kWh/m^2/day. Solar radiation levels are low as 2.0 – 3.5 kWh/m^2/day over the central mountains of the country. The following Figure shows yearly sum of irradiance received by countries in the world. Accordingly, Sri Lanka receives about 2000 kWh/m^2 of irradiance per year. Therefore, potential for harnessing solar energy is very high.

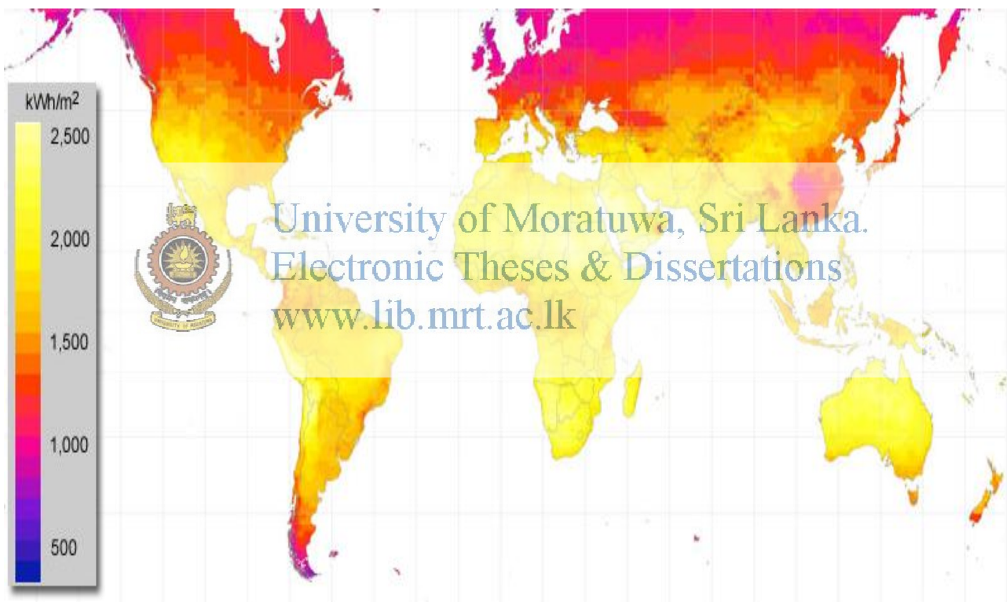

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Figure 1.7: Solar resource map

Source: REN 21, Renewable Global Status Report (2006-2013) [2]

1.7 Contribution of Solar Power for Sri Lankan Energy Market

Solar energy may prove to be the best choice for Sri Lanka's future. It is one of the best alternatives to meet the high target set to increase NCRE share to 10% in 2018 from a current level of 4% [4].

The population in Sri Lanka is currently 21 Million with an annual growth of 0.7%. The electrification rate is 98 % at national level. The electricity demand is growing by 5-8% p.a [3]. Off-grid commercial and institutional PV markets play an important role in pre-electrification of areas not reached by the Sri Lanka power grid.

The first ever grid connected solar energy park was commissioned in Baruthakanda of Hambantota, the first solar energy park in Asia. This is constructed with the grants of the Government of Japan and the Government of Korea. The total capacity of the system is 900 kW and amounts to USD 14.5 million. The goal of the project is to provide clean energy through solar power generation. The solar energy park generates 5.6 GWh per annum and this is capable of offsetting 860 tons of CO_2 [5].

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1.8 Net Metering

Net metering facilitates import and export of Electricity through a single, bidirectional meter. Customers can bank the excess electricity generated and trade the same against future consumption. Net metering is an electricity policy for consumers who own (generally small) renewable energy facilities, such as wind, solar power or home fuel cells.

Use of NCRE to produce electricity in Sri Lanka is open to all electricity customers. They can participate in producing electricity using NCRE in whatever small way they can afford.

The normal energy meter is replaced with a two-way meter. The meter have two registers: the "import" register and the "export" register. The consumer can produce electricity using a renewable source of energy, and first use that electricity for their own requirements, and send the surplus back to the grid. Such "exported" electricity units will be registered in the "export" register of the meter. During certain times of the day, the consumers own electricity production may not be adequate for their requirements. Then the consumption will be recorded in the "import" register. When the electricity meter is read once a month, consumer pays only for the difference between the "import" and the "export". If in any month the consumer have exported more than what he imported, the bill will only carry the monthly fixed charge (no charge for the units of electricity), and the excess exported units will be credited to the next month's bill.

1.9 Rooftop Solar Net Metering

With the introduction of Net Metering for NCRE systems, the energy generated during the sunshine hours of the day can be used or pumped back into the grid and the house meter will run in the opposite direction and reduce the consumers' monthly bill. Without a costly storage battery system this will produce reduction in the monthly bill.

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Maximum solar output is available only for 4.5 hours a day or one-sixth of the time. The level of utilization is only 16%.The economic life is only 20 years for a particular Solar Panel. Wherever a solar panel is installed, there's a subsidy coming to the user. The Sri Lankan government is trying to promote use of solar energy as alternative energy technologies by introducing net metering for roof top Solar Systems to cope with the energy crisis.

CEB and Lanka Electricity Company (LECO) has introduced roof top solar net metering in Sri Lanka, that is a roof top system where people who can afford solar power system on their roof tops can export energy during the day time to the national grid and consume some of it during the night and CEB or LECO will act as energy banks. There is no money transaction associated. Net metering is a program that provides rooftop solar customers with utility bill credits for the surplus clean energy that their solar systems feed onto the grid.

The utility energy meter will be replaced with an Import/Export meter. The electrical energy consumed from the grid is considered as import energy and electrical energy generated by the Solar Panel and supplied to the grid is considered as export energy. At the end of each billing period, CEB/ LECO will read the consumer's export energy meter reading and the import meter reading. The electricity bill will be prepared giving credit to the export, and charging the consumer for the difference between the import and the export.

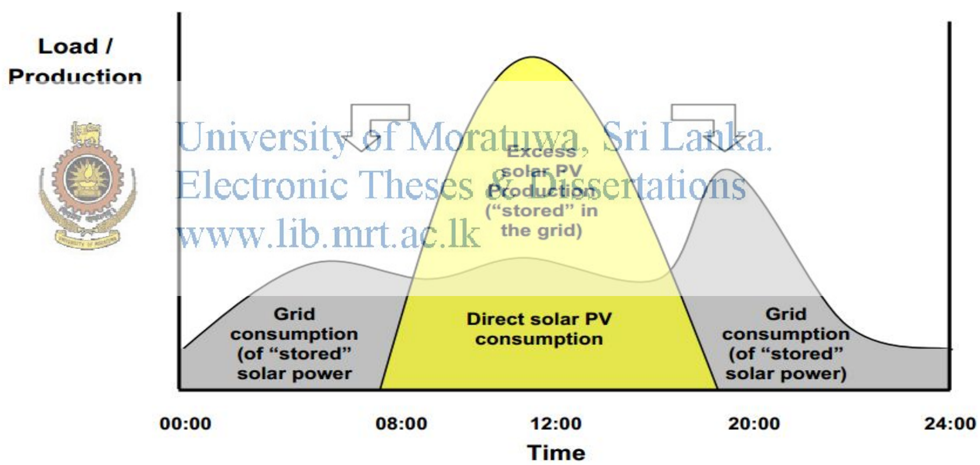

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Figure 1.8: Operation of Solar Net Metering System

Source: www.nrel.gov

When someone decides to put solar panels on their roof, they not only generate clean power, but also reduce strain on the grid while offering financial benefits to all electricity consumers. In addition to the bill-saving rooftop solar net metering avoids certain costs to the utility. It also provides environmental, public health and economic benefits.

Chapter 2

PROBLEM IDENTIFICATION

2.1 Research Approach

For the past couple of hundred years power generation rely more and more on fossil fuels. However it is becoming increasingly obvious that reliance on fossil fuels is causing problems. The fact is that, world is running out of fossil fuels. Fossil fuels are depleting rapidly. The demand for fossil fuels is increasing rapidly and it tends to price soaring. The severe problem with fossil fuels is the damage to the environment. The burning of fossil fuels increases the green house gases and leads to global warming. Therefore reliance on fossil fuels only is not a wise decision.

Unless we have a plan in place to address these issues, we will have severe problems in the future. Therefore, alternative technologies for producing electricity have received greater attention. There are verities of renewable energy sources used for electricity generation in the world. Hydro, Wind, Solar, Biomass and solar thermal are most popular renewable energy sources in Sri Lanka.

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Among them, my attention extended towards installation of Solar Panels in Rooftops to generate electricity in the day time. Net metering enables consumers to use their own generation from roof top solar systems to offset their consumption. When the customer generates electricity in excess of their demand, enables to feed the grid and receive credits for the excess electricity they generate. Solar Energy credits help to offset the electricity consumption of the customer. This method helps to reduce the overall burden on electric utilities during daytime peak hours by feeding power into the grid. It provides benefits not only to individual consumers, but also to the utility by increasing the avoided cost.

As similar to other renewable resources the main problem associated with roof top Solar PV is its high initial capital cost. But, Electricity rates are rapidly increasing while the cost of solar PV installation is rapidly decreasing. Therefore, the future of rooftop Solar is profitable option for electricity consumers. However the consumers as well as the utility must have a long-term perspective in order to justify an investment in Solar PV. Therefore, my aim is to conduct an **assessment of Roof top Solar Net Metering Concept from Consumer and Utility Point of View.**

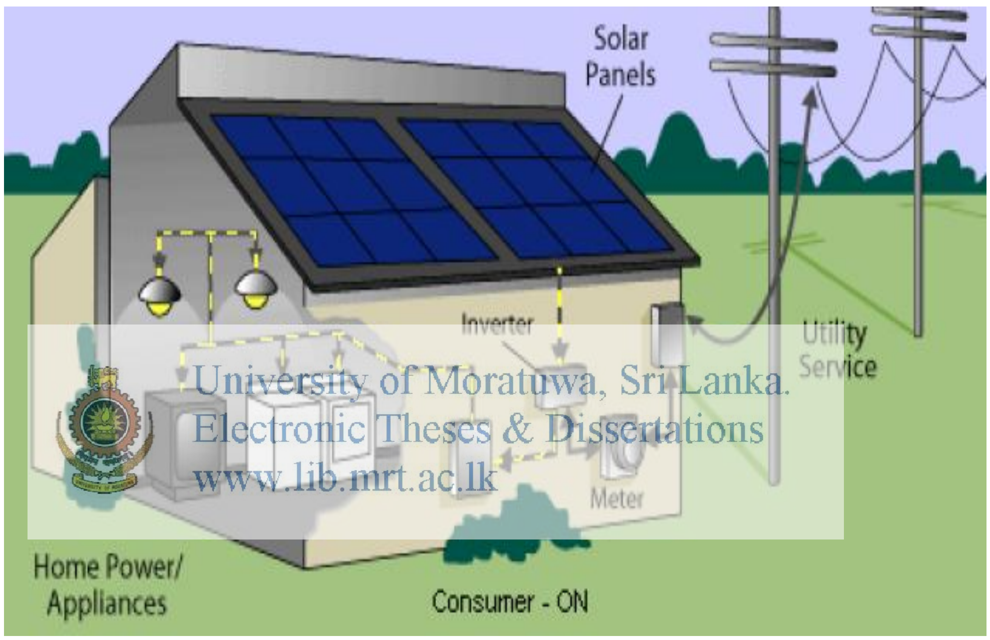

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Figure 2.1: Grid Connected Solar PV System

2.2 Literature Review

Several studies have been conducted on Solar PV in world wide. Out of them, following studies are found as the most relevant resources to the research on Rooftop Solar Net Metering concept on consumer and utility point of view.

A research on Modeling Adoption of Solar Photovoltaic and Analysis of Net Metering in the City of Austin has been conducted by Siva Kiran Josyula, MA from University of

Texas at Austin in 2011.The trends in costs and adoption of solar PV by residential and commercial customers in the city of Austin have been analyzed. It has been accomplished by tabular and graphical analysis of data on PV installations from 2004 to 2010. Technology diffusion models has been used to analyze and forecast the diffusion of residential PV systems in Austin. The net metering tariff mechanism in Austin has been described and the difference between the current and an alternative tariff has been explained in the literature.

Difference in revenue for Austin Energy with the alternative tariff has been calculated using simulated PV generation data. The results indicate that the alternative tariff adds little revenue to Austin Energy‟s energy charge revenues at the current level of penetration of solar PV. However, at a higher penetration level of PV, the alternative tariffs might result in significant additional revenue for the utility. The thesis concludes with a discussion on the possible rationale for the alternative tariff and directions for future research. The methodology used in this thesis for analyzing adoption of solar PV by residential customers has been referred for my research.

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A research on Economic Value of PV and Net Metering to residential customers in California has been conducted by Naim Darghouth, Galen Barbose and Ryan from Wiser Environmental Energy Technologies Division in California.

The bill savings from PV for residential customers of the California has been analyzed in this research. The bill saving has been calculated according to the existing net metering tariffs as well as under several alternative compensation mechanisms. It has been found that economic value of PV to the customer is dependent on the retail electricity rate. It can vary quite significantly from one customer to another. In addition, it has been found that value of the bill savings from PV generally declines with PV penetration level, as increased PV generation tends to offset lower-priced usage. The method used to analyze the bill saving has been incorporated to my research.

A Technical and Economical Assessment of Net-Metering in Kenya has been conducted by Georg Hilleet al and Michael Franz in 2012.

This research analyses the technical and economical feasibility for grid connection of solar photovoltaic systems through net-metering in Kenya. It assesses the technical, economical and social feasibility of solar net metering as an incentive policy in Kenya. All required data has been collected from consumers and local stakeholders including Ministry of Energy and Kenya Power Limited. Data received from the existing power plant structure and electric network as well as future extension plans also considered. Furthermore, the economic viability of the grid operations, as well as potential economic implications of investments under net-metering has been considered. It has been assessed whether many decentralized small scale PV installations interfere with the grid, impact to the Grid stability by the fluctuating generation, the avoided cost of net metering at the customer level and the impact of net metering on Kenya Power revenues has been studied in this research.

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Methodological considerations for the economic analysis comprise of determining the advisability of small scale grid connected PV market in Kenya. The discounted cash-flows mechanism has been used. The three essential elements have been determined :(i) discount factor, (ii) cost and (iii) benefits. The avoided cost to the utility due to solar net metering has been evaluated. The methodology used for calculation of above parameters has been referred for my research.

Another research has been conducted on Evaluation of Net Energy Metering Cost Effectiveness by the Energy Division of California Public Utilities Commission.

It provides a measure of the total net costs to ratepayers from solar customers participating in the solar net metering tariffs. This analysis also measures the overall cost-effectiveness of solar PV as an energy resource. The direct costs and benefits of net metering have been evaluated by calculating economic Net present value and Internal Rate of Return.

The report estimates that on a lifecycle basis, all PV generation on net metering tariffs (386 MW installed through 2008) will result in a net present value cost to ratepayers of approximately $230 million over the next 20 years, or approximately $20 million per year. Net metering as a policy is one small part of the utility's demand side efforts, which overall represent 7% of the average residential bill and provide a net savings to ratepayers.

The report estimates that the average net cost of net metering is $0.12 per kWh exported, which is relatively high on a cents per kWh basis .The report includes several sensitivity analyses that indicate potential areas for further policy study, including the costs associated with net metering billing and interconnection. The report uses a robust methodology for estimating the costs and benefits of the net metering mechanism. The report highlights a number of research and policy issues that merit further study and possible Commission action. The analysis used in the above literature was incorporated to my research.

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2.3 The Problem Statements

The initial capital cost of Solar Panel installation is very high. It prevented the wide-spread adoption of Solar PV. Electricity rates are rapidly increased while cost of solar PV installation is rapidly decreasing. Consumers must have a long-term perspective in order to justify an investment in Rooftop Solar PV with net metering. When people invest huge money on it, they should have a clear understanding whether it is worthwhile or not. Therefore it is important to assess the benefit to the consumer by roof top Solar Net Metering Concept. Solar Energy credits help to offset the electricity consumption of the customer. Furthermore it is required to determine the consumer category which receives the maximum benefit by installing rooftop solar PV.Rooftop solar net metering provides benefits not only to individual consumers, but also to the utility. When considering the utility, the impact (pros & cons) due to rooftop Solar Net metering should be discussed. It reduces the overall burden on electric utilities during peak daytime hours by feeding power into the grid. Hence, the avoided cost of the utility can be optimized. On the other hand rooftop solar net metering would lead to reduction of the revenue of utility. Therefore, it is very important to assess the impact to the utility.

2.4 Objectives

The main objective of the research is to conduct an economic evaluation on Solar Net Metering concept on residential consumers and determine the consumers (based on the units of consumption) who receives the maximum benefit.

The other objective is to determine the avoided cost to the utility due to implementation of rooftop solar net metering concept.

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Final objective is to assess the shortcomings of existing methodology and provide proposals to promote rooftop Solar PV with Net Metering.

2.5 Dissertation Outline

The dissertation reflects the research approach discussed above. Chapter 1 provides an introduction to the thesis topic. It discusses the global and local market of renewable energy and emphasis the importance of rooftop solar net metering concept to the consumer and the utility. Chapter 2 is dedicated to discuss the back ground for the thesis and describe the problem statement. In Chapter 3, the research methodology is discussed. Further a case study will be explained in the same Chapter. The data analysis required for the thesis has been presented in Chapter 4. Economic indices are calculated and summarized in Chapter 5.Chapter 6 discusses the procedure used for avoided cost calculation. Chapter 7 is dedicated for the discussion. In Chapter 8, shortcomings of the existing methodology of rooftop solar have been discussed and proposals are provided to promote net metering Sri Lanka. The conclusions and the topics for further research are also indicated in Chapter 8.

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Chapter 3

METHODOLOGY

3.1 Collection of Data

As the first step, a set of data was collected from the domestic consumers who have already installed Solar Panels on their rooftops under the Net Metering facility provided by CEB or LECO. The data used for the analysis was up to 31st May 2014.

The following information from each consumer was obtained and a database was prepared.

1. Capacity of Solar Panels
2. Cost of installation
3. Monthly Generation
4. Monthly Consumption

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Daily Solar Irradiance data was obtained from Department of Metrological. The data on Electricity tariff over last ten years has been obtained from CEB to predict the future behavior of electricity tariff. The dispatch schedule prepared by System Control centre for last few years and that the data on actual dispatch of each plant has been obtained. The fuel price data using last ten years has been collected from Ceylon Petroleum Corporation.

The sources of data obtained from are listed below.

1. Utility
   i. Ceylon Electricity Board
   ii. Lanka Electricity Company Ltd
   iii. Ceylon Petroleum Corporation
2. Solar Panel Manufacturers and Solution Providers
   i. J Lanka Technologies (Pvt) Ltd

ii. Eco Solar (Pvt) Ltd

iii. Aceess Solar (Pvt) Ltd

iv. Nikini Automation Systems

3. General Public
4. Department of Meteorological, Sri Lanka

3.2 Data Analysis

Most of the net metering customers are located in Colombo and suburbs. As at 31st May 2014, there are 2400 Nos of CEB consumers accounting to 5.2 MW and 540 Nos of LECO consumers accounting to 1.4 MW were registered as Rooftop Solar Net metering consumers which sums to 2640 Nos of consumers.

Table: 3.1 -Solar Net Metering consumers as at 31st May 2014

Utility	No of Consumers	Installed Capacity
CEB	2400	5.2 MW
LECO	540	1.4 MW

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Source: Data obtained from CEB, LECO and SEA

3.3 Case Study

A customer who has large span of data with successful continuous operation since year 2012 has been selected for the detailed analysis.

- **Category** :Domestic- 30A/1 Phase
- **Area** : Colombo South
- **Installed Capacity** : 6.1kW
- **Date of Installation** : 09/07/2012
- **Period of Data Collection** : August 2012 to December 2013

The following Figure shows the Monthly Electricity Generation by solar PV of the selected customer.

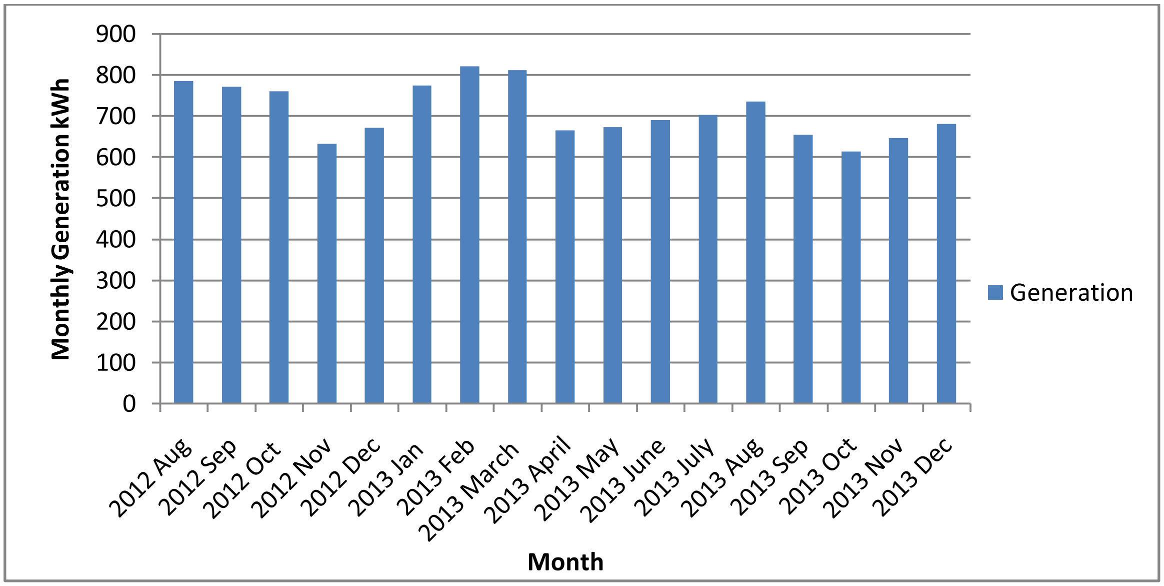

Figure 3.1 Monthly Electricity Generations

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The monthly average generation by 6.1 kW Solar Panel is about 700kWh per month. The maximum generation occurs in the months of March and April.

According to Table: 3.3, Net metering significantly reduces the amount of monthly Billing Units.

Table 3.2: Comparison of Monthly Billing Units with and without Net Metering

Billing Period	Net Generation kWh	Net Import kWh	Net Export kWh	Energy Credit kWh	Consumption from Solar kWh	Billing Units with Net Metering kWh	Billing Units without Net Metering kWh
2012 Aug	784.78	568	511	0	273.78	57	841.78
2012 Sep	770.10	512	534	22	236.10	0	748.10
2012 Oct	760.37	721	469	0	291.37	230	1,012.37
2012 Nov	631.91	690	349	0	282.91	341	972.91
2012 Dec	670.87	622	380	0	290.87	242	912.87
2013 Jan	774.31	832	451	0	323.31	381	1,155.31
2013 Feb	820.16	626	547	0	273.16	79	899.16
2013 March	810.90	775	537	0	273.90	238	1,048.90
2013 April	665.24	674	441	0	224.24	233	898.24
2013 May	671.50	834	505	0	166.50	329	1,000.50
2013 June	689.25	600	374	0	315.25	226	915.25
2013 July	701.50	555	412	0	289.50	143	844.50
2013 Aug	734.50	601	445	0	289.50	156	890.50
2013 Sep	653.57	560	395	0	258.57	165	818.57
2013 Oct	612.48	730	352	0	260.48	378	990.48
2013 Nov	645.00	713	401	0	244.00	312	957.00

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The Figure 3.2 shows the reduction of units of Electricity Consumption due to Solar Net metering.

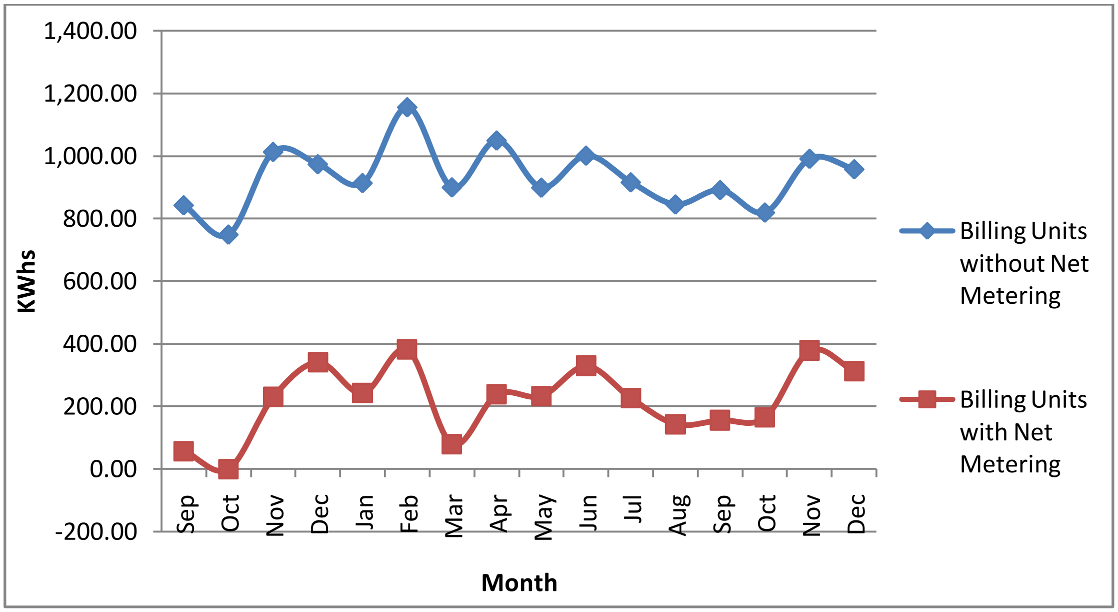

Figure 3.2 Comparison of Monthly Billing Units

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Monthly Bill Saving for each consumer was calculated using the Tariff prevailed during the period of concern.

Example calculation was performed for a particular customer using the actual data.

Generation of the Solar Panel for the month of August	: 770 kWh
Monthly consumption	: 748 kWh
Net Metering Credits (Carry forward)	: -22 kWh
Monthly Bill (for 748 units) in case of Net Metering is not present	: Rs: 38,837.00
Monthly Bill with Net Metering	: Rs: 0
Net Saving per month	: Rs: 38,837.00

The calculated annual saving for this consumer is Rs: 505,060.00.

The above example calculation emphasis that Net Metering is very cost effective for consumers.

Chapter 4
DATA ANALYSIS

4.1 Data Prediction

The available Solar Panel Generation data is from 5 months to 27 months periods. This data has to be predicted over 20 years period since the average life time of a particular Solar Panel is about 20 years. The Electricity generated by Solar Panel is proportional to Solar Irradiance (Isolation).Solar Irradiance varies with Meteorological parameters such as precipitation, temperature and wind. However the average variation of irradiance per year due to above mentioned meteorological parameters is considered as constant.

4.2 Solar Irradiance and Insolation

Irradiance is a measurement of solar power and is defined as the rate at which solar energy falls onto a surface. In the case of solar irradiance, power per unit area is measured. Irradiance is typically quoted as W/m^2 - that is Watts per square meter. The irradiance falling on a surface does vary from moment to moment. Because, irradiance is a measure of power - the rate that energy is falling, not the total amount of energy.

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The total amount of solar energy that falls over a given time is called the insolation. Insolation is a measure of energy. It is the power of the sun added up over some time period. If the sun shines at a constant 1000 W/m^2 for one hour, it has delivered 1 kWh/m^2 of energy. Accordingly, Solar Irradiance is 1000 W/m^2 and Insolation is 1 kWh/m^2. The irradiance varies throughout the year depending on the season. It also varies throughout the day, depending on the position of the sun in the sky, and the weather. Solar Isolation is a measure of solar irradiance over a period of time - typically over the period of a single day.

4.2.1 Colombo Average Solar Insolation

Colombo is situated in 6.9167° N, 79.8333° E coordinates. Monthly Average Isolation data for Colombo for ten years has been obtained from Meteorological Department. The average isolation for each month was calculated and presented in Table: 4.1

Table 4.1: Monthly Average insolation, Colombo.

Month	Monthly Average Isolation kWh/m²/day
Jan	5.44
Feb	6.20
Mar	6.59
Apr	5.87
May	5.20
Jun	5.21
Jul	5.31
Aug	5.56
Sep	5.57
Oct	5.23
Nov	4.88
Dec	5.11

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Source: Department of Meterological, Colombo,Sri Lanka

Monthly average Solar Insolation of Colombo is plotted to observe the pattern of variation. According to Figure 4.1, the highest average insolation of 6.59kWh/m²/day is received in month of March whereas as the minimum occurs in November.

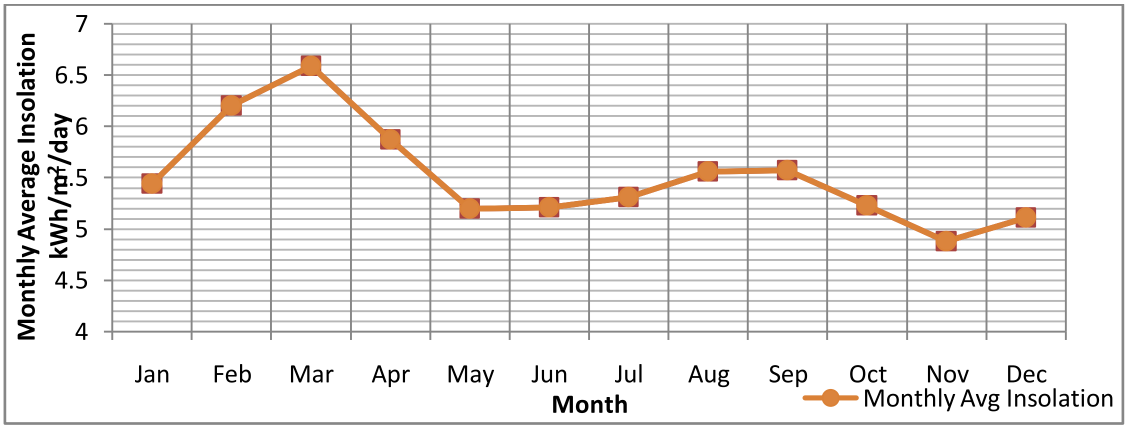

Figure 4.1: Variation of monthly Average Solar Insolation

4.3 Efficiency of Solar Cells

Solar cell efficiency is the ratio of the electrical output of a solar panel to the incident energy in the form of sunlight. The energy conversion efficiency (η) of a solar cell is the percentage of the solar energy to which the panel is exposed that is converted into electrical energy. This is calculated by the following formula:

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$$\text{Solar cell Efficiency } (\eta) = \frac{\text{Power output at maximum power point (W)}}{\text{Input light (W/m}^2) * \text{Surface area of the solar cell (m}^2)}.$$

Manufacturers mention the solar cell efficiencies measured under standard test conditions . Standard test conditions specify a temperature of 25 °C and an irradiance of 1000 W/m^2 with an air mass 1.5 (AM1.5) spectrum. Under these test conditions theoretically average efficiency of solar panel is about 20% [11].

4.3.1 Factors affecting the efficiency of Solar Panels:

The Solar Panel efficiency values quoted by the manufacturer that have been tested under Standard Test Condition are not matched with the module efficiency measured on site under real climate conditions. There are several factors affecting the efficiency of

Solar systems. Basically Temperature, Dust and shade directly affected to the performance of Solar panels resulting reducing the efficiency.

The temperature of PV surface rises with longer exposure period to sunlight and high ambient temperature. The temperature of the solar panel directly impact the PV efficiency. When the temperature increases, Atom vibrations in the p-n junction is increased. Therefore, it obstructs the charge carrier movement and decreases the efficiency. EIA has conducted a study to analyze data from 18 grid connected PV plants located on different geographic locations and it showed a direct relation between temperature and PV module efficiency. The plants were located in Austria, German, Italy, Japan, India, China and Switzerland. The study concluded that 17 out of the 18 systems showed annual losses in efficiency due to temperature changes by 1.7% to 11.3%.The average efficiency reduction in South Asian countries is about 7.5% [16]. A study was conducted on a ploy crystaline PV module with solar tracker on Saudi Arabia showed similar temperature effect. The data were compared based on daily peak power output. PV module efficiency decreased from 5% to 8% when module temperature increased from 35°C to 45°C [17].

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On a typical sunney day, it is not uncommon for a solar cell to reach an average temperature of 40 °C. The efficiency of so solar cells can decrease more than 0.5% for every 1 °C above 25 °C. When the temperature increase beyond 25 degree Celcius, the efficiency of solar panel reduces. Because sunlight consists invisible infrared radiation, which carries heat. The solar panel will perform great if it gets a lot of light, but as it gets hotter, its performance degrades.It has been identified that for each degree over 25˚C, the maximum power of the panel is reduced by 0.5% [18].

The accumulation of dust on solar panels (Soiling) can have a significant impact on performance of PV systems. The performance reduction due to dust depends on several factors such as the location of the PV system, orientation, rainfall and wind. There are several studies has been conducted to identify the effect of dust on efficiency of solar panels. There are several studies has been conducted to assess the impact of dust accumulation on solar panels to their performance. A study has been conducted to concentrate on the effects of settling dust on photovoltaic solar panels in Israel [19]. It was concluded that regular dust accumulation decreases the efficiency of solar photovoltaic panels by about five to six percent. A study conducted on "Effects of Dust on the Performance of PV Panels" [20] has been concluded that it causes 6% decrease in the solar panel efficiency due to dust in urban areas expose to normal environment.

By summarizing above values obtained from different literatures, the actual efficiency of Solar Panel is considered as 9% after accounting the effect of temperature and dust.

Table 4.2: Effect of temperature and dust for the efficiency of the solar panel

Manufacturer Quoted Efficiency under Standard Test Conditions	**Efficiency reduction due to the effect of Temperature rise (40^oC)**	**Efficiency reduction due to the Effect of Dust**	**Actual Efficiency**
20%	7.5%	6%	9%

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Considering the effect of Temperature rise and the accumulated dust on the solar panel the actual efficiency of the solar system is considered as 9%.The actual data obtained from several solar systems has been used to examine the accuracy of considering 9% as the solar panel efficiency for the analysis.

In practical case, following formular has been used to calculate the Solar Panel Efficiency(η).

- Solar Panel Efficiency(η) $= \frac{\text{Actual Generation Output kWh/m}^2\text{/Day}}{\text{Average Solar Insolation kWh/m}^2\text{/Day}} * 100\%$

Solar Panel efficiency (η) is the ratio of the electrical output of a solar Panel to the incident energy in the form of sunlight. It is calculated by dividing a panel's power output (in $kWh/m^2/Day$) by the Average input Solar Insolation (in $kWh/m^2/Day$)

To calculate the Solar Panel Efficiency, the actual data obtained from each customer is plotted to obtain a comparison between the meteorological data and the actual data. Monthly actual solar panel output of randomly selected customers and their efficiencies are tabulated below.

Customer 1:

Installed Capacity: 1 kW

Area of the Solar Panel: 8 m^2

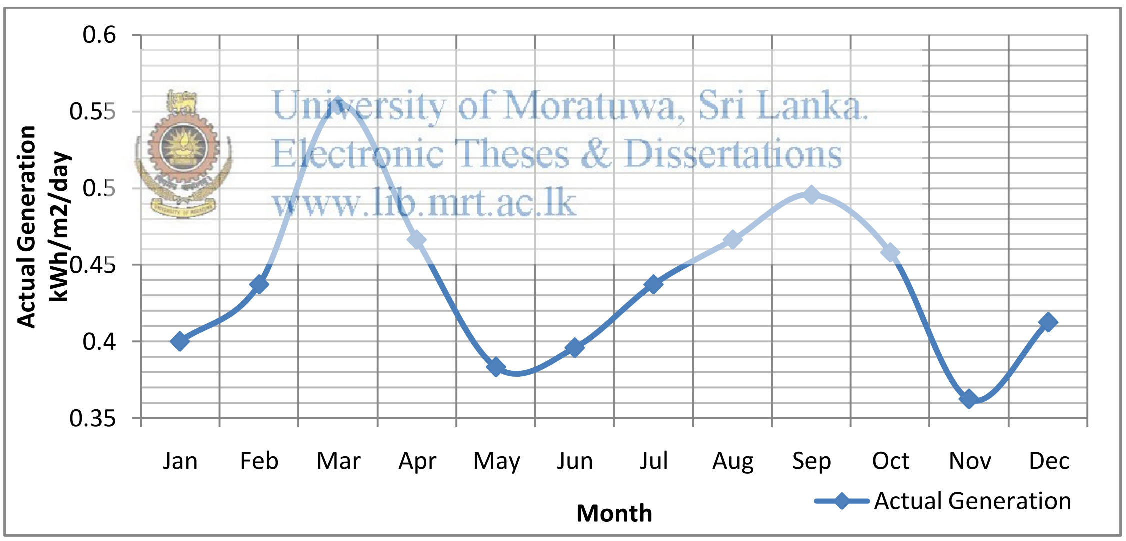

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Figure 4.2: Actual Generation of 1 kW Solar Panel

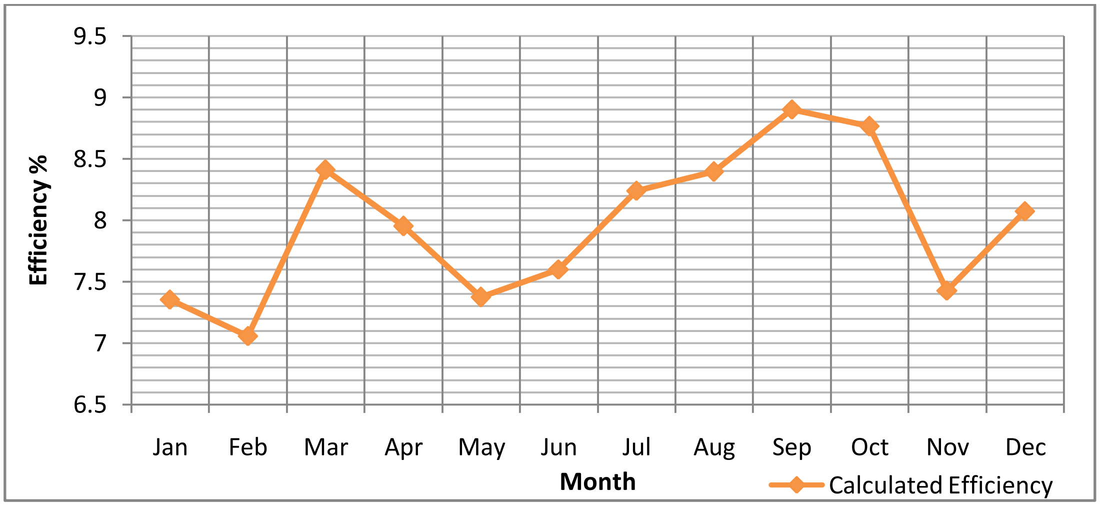

Figure 4.3: Calculated Solar Panel Efficiency

Customer 2:

Installed Capacity: 2.2 kW

Area of the Solar Panel: 17.5 m^2

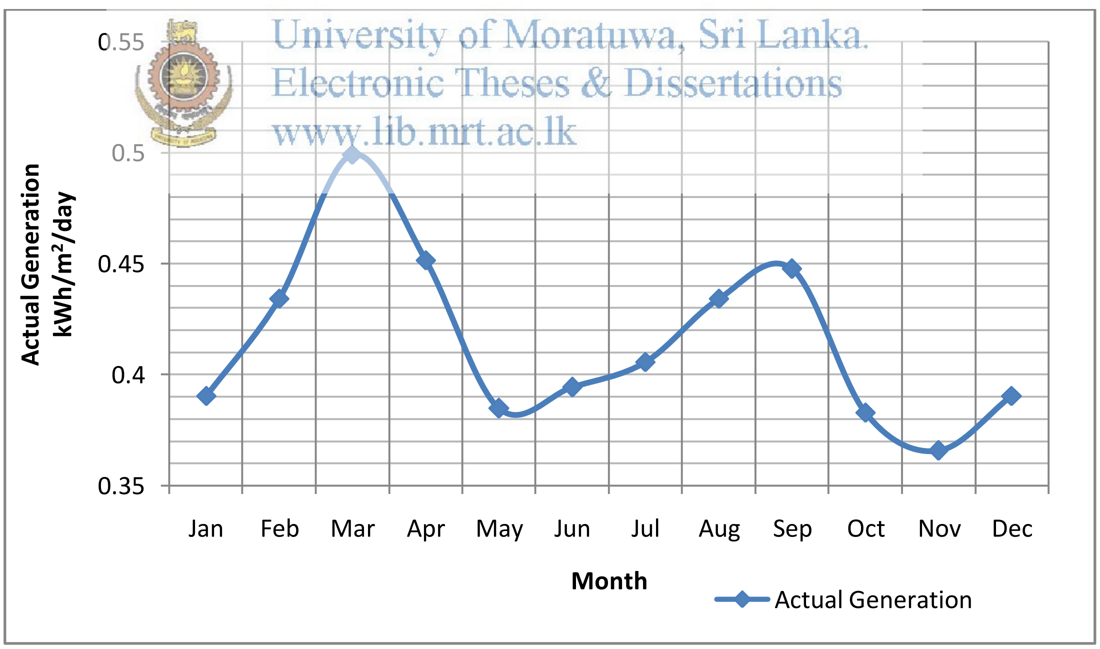

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Figure 4.4: Actual Generation of 2.2 kW Solar Panel

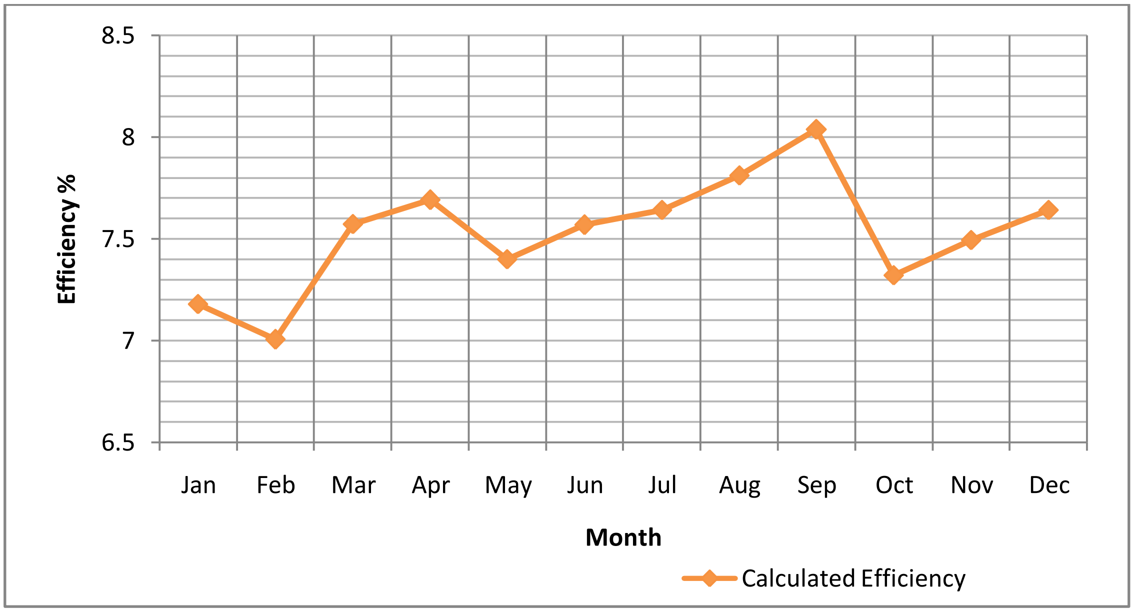

Figure 4.5: Calculated Solar Panel Efficiency

Customer 3

Installed Capacity: 6 kW

Area of the Solar Panel: 49 m^2

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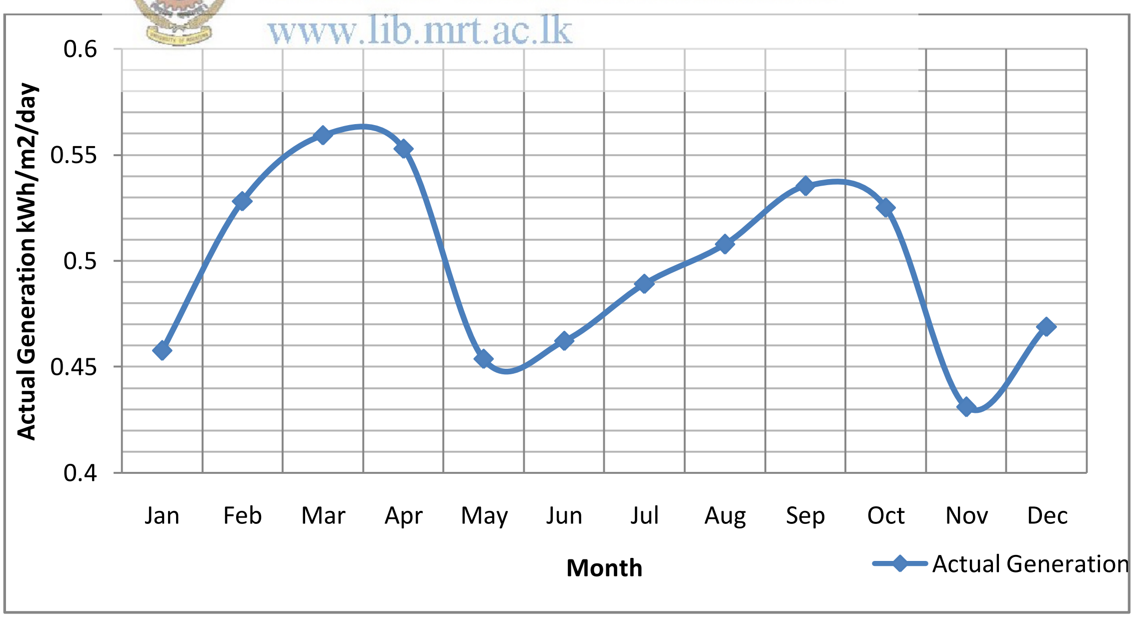

Figure 4.6: Actual Generation of 6 kW Solar Panel

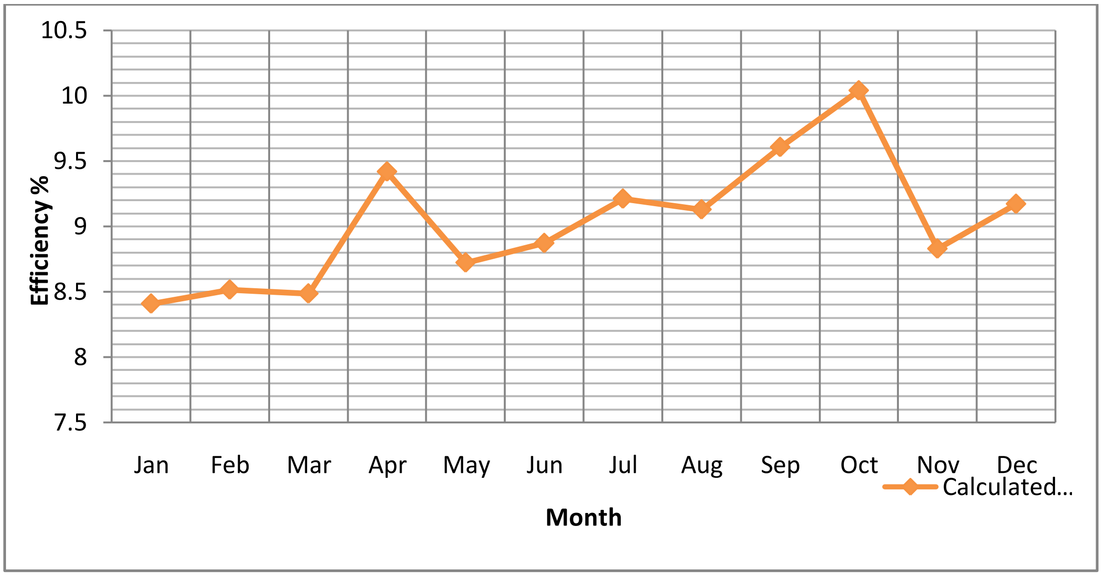

Figure 4.7: Calculated Solar Panel Efficiency

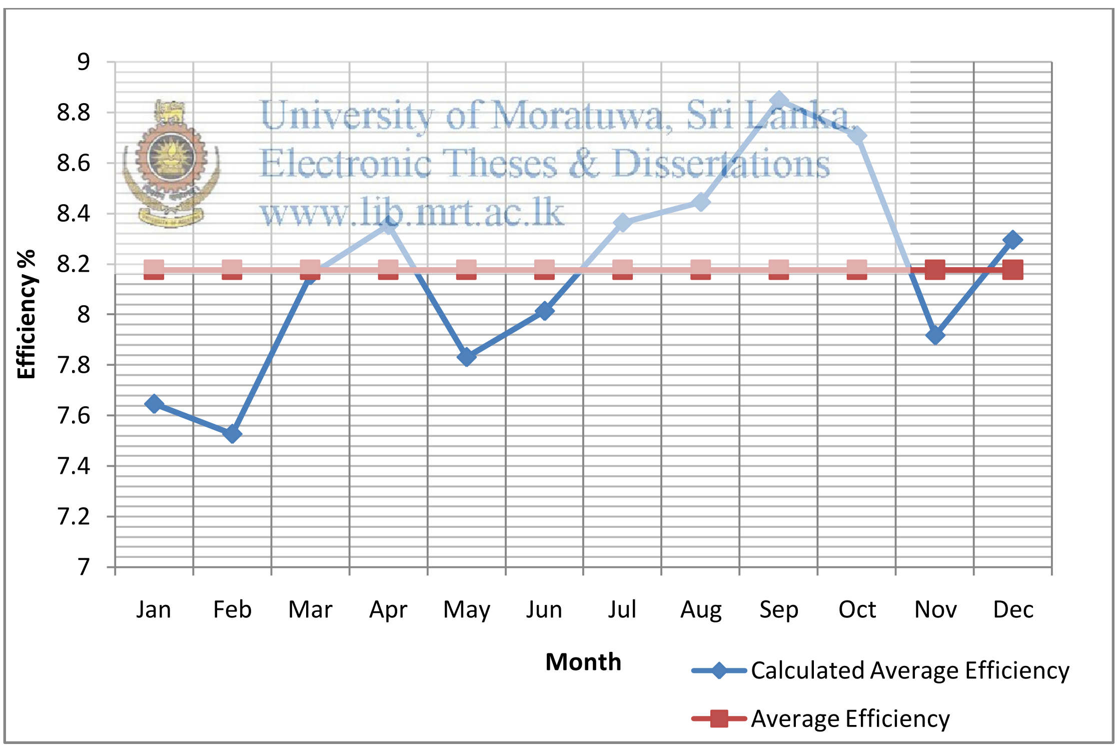

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Figure 4.8: Calculated Average Efficiency

The calculated average Efficiency of solar system is 8.18 % for the actual situation. However it is close to the findings of researches explained above. Therefore the efficiency of solar systems is considered as 9% for the analysis.

4.4 Solar Panel output degradation

It is very important to predict the power delivery by a solar panel over the lifetime. The rate, at which power generation decline over the time is called as degradation rate. It is an essential factor to utility companies, integrators, investors, and researchers. Solar panels degrade naturally over time because they are designed to react to photons that strike the surface. A good quality and well looked after solar panel can last around 20 years with good output. Technically, degradation mechanisms are important to understand because they may eventually lead to failure. Financially, degradation of a PV module is important, because a higher degradation rate leads to less power produced and, therefore, reduces future cash flows.

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According to a Research [1] conducted by NREL, the average degradation rate for PV Solar Panel Modules is 1% per year. Therefore panel degradation per year is assumed as 1% throughout the analysis.

4.5 Sunspot

Sunspots are cooler regions of the Sun's surface that appear dark against their brighter, hotter surroundings. The amount of sunspots on the Sun varies from a minimum to a maximum over an eleven year cycle. The reason for this variation has not been found yet. Solar irradiance is proportional to sunspot number according to National Oceanic and Atmospheric Administration's (NOAA's) National Geophysical Data Center (NGDC). The following graph shows the relationship between Sunspot Number and Solar Irradiance.

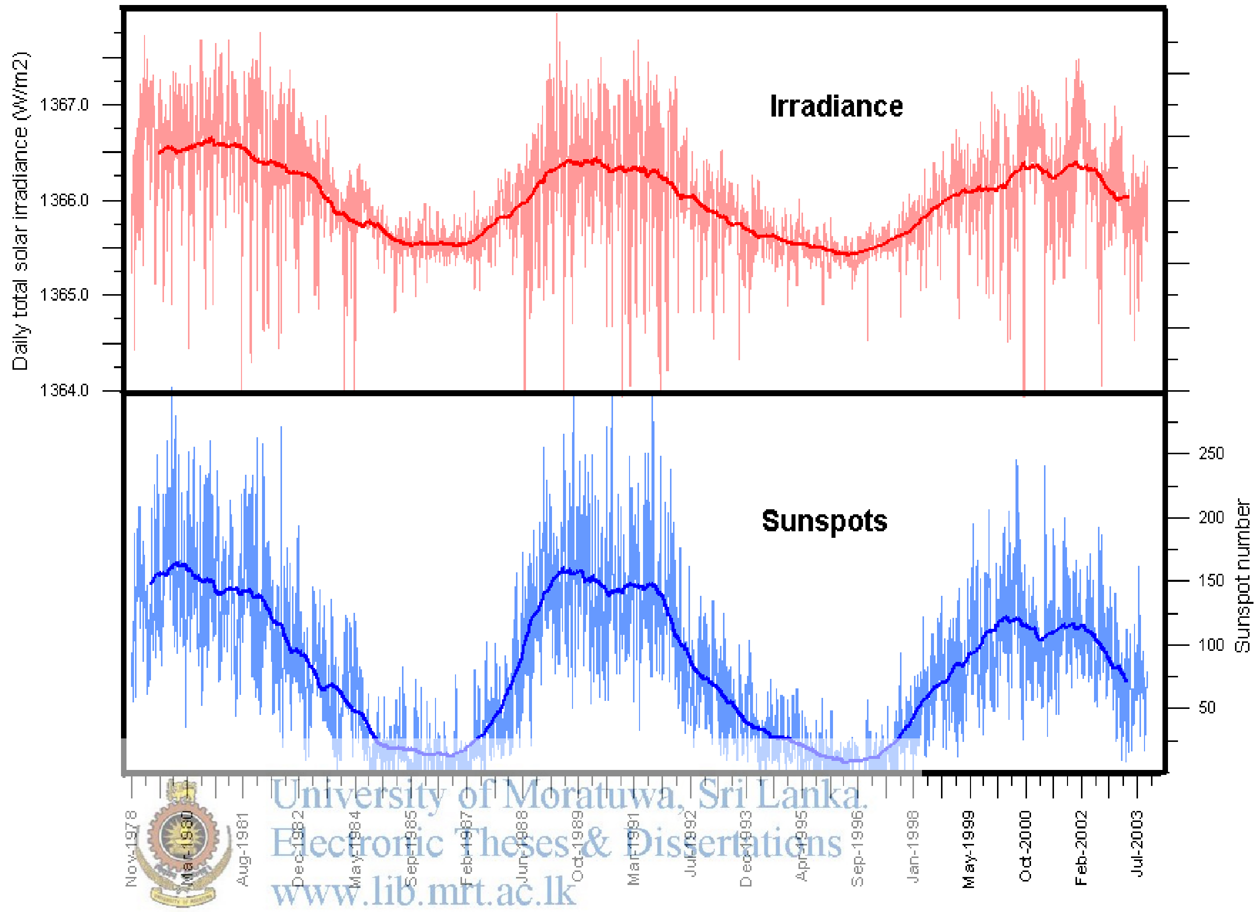

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Figure 4.9: Relationship between Sunspot number and Solar Irradiance

Source: National Geophysical Data Center (NGDC) http://www.ngdc.noaa.gov

Sunspot Numbers and Solar Irradiance from 1997 to 2012 have been studied and the graph of Sunspot Cycles and graph of Solar Irradiance were plotted to obtain the relationship.

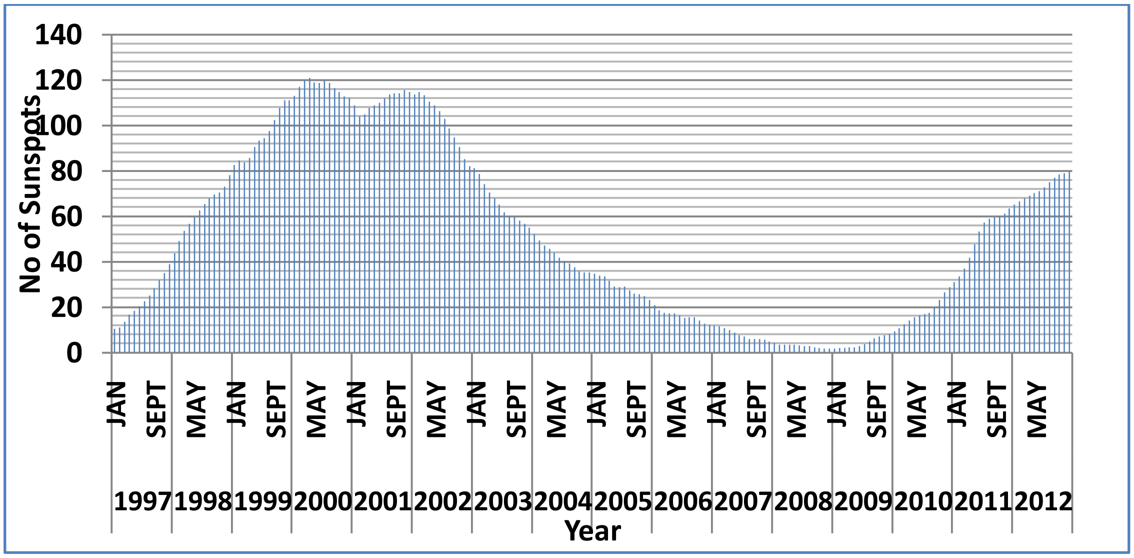

Figure 4.10: Sunspot cycles from 1997 to 2012

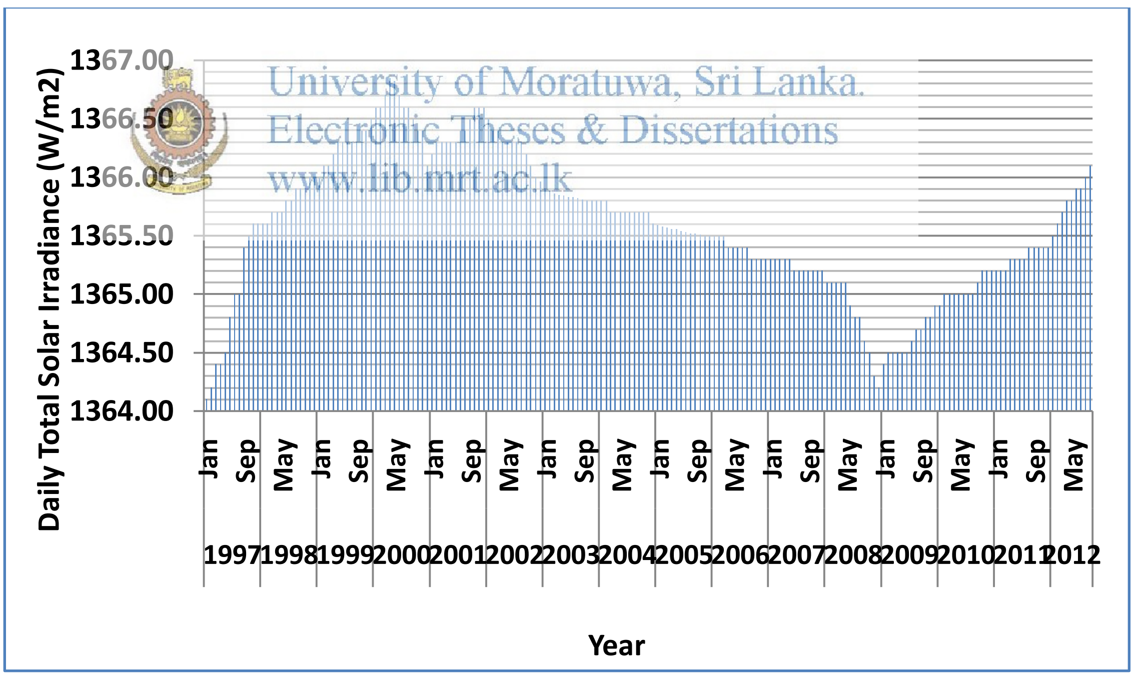

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Figure 4.11: Daily Total Solar Irradiance from 1997-2012

Table 4.3: Variation of Solar Irradiance with the at maximum and minimum Sunspot number.

	Sunspot Number	**Solar Irradiance**
Worst year within the sunspot Cycle	1.70	1364.3 W/m^2
Best year within the sunspot Cycle	120.80	1366.85 W/m^2

The total variation of solar irradiances during one sunspot cycle

$$= \frac{(1366.85-1364.3) \times 100\%}{(120.80-1.70)}$$

$$= 2.14\ \%$$

NGDC has predicted Sunspot Numbers expected in future. The data from 1997 to 2032 (period considered for the research) has been obtained and plotted the following graph.

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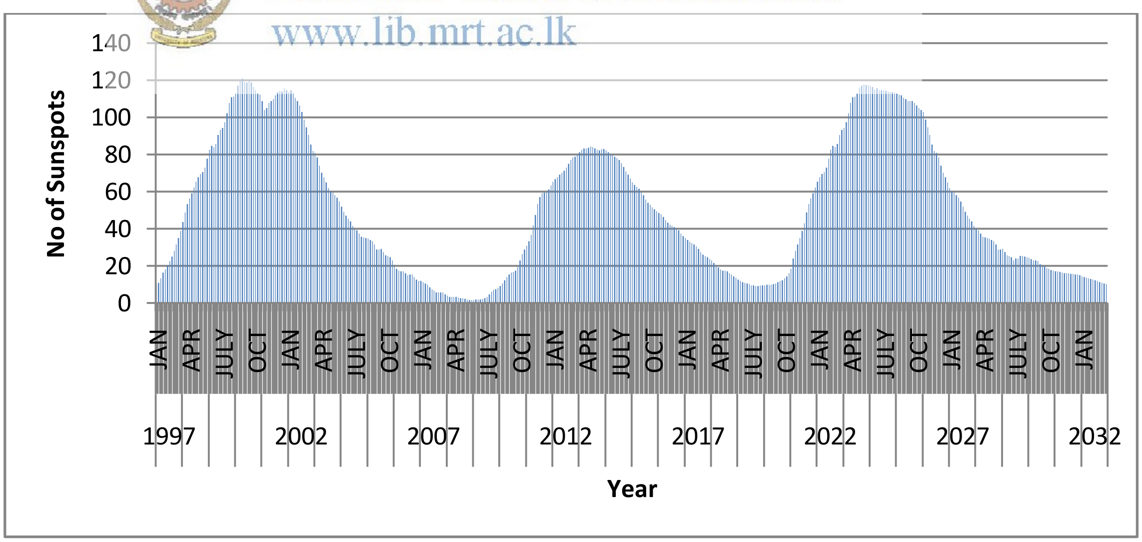

Figure 4.12: Variation of sunspot number -from 1997 to 2032

There are only two sunspot cycles occurs from 2012 to 2032.According to the above finding, the average variation of solar irradiance during a sunspot cycle is about 2%. Therefore, effect of Sunspots on Solar Irradiation was neglected and assumed constant throughout the study. Solar Irradiance during 20 years period (period of concern for the study) is considered as 1366 W/m^2.

4.6 Tariff Variation

The electricity tariff of Sri Lanka is increasing rapidly. The following table explains the manner it has been increased during last 13 years from year 2000.

Table 4.4: Variation of energy charge for domestic consumer category

Block	from 1-06-2000	From 1-04-2002	from 1-08-2002	from 1-02-2006	from 2006-09-01	from 2007-02-01	from 2008-03-15	from 2008-11-01	from 2011-01-01	from 2013-04-20
0-30	2.40	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
31-60	2.90	4.00	3.70	3.70	4.70	4.70	4.00	4.70	4.70	4.70
61-90	2.90	4.40	4.10	4.10	5.10	7.50	5.50	7.50	7.50	12.00
91-120	5.50	10.60	10.60	10.60	12.10	14.00	10.00	16.00	21.00	26.50
121-180	5.50	10.60	10.60	10.60	12.10	14.00	11.00	25.00	24.00	30.50
>180	7.20	15.80	15.80	15.80	17.30	19.80	15.00	30.00	36.00	42.00
240-360							18.00			
360-600							21.00			
>600							25.00			

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Table 4.5: Variation of fixed charge over years for domestic consumer category

<table>
<tr><th></th><th>from 2013-04-20</th><th>from 2011-01-01</th><th>from 2008-11-01</th><th>from 2008-03-15</th><th>from 2007-02-01</th><th>from 2006-09-01</th><th>from 1-02-2006</th><th>from 1-08-2002</th><th>from 1-04-2002</th><th>from 1-06-2000</th></tr>
<tr><td>0-30</td><td>30</td><td>30</td><td>60</td><td>60</td><td>60</td><td>60</td><td>60</td><td>30</td><td>30</td><td>30</td></tr>
<tr><td>31-60</td><td>60</td><td>60</td><td>90</td><td>90</td><td>90</td><td>90</td><td>90</td><td>30</td><td>30</td><td rowspan="2">30</td></tr>
<tr><td>61-90</td><td>90</td><td>90</td><td>120</td><td>90</td><td>120</td><td>120</td><td>120</td><td>30</td><td>30</td></tr>
<tr><td>91-120</td><td>315</td><td>315</td><td>180</td><td>90</td><td rowspan="2">180</td><td rowspan="2">180</td><td rowspan="2">180</td><td rowspan="2">30</td><td rowspan="2">30</td><td rowspan="2">30</td></tr>
<tr><td>121-180</td><td>315</td><td>315</td><td>240</td><td>90</td></tr>
<tr><td>>180</td><td rowspan="4">420</td><td rowspan="4">315</td><td rowspan="4">240</td><td>90</td><td rowspan="4">240</td><td rowspan="4">240</td><td rowspan="4">240</td><td rowspan="4">30</td><td rowspan="4">30</td><td rowspan="4">30</td></tr>
<tr><td>240-360</td><td>90</td></tr>
<tr><td>360-600</td><td>90</td></tr>
<tr><td>>600</td><td>3000</td></tr>
</table>

The following graph describes the block wise tariff variation from year 2000 to 2013 for domestic consumers.

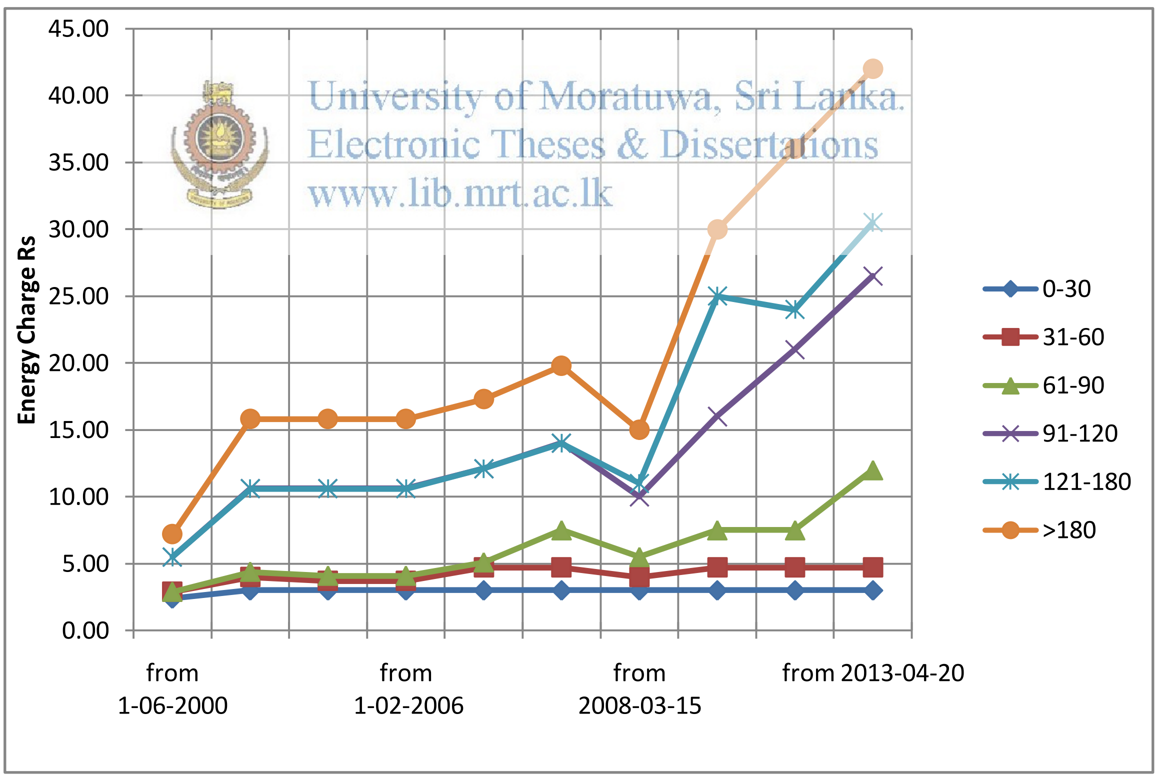

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Figure 4.13: Block wise variation of Energy Charge for Domestic Consumers

According to the graph 4.13, the tariff of the lowest block remains at Rs: 3.00 for 13 years. The Tariff up to block 3 has not been changed significantly. However, an exponential increase of Tariff from last three blocks can be seen after 2008.

The average tariff escalation rate during period of 13 years (from year 2000 to 2013) is calculated using the above information and tabulated below.

Table 4.6: Block wise Tariff escalation rate and % tariff escalation per year

Block	Tariff Escalation Rate over 13 years	% Tariff Escalation per year
0-30	25.00	1.9230769
31-60	62.07	4.7745358
61-90	313.79	24.137931
91-120	381.82	29.370629
121-180	454.55	34.965035
>180	483.33	37.179487

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Percentage tariff escalation per year has been calculated and forecasted the tariff from 2014 to 2032. The following graph shows the forecasted tariff for each block up to 2032.

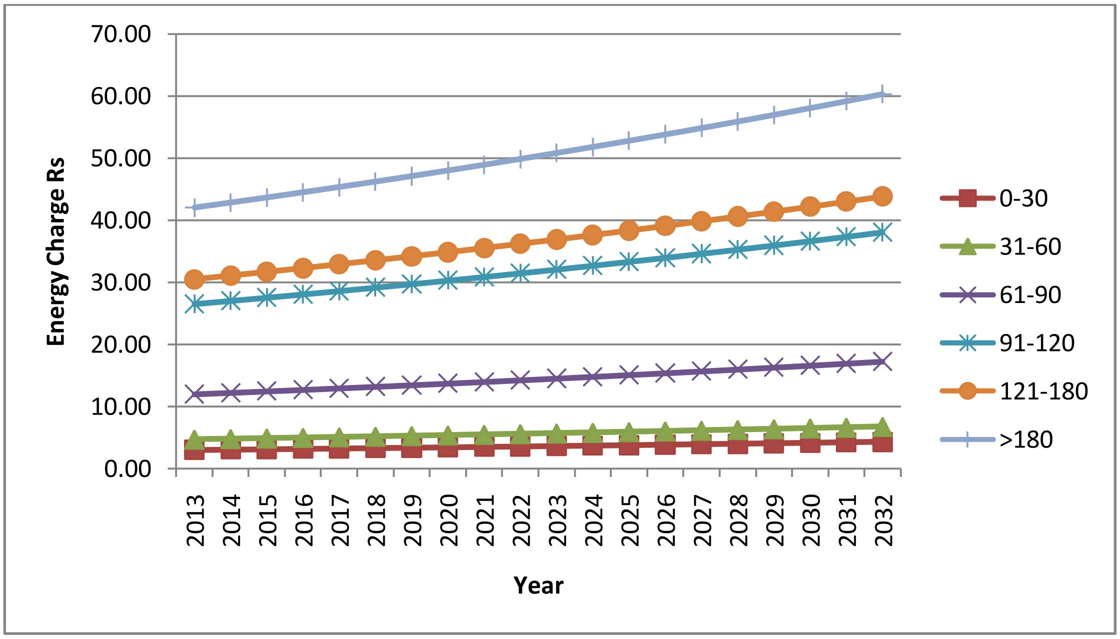

Figure 4.14: Forecasted Block wise Tariff from 2013 to 2032

The above projected tariff has been used to calculate the financial indices.

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4.7 Lifetime of Solar PV

The financial life for a solar PV system is usually considered to be the manufacturer's guarantee period which is often 20 to 25 years. However, research has shown that the life of solar PV panels is well beyond 25 years. Life times of 30 year or more is realistic.

For solar PV, the Operation and maintenance costs are due to replacing inverters (usually every 10 years), occasional cleaning and electrical system repairs. Economic life of the system depends on the acceptable energy output, which depends on the degradation rate (rate at which there is a reduction in output). It has been found that, more than 65.7% of panels are below the 1% per year degradation rate. The end of life of the system has not been reached once the power output still satisfies the user. Gradual degradation occurs due to chemical and material processes associated with weathering, oxidation, corrosion, and thermal stresses. Considering above factors, the average economic life for rooftop solar PV modules are taken as 20 years for economic calculations.

4.8 System Costs

The cost of Solar Panels has been reduced drastically during last few years. The main reason behind that is the introduction of Chinese products to the market. As the demand for systems rises and manufacturing volume increases, costs will decrease. It leads to reduction of economic payback time of future investments. The following graph shows the variation of the cost of Crystalline Silicon PV Cells with time.

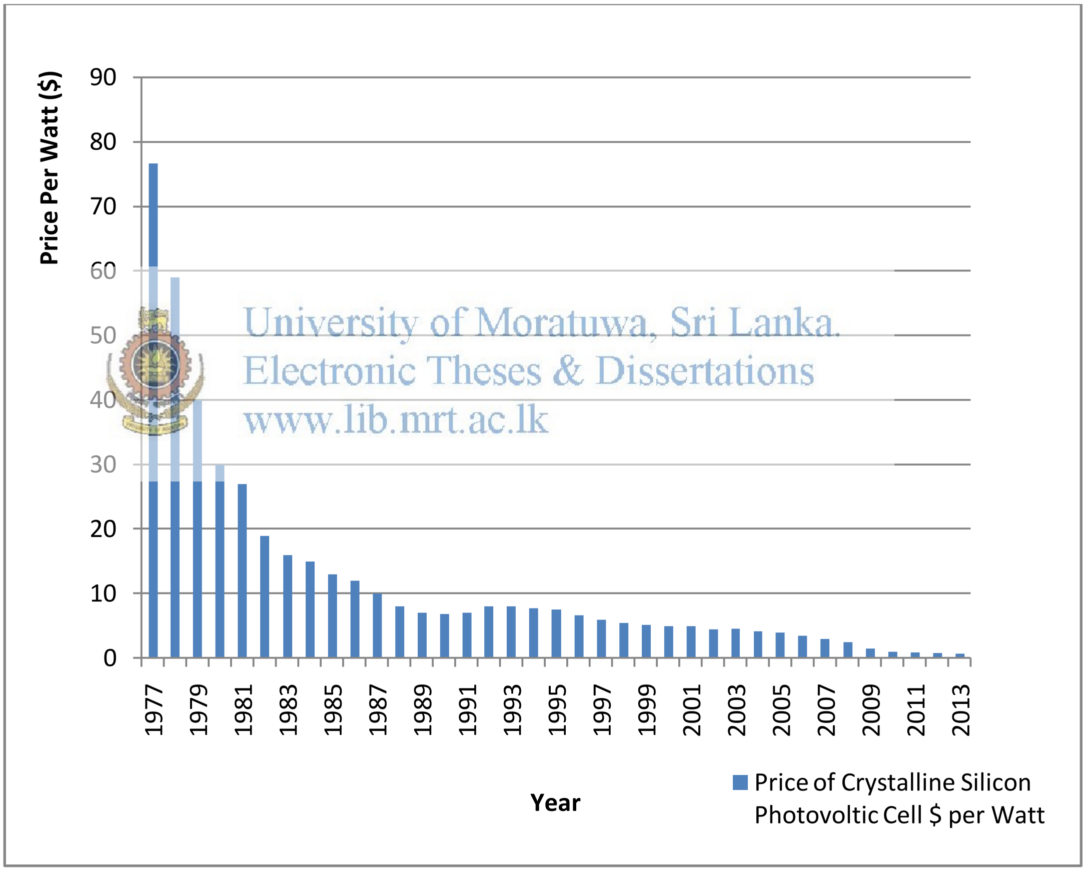

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Figure 4.15: Price reduction of Crystalline PV Cells

Source: International Energy Agency: www.iea.org

As seen from the above figure, solar cell prices have come down by a factor of 100 over the last 35 years. The 2013 average price expected was to be $.0.74. The sharp drop has been occurred due over production, especially in China, which has caused prices to collapse. The Figure 4.16 shows the Price variation of Chinese Solar Cells during last few years.

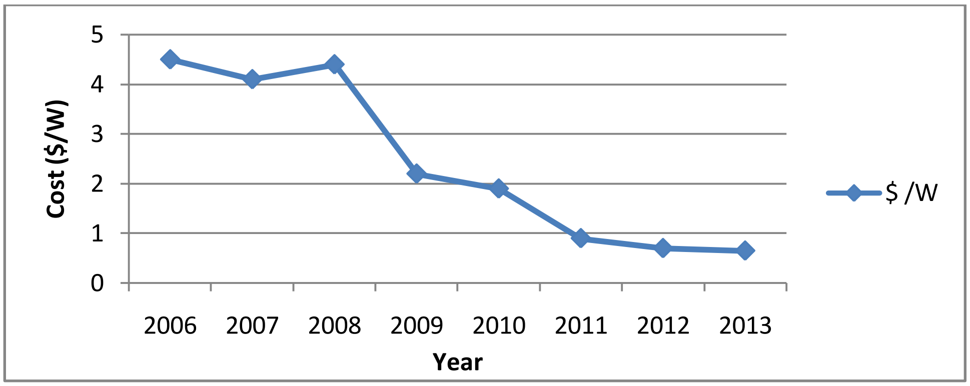

Figure 4.16: Price variation of Chinese Solar Cells

Source: International Energy Agency: www.iea.org

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As seen from the Figure 4.16, recent solar cell prices have had a dramatic price reduction. From 2006 to 2011, a five year span, Chinese "cell" prices have dropped 80% from $4.50 per watt to about $.90 per watt, an incredible drop. The main reason crystalline silicon cell prices dropped was because the price of the raw material poly silicon, which makes up a very significant part of the total cost, dropped so tremendously.

In addition to the poly silicon issue, the decline is also being driven by the increasing efficiency of solar cells and dramatic manufacturing technology improvements.

The price of a PV system depends on the overall size and complexity of the system.In order to begin the calculations, at first, it is required to determine the initial costs. The cost of solar panel depends on the capacity, technology and the manufacturer's identity. The initial cost components that make up a residential solar system are: system design, solar modules, inverter, bi-directional billing meter, connection devices, and installation labor.

The total average cost of solar systems installed in Sri Lanka during the period of research is shown in Table 4.5.The data has been obtained from Solar System solution providers in Sri Lanka and interviewing consumers who has already made the investments on Soalr Systems.

Table 4.7: Average Cost of installed Solar Systems

Capacity of the System kW	Average Cost LKRs	Capacity of the System kW	Average Cost LKRs
1	650,000	4.5	1,225,000
1.5	700,000	5	1,300,000
2.2	750,000	5.5	1,450,000
2.5	850,000	6	1,650,000
2.8	870,000	6.5	2,000,000
3	900,000	8	2,700,000
3.25	950,000	10	3,350,000
3.7	1,100,000	12	4,200,000
4	1,130,000	16	5,750,000

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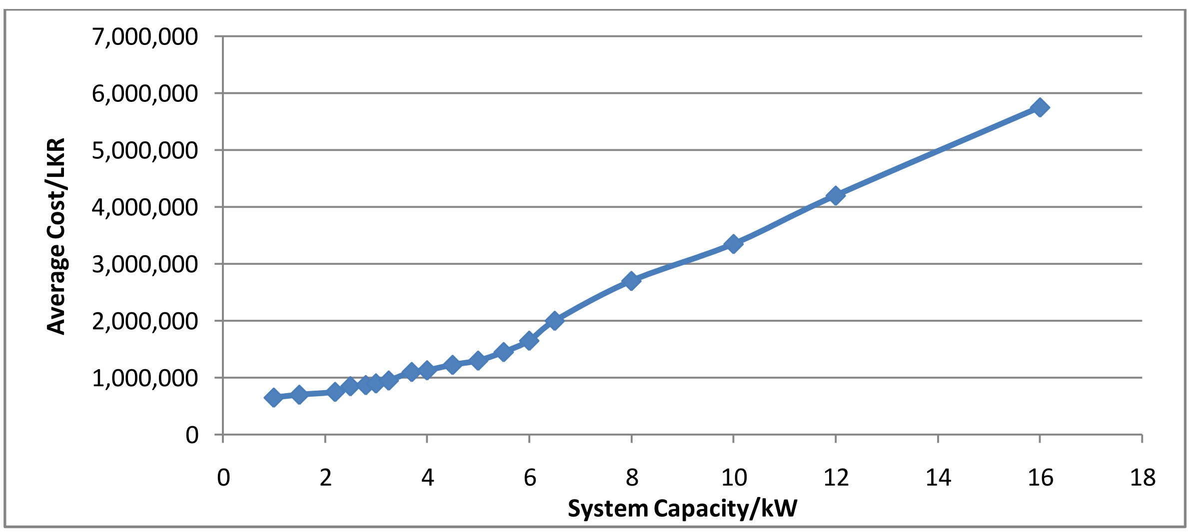

Figure 4.17: Average Cost of installed Solar Systems

According to Figure No 4.17, the rate at which the module cost increase is sharp when the System capacity exceeds 6kW.

The initial cost of installation is the cost for year zero. Normally inverter has to be replaced after 10 years of the operation. The electrical installation cost and annual maintenance cost should be taken into account for determining the system cost. Therefore, following assumptions are incorporated with the system cost calculation.

System Cost is calculated based on following assumptions.

- Lifetime of the System is 20 years.
- The inverter is replaced at the 10^{th} year. The cost of replacement is 10% of the initial investment.
- The annual maintenance cost is 1% of the total initial cost.

Then, the total cost of the system throughout the life time is calculated.

4.9 Discount Rate

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The discount rate refers to the interest rate used in discounted cash flow (DCF) analysis to determine the present value of future cash flows. The discount rate in DCF analysis takes into account not just the time value of money, but also the risk or uncertainty of future cash flows; the greater the uncertainty of future cash flows, the higher the discount rate. For any single project the discount rate will affect whether the NPV is greater or less than zero. For comparing projects, the discount rate will affect the NPV ranking. For the analysis, the discount rate is considered as 6%.

Chapter 5
ECONOMIC ANALYSIS

Solar PV systems vary greatly in size and cost. Calculating the economics of a Solar System is a key to understanding whether a solar system is right for the investors. It is very useful to households and Industries considering the installation of a solar energy system as a means of cutting their utility bills.

Standard financial analysis is applied to compute Payback Period, Net Present Value (NPV) and Internal Rate of Return (IRR). This study is focused on residential rooftop PV Systems in Sri Lanka.

Economic calculations are done based on following assumptions.

- Lifetime of the System is 20 years.
- The inverter is replaced at the 10^{th} year. The cost of replacement is 10% of the initial investment.
- The annual maintenance cost is 1% of the total initial cost.
- The efficiency of the solar panel is 9%.
- Electricity tariff escalation is in accordance with Table No: 4.6 & Figure No: 4.14.
- Discount rate is 6%.
- Panel output degradation rate is 1% per year.
- Average Solar irradiance is constant over 20 years period.

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5.1 Simple Payback Period

It is essential to determine the ability of consumers to afford solar panels and how long it takes to meet their initial investment. With basic information on the system price, and the value of the electricity generated, it is possible to calculate the payback time on the investment using discounted cash flow analysis. As the demand for system rises and manufacturing volume increases, costs of solar panels will decrease and the economic payback time will also decrease for future investments.

The simplest financial metric is simple payback period. This is simply the number of years in the future when the sum of the expenses (negative cash flows) is equal to the sum of the income/savings (positive cash flows). If the expense is all up-front, and the income/savings are consistent year-to-year, payback period can be calculated with simple division:

$$\textbf{Simple Payback Period} = \frac{\textbf{Investment}}{\textbf{Income or Savings}}$$

This form of the metric is widely used due to its simplicity, despite its limitations. Since the future savings generated by a solar system are unlikely to be constant and because it ignores the time-value of money, this metric is not exactly accurate for this kind of analysis.

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5.2 Simple Payback Period calculation

Step 1: Calculating the cost of Investment

The total investment is the summation of initial cost, maintenance cost and the inverter replacement cost. Initial cost includes the cost of purchasing solar panels and the cost of installation.

Step 2: Calculating System Savings

The next step in a payback calculation for a PV system is to figure out how much money the system will save each month. The output of a PV system can be estimated with good accuracy based on the specifications of the system installation and the solar insolation data.

Following data is available with the System

- Monthly output of the Solar PV System. (G)
- Average household consumption (from Solar PV). (C)
- The import register of the Energy Meter records the number of units have been imported (I)
- The export register records the exported units (E)

Monthly Billing Units with Net Metering	=	I-E
Monthly Billing Units without Net Metering	=	C+I

The Energy Bill with Net Metering and without Net Metering can be calculated separately. Based on this analysis, annual cost savings for the system can be determined.

It is required to know how much energy that solar panels are going to produce during the 20 years of life time. For a worst case scenario, 80% of that number is taken.
The expected monthly electricity bill without Solar Net Metering and with Solar Net Metering was calculated separately. The difference shows the amount can be saved per month.

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Step 3:

Now for the final step, the cost for initial installation adds discounted annual maintenance cost and inverter replacement cost and divides it by the yearly savings. The value is the payback period in years. This number represents the number of years it will take to recoup the investment.

After this number of years, the monthly saving is the profit to customer. Obviously it shows how the customer can save money in the long run by investing in green energy.

The less expensive the solar system and the higher the regular electricity rate, the faster the payback can be achieved on the system.

1kW Solar Panel

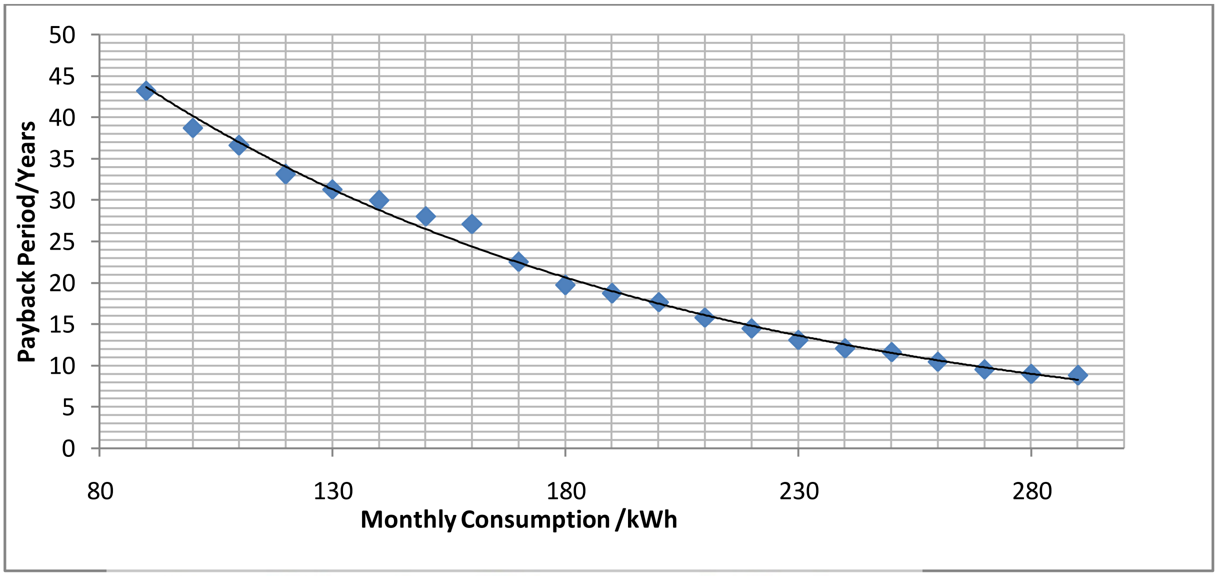

Figure: 5:1 Payback Period of 1kW Solar Panel

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2kW Solar Panel

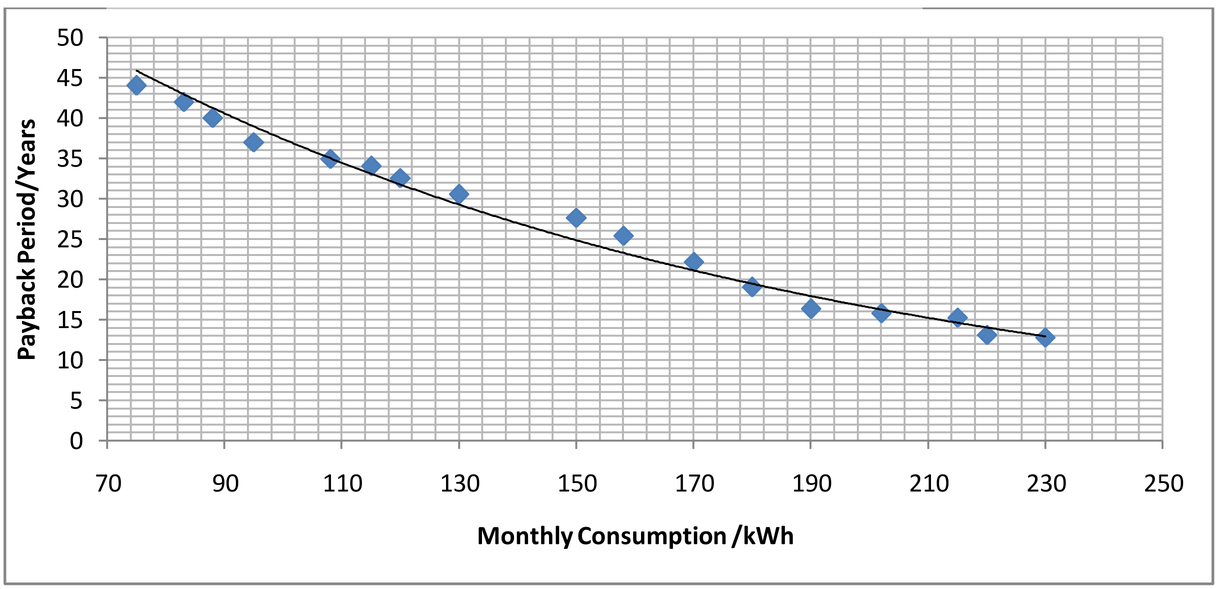

Figure 5:2: Payback Period of 2kW Solar Panel

3kW Solar Panel

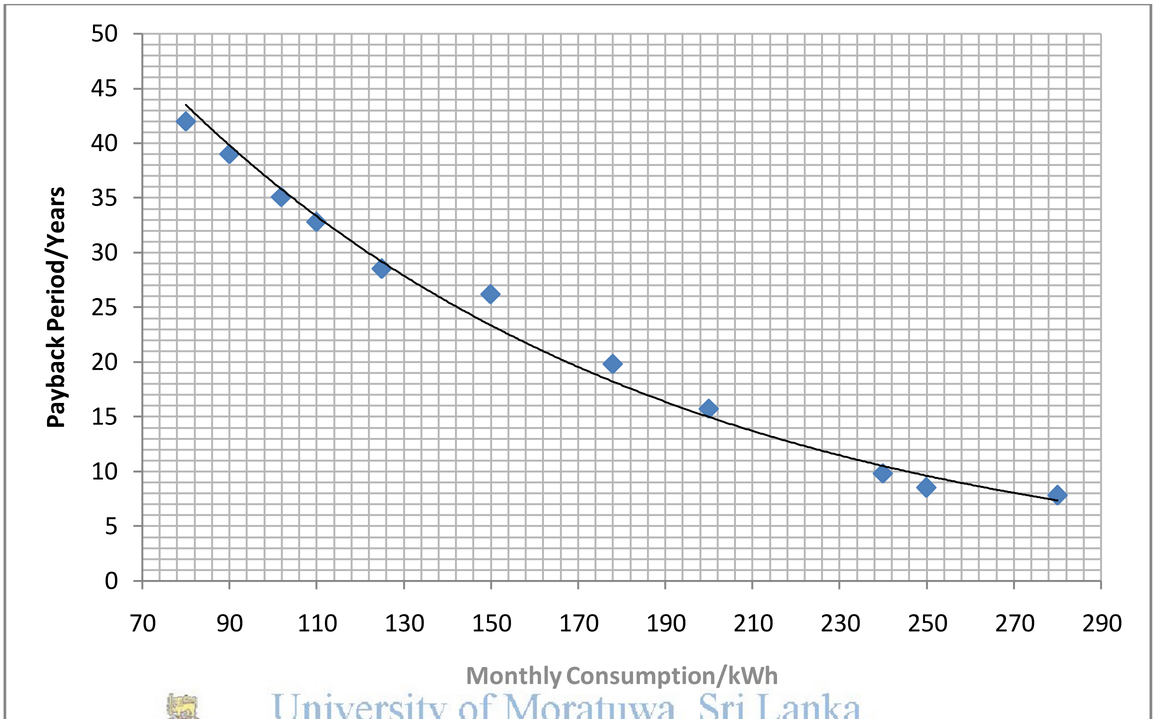

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Figure 5.3: Payback Period of 3kW Solar Panel

According to above graphs, Payback period falls below 20 years when the monthly consumption exceeds 170 kWhs. People who consume less than that are unable to benefit financially.

When all the data is plotted in a single graph irrespective of the Solar panel capacity, following graph can be obtained.

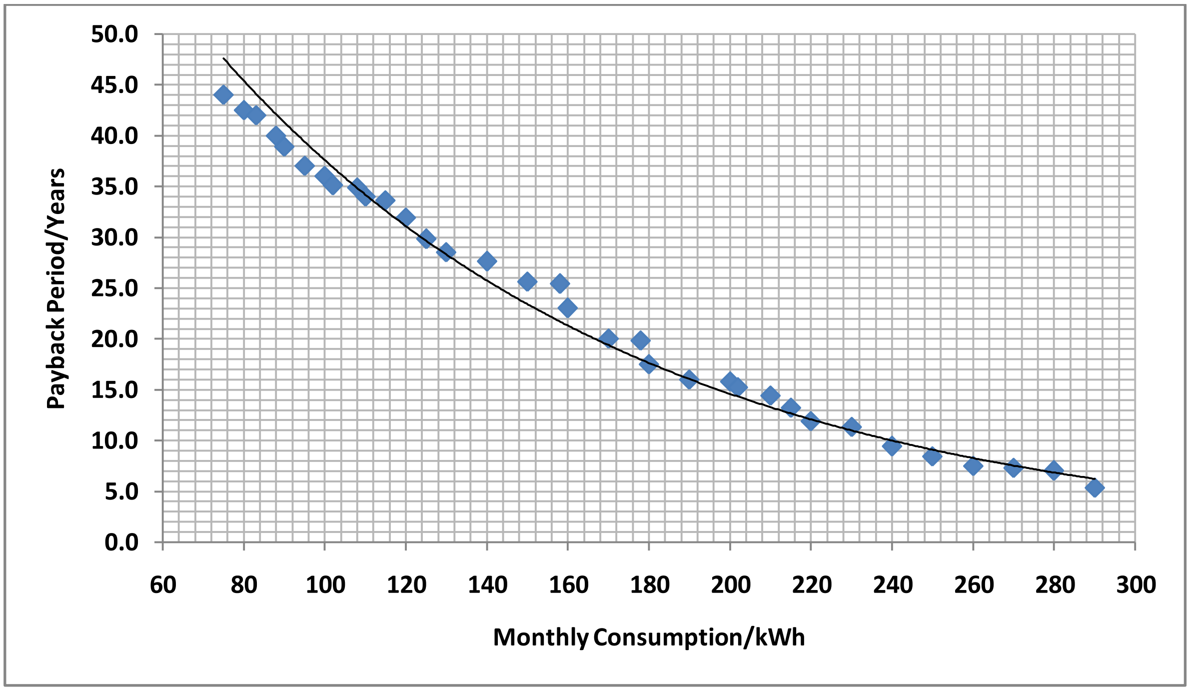

Figure 5.4: Payback Period of Solar Panel against monthly consumption

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As shown in above graph, payback period varies with the net electricity consumption. Consumers who consume fewer units are not likely to get benefits. It means that they are unable to meet their investment during the lifetime of the solar panel. Since we consider the life time of solar panels is 20 years, very few numbers of consumers are getting the benefit. That group is the people who consume more than 170 kWh per month.

5.2.1 Sensitivity Analysis

Above calculation has been performed assuming that the tariff variation in future is at the same rate at which it increased in last 13 years from 2000. During last 13 years, the power sector was highly depending on fossil fuel burn thermal plants where the operating cost is extremely high. But Sri Lanka is rapidly moving towards Coal fired plants while existing thermal plants are retiring from the system.CEB has already commissioned the 900MW Coal power plant in Norochchole. A new coal plant in

Sampur is under construction. According to the long term Generation expansion plan prepared by Generation Planning Division of CEB, there are 11 Nos of Coal fired plants in the pipeline which will contribute 3700 MW to the System at the end of year 2032.Therfore the unit cost of generation will reduce and the tariff variation may deviate from the rate at which it varied from Year 2000 to 2013.

Considering above facts, a sensitivity analysis is performed and calculate the Payback Period considering two scenarios of Tariff variation.

1. Tariff is constant from Year 2013.
2. Tariff escalation rate is half of the rate at which tariff has increased during last 13 years (Year 2000-Year 2013).

Scenario 1: Tariff is constant from Year 2013

Payback period has been calculated assuming that the electricity tariff announced for year 2013 is remained unchanged throughout the lifetime of the solar systems considered.

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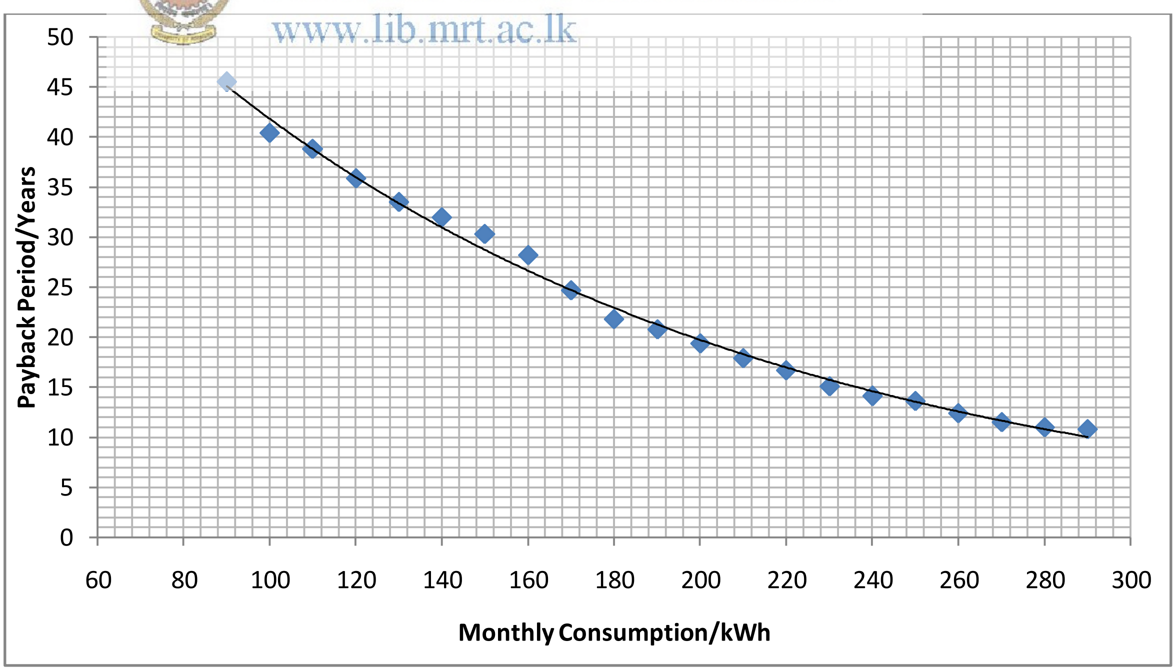

Figure 5.5: Payback Period assuming constant tariff

Scenario 2: Half of the rate at which tariff has increased during last 13 years (Year 2000-Year 2013).

Payback period has been calculated assuming that the tariff escalation rate for next 20 years is half of the rate at which it increased during last 13 years.

Table 5.1 Tariff escalation rate used for the sensitivity analysis

Block	% Tariff Escalation per year	Half of the % Tariff Escalation per year
0-30	1.92	0.96
31-60	4.77	2.38
61-90	24.13	12.06
91-120	29.37	14.68
121-180	34.96	17.48
>180	37.18	18.59

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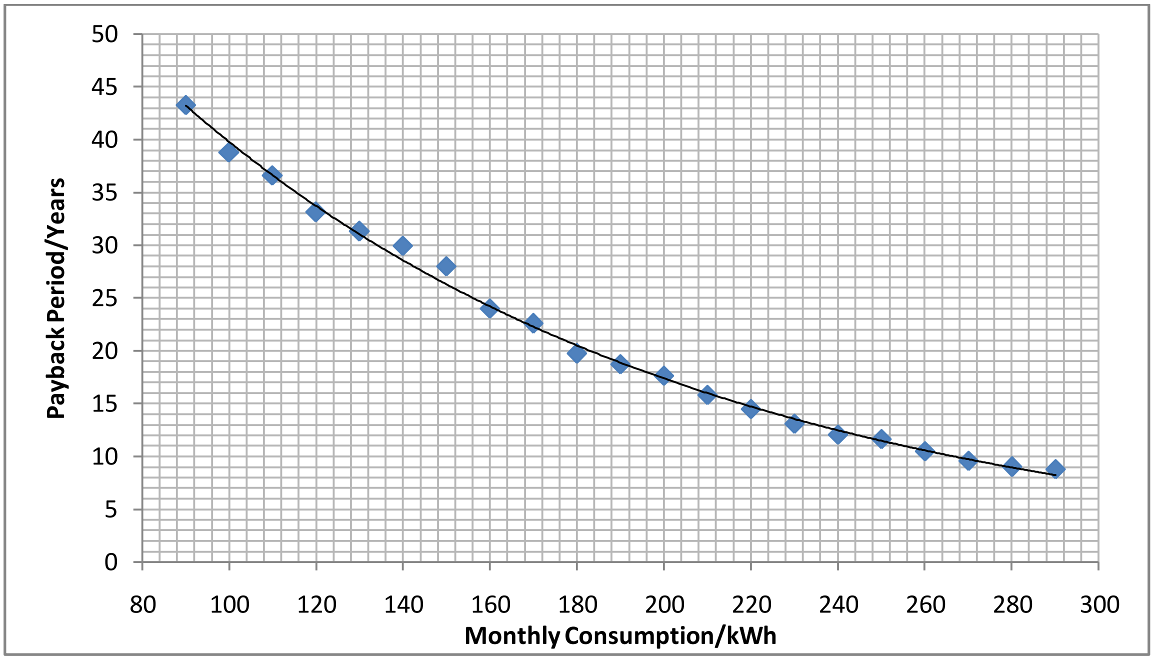

Figure 5.6: Payback Period assuming tariff escalation rate is half of the rate at which tariff has increased during last 13 years (Year 2000-Year 2013).

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Table No 5:2 summarizes the Payback Period variation with variation of average monthly consumption for domestic consumers.

Table 5:2 Payback Period of variation with different tariff scenarios

Average monthly Consumption /kWh	Payback Period /Years		
	Tariff escalation rate is as same as last 13 years	Constant tariff from year 2013	tariff escalation rate is half of the rate at which tariff has increased during last 13 years
90	41	45	43
120	31	36	34
150	24	29	26
180	17	24	22

Payback Period /Years	Average monthly Consumption /kWh		
	Tariff escalation rate is as same as last 13 years	**Constant tariff from year 2013**	**tariff escalation rate is half of the rate at which tariff has increased during last 13 years**
10	230	290	260
20	170	190	180

According to the above table, installing rooftop solar panels with net metering facility is marginally profitable for consumers who consume more than 190 kWh per month irrespective of the tariff escalation mechanism. A financial project is said to be economical when the investment can be recovered within 10 years. Therefore, according to above table, rooftop solar net metering is financially beneficial for consumers who exceed their monthly consumption 290 kWh even the electricity tariff is remain constant for the next 20 years period.

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5.3 Net Present Value

One of the most recognized metric for capital projects such as solar systems is Net Present Value (NPV). This is more complex than calculating payback period, but provides better information. It may be unclear what payback period is acceptable, but NPV provides the actual value of completing a project. NPV also recognizes the time value of money. NPV is simply the sum of all cash flows (positive and negative),discounting future cash flows for the present. It can be calculated by the following formula.

$$NPV = \sum_{t=0}^{n} \frac{\mathrm{C_t}}{(1+\mathrm{r})^{\mathrm{t}}}$$

Where,

t - Time of the cash flow

n - Total time of the project

r - Discount rate (the rate of return that could be earned on an investment in the financial markets with similar risk.)

Ct - Net cash flow (the amount of cash) at time t.

Using the above formula, NPV of domestic solar systems has been calculated. The savings due to solar PV is calculated for each year of the solar PV system lifetime and when discounted, savings at present value can be obtained. This is nothing but the NPV of the yearly savings. From the concept of NPV, if the value of NPV is positive then the system is making a benefit. Hence the system with higher NPV savings per kWh is the best system. The larger the NPV, the greater the total savings can be expected.

5.4 Calculation of NPV

Step 1:

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In order to calculate the NPV, a spreadsheet was set up displaying the financial information. The NPV is calculated using the cumulative cash flows for the 20 years. A table was created to show the system cost, annual cash Inflows (bill saving due to solar PV Net metering), annual cash Outflows (System maintenance cost, Inverter replacement cost, etc),The system cost is a one-time cost in the year zero.

Step 2:

The future cash flows are discounted to year 0 assuming 6% discount rate using the following formula.

$$NPV = \frac{C_t}{(1 + r)^t}$$

The discount rate is an estimate based on the bank interest rate. The current average 20-year loan rate is approximately 6%, which for this study will be rounded to 6%.

NPV of the annual cash flows are calculated and hence obtained the cumulative NPV.

The annual bill saving by installing rooftop solar Panels were calculated using the 2013 electricity tariff. However, using that number every year for 20 years would be unrealistic and thus the electricity tariff escalation rate should be accounted for starting in year one. Due to the complexity of the calculation, assume that electricity tariff remains constant for entire life of solar Panel.

Step 3:

Cumulative NPV was calculated and the result is the NPV of the entire project. The following table shows a sample NPV calculation.

Example:

Capacity of the Solar Panel	:	1kW
Net consumption per month	:	80 Units
Discount Rate	:	6%

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It has been considered several consumers who have various amounts of electricity consumption during the month. Assuming that each consumer has installed 1kW Solar Panel in their rooftops and NPV was calculated.

Table 5:3: NPV of several consumers after installing 1kW Solar Panel

Monthly Consumption kWh	NPV
80	(548,907.40)
90	(455,037.56)
120	(345,200.36)
150	(218,432.60)
175	(95,937.27)
180	(75,704.33)
190	1,511.18
200	64,274.59

According to above table, it is obvious that installing rooftop solar panels on net metering concept is economical when the consumption is more than 190 kWh per month.

It has been found that, the cumulative NPV becomes positive after the year 15 for the consumer who consumes 190kWh per month.. This shows that after 15 years, the solar panel system will begin operating as a positive cash flow and no longer a financial burden.

5.5 Calculation of Internal Rate of Return (IRR)

IRR of a series of cash flows is the discount rate that would set the NPV to zero. This metric is commonly used for project accept/reject decisions. The advantage of using IRR vs. NPV is that the analysis can be done without choosing a specific discount rate.

IRR is the discount rate that makes the net present value of all cash flows from a particular project equal to zero. When the IRR of particular project is high, it is more desirable to undertake the project. For example, an IRR of 12% means the consumer makes a profit of 12% per year on the investment.

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IRR has been calculated for several consumers who have installed 1kW solar panel with various monthly consumption patterns.

Table 5:4: IRR of 1kW rooftop Solar Panels

Monthly Consumption /kWh	IRR
80	-5.0%
90	-4.2%
120	-3.4%
150	-1.2%
175	4.6%
180	6.2%
190	6.5%
200	6.8%

When the average monthly consumption exceeds 175 kWh, the IRR becomes positive and the investment becomes profitable.

Table 5.5 summary of economic calculations

Monthly Consumption/ kWh	Payback Period/Years (Assuming Tariff Remains Constant)	NPV	IRR
80	49	(548,907.40)	-5.0%
90	45	(455,037.56)	-4.2%
120	36	(345,200.36)	-3.4%
150	29	(218,432.60)	-1.2%
175	26	(95,937.27)	4.6%
180	24	(75,704.33)	6.2%
190	20	1,511.18	6.5%
200	19	64,274.59	6.8%

According to Table 5.5, rooftop solar net metering system is financially viable when monthly consumption exceeds 190 units where payback period is 20 years while NPV is positive and IRR is positive and close to discount rate.

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Chapter 6

AVOIDED COST

6.1 Introduction

When the power generated from rooftop solar Panels are connected to the grid, some costs are avoided elsewhere in the system. The power plants, which would normally have produced the power (now being reduced due to solar power), reduces its power output. It will be the benefit to the utility. There are several potential costs avoided due to rooftop solar net metering.

Table 6.1: potential costs avoided due to rooftop solar net metering

Avoid Cost	Description
Avoided energy cost	All fuel, variable operation and maintenance costs and any charges associated with the marginal unit generation costs.
Avoided Transmission and Distribution Capacity	Contribution to deferring the addition of transmission and distribution resources needs to serve load points, far reaching resources, or elsewhere
Avoided environmental pollution	Reduction of greenhouse gas emission from operating of the marginal units.
Avoided Outages Costs	Estimated cost of power interruptions that may be avoided by rooftop solar generation that are still able to operate during outages

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Avoided Cost is the cost an electric utility would otherwise incur to generate power if it did not purchase electricity from another source.

Avoided cost is the incremental cost to the electric utility that the utility would either generate itself or purchase from thermal IPPs if it did not purchase from a renewable energy producer. In the avoided cost mechanism, when a renewable energy generator is connected to the grid, some costs are avoided in the system. First of all, the power plant, which would normally have produced the power (now being provided by the renewable source), saves some fuel and operation costs because it reduces its power output.

Avoided cost of energy represents the maximum value of generation avoided by CEB as a result of any purchase of energy from sources outside the CEB system. This value is usually equal to the value of one unit of energy (kWh) displaced at the margin by a unit of energy purchased from such sources. According to this definition, the avoided cost of a unit of electricity comprises fuel and variable O&M costs of generation displaced at the margin by a unit purchased at a given instant. This is generally the cost of the most expensive unit being generated at that instant.

6.2 Fuel used in various power plants:

Presently petroleum based fuels and coal are the only few feasible fuel options for thermal power generation in Sri Lanka. Other fuel options such as Liquid Natural Gas (LNG) and Nuclear are being studied. During past two years, global fuel prices have fluctuated drastically. Therefore it is impossible to predict the future fuel prices. It is assumed that fuel price remains constant during the period of concern.

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Following table shows the price of each fuel (Rs/Liter/kg) which is in effect on February 2013 which used to generate electricity in CEB owned and IPP thermal power plants.

Table 6:2 Fuel Prices effect from February 2013

Fuel Type	Fuel Prices (Rs/Liter, kg)
Lanka Heavy Fuel	90
Lanka Disstillate Fuel	121
Naptha	90
Lanka Furnace Oil	92
Coal	15.11

6.3 Determination of fraction of time each Power Plant in Margin

To estimate the fraction of time each power plant is operating in margin, it is required to find the plant factors of power plants.

Plant factor is a value used to express the average percentage of full capacity used over a given period of time. For example, a power plant which operates at an average of 60% of its normal full capacity over a measured period has a plant factor of 0.6 for that period. To calculate the plant factor, take the total amount of energy the plant produced during a period of time and divide by the amount of energy the plant would have produced at full capacity. The plant factor of a power plant is the ratio of the actual energy output of the power plant over a period of time to its potential output if it had operated at full nameplate capacity the entire time.

Plant Factors vary greatly depending on the type of power plants and it is calculated according to the following formula.

$$\textbf{Plant Factor} = \frac{\textbf{Actual Energy Production during the Nominal Period}}{\textbf{Potential Energy Production during the Period}}$$

6.4 CEB Dispatch Schedule

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Dispatch schedule is prepared monthly basis based on the expected fuel prices, availability of hydro capacities, machine maintenance schedule, and expected System Demand. Generators are connected and disconnected or 'dispatched' manually by the CEB, based on a 'merit order' which lists plants from the cheapest to the most expensive.

CEB has to follow the power demand in the country by varying its generation accordingly, matching consumer demand. During the early morning and the day time, CEB has lot of generating options as the demand is much lower than the combined generating capability called the installed capacity of the CEB. Thus, the CEB can afford to generate from the cheapest sources without resorting to expensive ones. CEB start generation from the cheaper plants first and go on adding more and more expensive generation as the demand goes up. This is called Merit Order Dispatch. When the demand drops, the reverse activity takes place and the CEB reduces generation starting from the most expensive power plant.

As it stands in 2013, capacity of total CEB hydro is 1356 MW. Since present generation is varying from 2160 MW to 900 MW, theoretically there is a possibility of meeting the total demand in certain times of the day only with CEB hydro power plants, However, System Control Center dispatches CEB hydro power plants to optimize the available CEB hydro generation. Therefore, under normal circumstances System Control Center dispatches CEB hydro for its full capacity to meet peak load and keep the hydro generation at low level during off peak hours to preserve water in the reservoirs for peak operation. In order to reflect the true avoided cost of generation from renewable energy sources, summation of fractions of time in margin should be decided for each year separately. For current generation mix, this value should be very much close to 1. CEB implements a generation dispatch schedule every 6 months before operation. It contains the amount of energy to be produced by each power plant for the coming year. Due to various reasons the actual dispatch could be deviated from this schedule.

6.5 Avoided Cost Calculation methodology

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Step 1-Calculation of Unit cost of generation in each thermal plants

The average cost of generation of each thermal plant (CEB owned and IPPs) is calculated based on the data on annual generation and the total cost to the CEB. The following table summarizes the average Unit cost of Generation of CEB operated and Private Thermal Power Plants in 2013.

Table 6.3: Generation cost of CEB Thermal Plants

Power Plant	**Average Unit Cost Rs/kWh**
KPS GT - 5 x 17 MW	56.45
KPS Combined - 165 MW	31.10
KPS GT- 115 MW	30.66
AES Kelanitissa - 165 MW	29.87
Kerawalapitiya DPP- 270 MW	24.48
ASIA Power - 51 MW	22.04
LakdanaviSapu. - 225 MW	19.68
ACE - Horana - 24.8 MW	18.84
ACE - Embilipitiya - 99 MW	18.77
Barge - 60 MW	18.30
ACE - Matara - 24.8 MW	17.94
Heladhanavi - 99 MW	16.92
Sapu Old - 4 x 18 MW	13.97
Sapu Ext.- 8 x 9 MW	12.75
Coal Puttalam- 300MW	7.67

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After calculating the average unit cost of each thermal plant in the system, thermal plants would be sorted in descending order based on their average unit cost. Following Graph shows the average unit cost of each thermal plant in descending order.

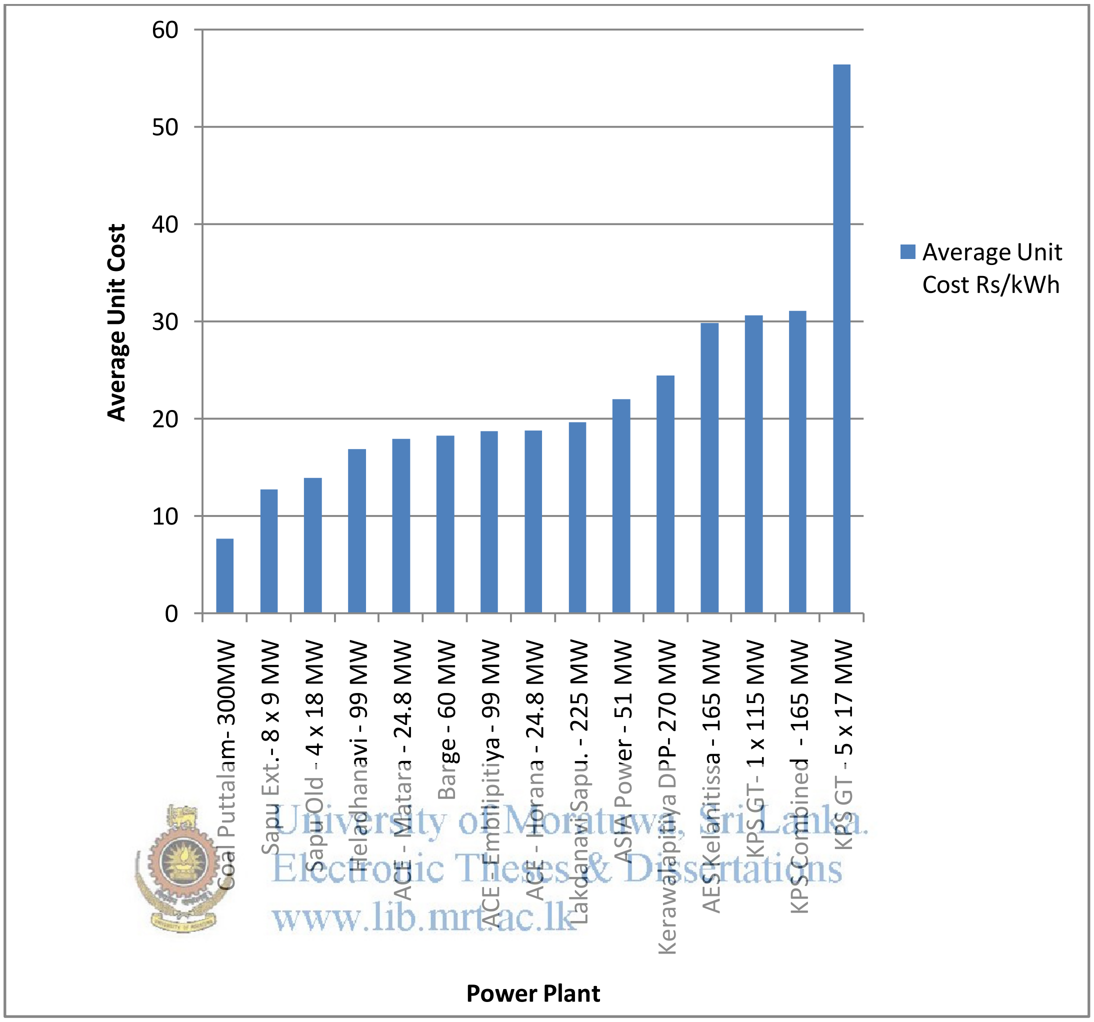

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Figure 6.1: Average Unit Costs of Thermal Power Plants in 2013

Source: Generation Performance Report 2013 prepared by PUCSL

6.6 Dispatch Schedule

When dispatching power plants to meet the demand, System Control dispatches power plants based on merit order. Thus, most expensive thermal power plant is to dispatch as the last option to meet the demand by keeping hydro generation capacities at optimum level. Dispatching and backing off power plants to meet the demand is a complex real time exercise done by System Control engineers.

The Systems Control Centre uses the short term planning model called the METRO model, which provides estimates of energy expected to be delivered from each power plant during each month of the particular year. It is implemented every 6 months prior operation. While estimating the energy expected to be delivered by a particular plant, the model optimizes various power plants based on the generation cost along with other constraints and inputs in the model. Due to numerous reasons the actual dispatch is deviated from this schedule. The dispatch schedule of CEB for the year 2013 is as shown in Table 6.4.

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Table 6.4 Dispatch Schedule 2013

No	Plant	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	Heladhanavi - Pul - 99 MW	59.1	62.1	70	59.7	60.1	54.9	60	60	58.1	60	58.1	60	722.1
2	ACE - Embilipitiya - 99 MW	59.3	53	58.5	48.4	63.7	56.1	54.5	54.5	52.6	54.5	52.5	54.5	662.1
3	Barge - 60 MW	42.8	40.1	43.1	41.3	44	40.9	42	42	40.6	42	40.6	42	501.4
4	ACE - Horana - 20 MW	17.7	16.6	17	13.8	16.9	17.2	17	17	16.4	17	16.4	11.5	194.5
5	ACE - Matara - 20 MW	17.1	15.8	10	0	0	0	0	0	0	0	0	0	42.9
6	ASIA Power - 51 MW	29.8	31.5	34.1	27.6	32.6	32	31	31	30	31	30	31	371.6
7	LakdanaviSapu. - 225 MW	10.7	10.7	9.8	8.2	8.4	9.1	10	10.9	10.5	10.9	7	0	106.2
8	Kerawalapitiya IPP 270 MW	162	145	170	104	157	19.2	158	158	63.3	157	152	166	1610
9	AES Kelanitissa - 165 MW	85.4	69.6	65.2	41.3	55.6	60.6	67.6	61.7	76.4	67.6	64.7	71.5	787.2
10	Coal Puttalam-300MW	79.7	56.3	177	146	171	161	169	169	164	169	164	169	1796
11	Sapu Ext. 8 x 9 MW	47.1	43.2	46.8	46.2	42.8	44	44.5	44.5	43.1	44.5	43.1	44.5	534.3
12	Sapu Old 4 x 18 MW	32.9	30.6	33.7	32.8	32.7	32.8	32.7	32.7	31.7	32.7	31.7	32.7	389.7
13	KPS Combined -165 MW	79.6	83.9	89.5	57.8	83.8	90.4	75.9	43.3	81.8	75.9	72.6	75.9	910.4
14	KPS GT 1 x 115 MW	50.9	53.6	15.7	0	0	0	0	0	0	0	0	0	120.2
15	KPS GT 5 x 17 MW	17.3	16.4	3.1	0.1	0.4	13.8	17.7	17.7	17	17.7	17	17.7	155.9

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Step 2: Calculation of Plant Factors:

Then expected plant factor of each thermal power plant for each month is calculated as per the dispatch schedule in Table 6.4. The table below gives the calculated plant factors for the year 2013.

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Table 6.5 Calculated Plant Factors

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
No of Days in the Month	**31**	**29**	**31**	**30**	**31**	**30**	**31**	**31**	**30**	**31**	**30**	**31**	**366**
KPS GT 5 x 17 MW	0.27	0.28	0.05	0.00	0.01	0.23	0.28	0.28	0.28	0.28	0.28	0.28	0.21
KPS Combined - 165 MW	0.65	0.73	0.73	0.49	0.68	0.76	0.62	0.35	0.69	0.62	0.61	0.62	0.63
KPS GT 1 x 115 MW	0.59	0.67	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12
AES Kelanitissa - 165 MW	0.70	0.61	0.53	0.35	0.45	0.51	0.55	0.50	0.64	0.55	0.54	0.58	0.54
Kerawalapitiya DPP 270 MW	0.81	0.77	0.85	0.53	0.78	0.10	0.79	0.79	0.33	0.78	0.78	0.82	0.68
ASIA Power - 51 MW	0.79	0.89	0.90	0.75	0.86	0.87	0.82	0.82	0.82	0.82	0.82	0.82	0.83
LakdanaviSapu. - 225 MW	0.06	0.07	0.06	0.05	0.05	0.06	0.06	0.07	0.06	0.07	0.04	0.00	0.05
ACE - Horana - 24.8 MW	0.96	0.96	0.92	0.77	0.92	0.96	0.92	0.92	0.92	0.92	0.92	0.62	0.89
ACE - Embilipitiya - 99 MW	0.81	0.77	0.79	0.68	0.86	0.79	0.74	0.74	0.74	0.74	0.74	0.74	0.76
Barge - 60 MW	0.96	0.96	0.97	0.96	0.99	0.95	0.94	0.94	0.94	0.94	0.94	0.94	0.95
ACE - Matara - 24.8 MW	0.93	0.92	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20
Heladhanavi - 99 MW	0.80	0.90	0.95	0.84	0.82	0.77	0.81	0.81	0.82	0.81	0.82	0.81	0.83
Sapu Old 4 x 18 MW	0.61	0.61	0.63	0.63	0.61	0.63	0.61	0.61	0.61	0.61	0.61	0.61	0.62
Sapu Ext. 8 x 9 MW	0.88	0.86	0.87	0.89	0.80	0.85	0.83	0.83	0.83	0.83	0.83	0.83	0.84
Coal Puttalam-300MW	0.36	0.27	0.79	0.68	0.77	0.74	0.76	0.76	0.76	0.76	0.76	0.76	0.68

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The following table shows the calculated plant factor of each power plant along with their capacities.

Table 6.6 Calculated Plant Factors along with the plant capacity

Plant	Capacity MW	Plant Factor
KPS GT- 5 x 17 MW	85	0.21
KPS Combined - 165 MW	165	0.63
KPS GT 1 x 115 MW	115	0.12
AES Kelanitissa - 165 MW	165	0.54
Kerawalapitiya DPP -270 MW	270	0.68
ASIA Power - 51 MW	51	0.83
Lakdanavi. - 225 MW	225	0.05
ACE - Horana - 24.8 MW	24.8	0.89
ACE - Embilipitiya - 99 MW	99	0.76
Barge - 60 MW	60	0.95
ACE - Matara - 24.8 MW	24.8	0.2
Heladhanavi - 99 MW	99	0.83
Sapu Old 4 x 18 MW	72	0.62
Sapu Ext. 8 x 9 MW	72	0.84
Coal Puttalam-300MW	300	0.68

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After calculating the plant factor of each thermal plant, they are sorted in the order of unit cost of generation.

Table 6.7: Power Plants sorted in the descending order of unit cost

Plant	Plant Factor	Cost Rs/kWh
KPS GT - 5 x 17 MW	0.208802	56.45
KPS Combined - 165 MW	0.628132	31.1
KPS GT- 1 x 115 MW	0.118991	30.66
AES Kelanitissa - 165 MW	0.543136	29.87
Kerawalapitiya DPP- 270 MW	0.678844	24.48
ASIA Power - 51 MW	0.829494	22.04
LakdanaviSapu. - 225 MW	0.053734	19.68
ACE - Horana - 24.8 MW	0.892844	18.84
ACE - Embilipitiya - 99 MW	0.761371	18.77
Barge - 60 MW	0.951351	18.3
ACE - Matara - 24.8 MW	0.196931	17.94
Heladhanavi - 99 MW	0.830367	16.92
Sapu Old - 4 x 18 MW	0.616177	13.97
Sapu Ext.- 8 x 9 MW	0.844813	12.75
Coal Puttalam- 900MW	0.681504	7.67

Step 3: Calculate the fraction of time that each plant in margin.

Using the calculated plant factors in Table 6.6, fraction of time each plant operates in margin is calculated.

Table 6.8: Fraction of time each plant operate in margin

Plant	Fraction of Margin
KPS GT 5 x 17 MW	0.21
KPS Combined - 165 MW	0.42
KPS GT 1 x 115 MW	0.00
AES Kelanitissa - 165 MW	0.00
Kerawalapitiya DPP 270 MW	0.05
ASIA Power - 51 MW	0.15
LakdanaviSapu. - 225 MW	0.00
ACE - Horana - 24.8 MW	0.06
ACE - Embilipitiya - 99 MW	0.00
Barge - 60 MW	0.06
ACE - Matara - 24.8 MW	0.00
Heladhanavi - 99 MW	0.00
Sapu Old 4 x 18 MW	0.00
Sapu Ext. 8 x 9 MW	0.00
Coal Puttalam-300MW	0.00

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As shown in above table, following plants are considered as marginal plants.

- KPS GT- 5 x 17 MW
- KPS Combined - 165 MW
- Kerawalapitiya IPP 270 MW
- ASIA Power - 51 MW
- ACE - Horana - 24.8 MW
- Barge - 60 MW
- Hydro and other plants

The time of which a particular plant operates at margin is stacked in the increasing order of their average unit costs and builds up the load duration curve as shown in Figure 6.2.

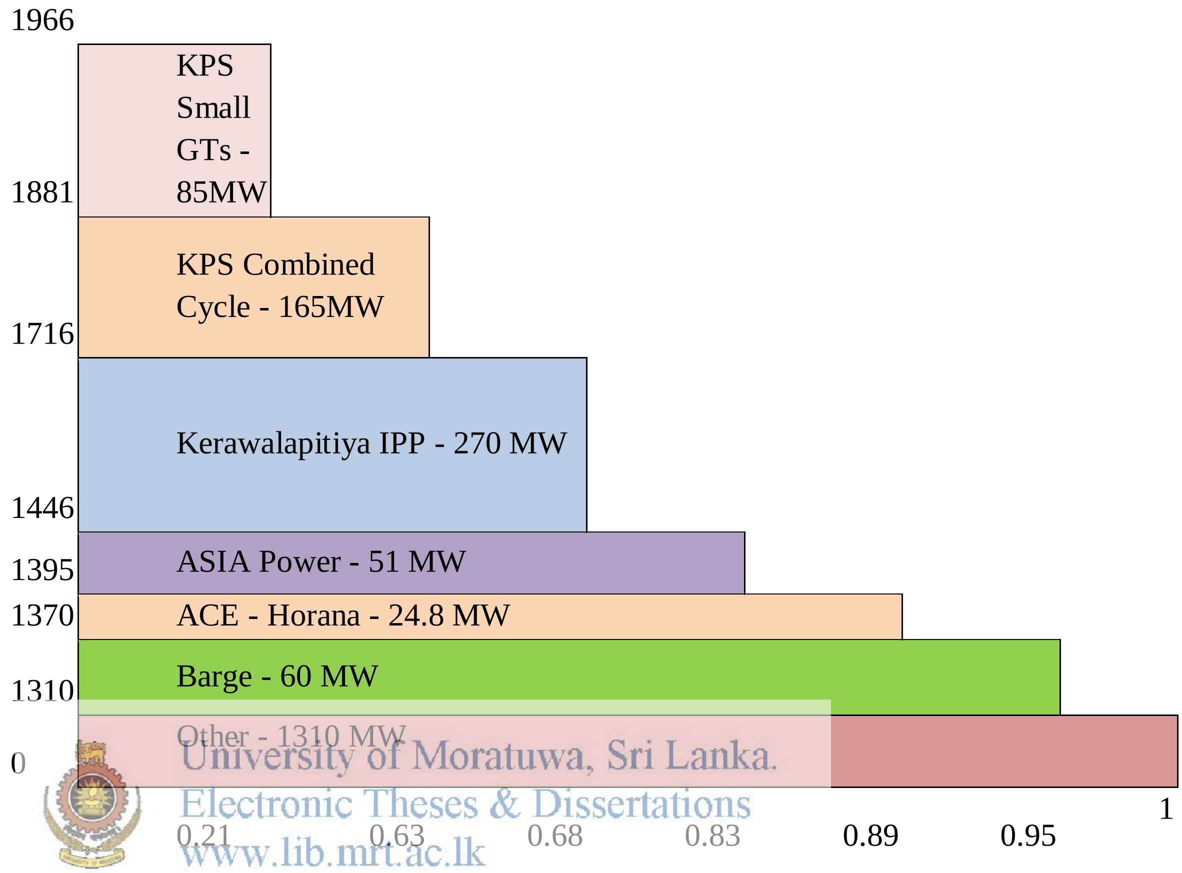

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Figure 6.2: Load Duration Curve

Step 4: Calculation of Avoided Cost

- Avoided cost without solar power and with solar power was calculated.
- Avoided cost = Fraction of Margin * Unit Cost
- Annual Solar Energy fed to the System in year 2013: 7.58 GWh

Table 6.9: Installed rooftop solar capacity as at 31st December 2013

Capacity kW	No of Consumers	Total kW	Monthly Generation of each consumer kWh	Average Annual Generation of each consumer kWh	Total Annual Generation kWh
1.0	520	520	105	1,260	655,200
1.5	202	303	151	1,812	366,024
2.0	246	492	210	2,520	619,920
2.5	270	675	273	3,276	884,520
3.0	110	330	320	3,840	422,400
3.5	54	189	372	4,464	241,056
3.8	95	361	405	4,860	461,700
4.0	132	528	416	4,992	658,944
4.5	160	720	482	5,784	925,440
5.0	86	430	523	6,276	539,736
6.0	85	510	648	7,776	660,960
8.0	64	512	848	10,176	651,264
10.0	38	380	1100	13,200	501,600
Total	2062	5950	5853	70,236	7,588,764

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Installed solar capacity in CEB and LECO as at 31st December 2013 is 5.95 MW.

Rooftop solar consumers have fed 7.59 GWh to the national grid during 2013.

As found in the above analysis, the behavior of marginal plants has been considered.

Table 6.10: Total dispatch energy of thermal plants in 2013

Plant	GWh (Without Solar PV)	GWh (With Solar PV)	Total capacity of the plant
Heladhanavi - Pul - 99 MW	722.1	714.5	869.6
ACE - Embilipitiya - 99 MW	662.1	654.5	869.6
Barge - 60 MW	501.4	493.8	527.0
ACE - Horana - 20 MW	194.5	186.9	217.8
ACE - Matara - 20 MW	42.9	35.3	217.8
ASIA Power - 51 MW	371.6	364.0	447.9
LakdanaviSapu. - 225 MW	106.2	98.6	1976.4
Kerawalapitiya DPP 270 MW	1610.0	1602.4	2371.7
AES Kelanitissa - 165 MW	787.2	779.6	1449.4
Coal Puttalam-300MW	1795.9	1788.3	2635.2
Sapu Ext. 8 x 9 MW	534.3	526.7	632.5
Sapu Old 4 x 18 MW	389.7	382.1	632.5
KPS Combined -165 MW	910.4	902.8	1449.4
KPS GT 1 x 115 MW	120.2	112.6	1010.2
KPS GT 5 x 17 MW	155.9	148.3	746.7

As shown in Table 6.10, Plant Factors of each thermal plant has been calculated considering the two scenarios i.e. without rooftop solar and with rooftop solar PV.

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Table: 6.11 Plant Factors of thermal plants

Plant	Plant Factor without Solar PV	Plant Factor with Solar PV	Capacity MW	Cost Rs/kWh
KPS GT 5 x 17 MW	0.21	0.20	85	56.45
KPS Combined - 165 MW	0.63	0.62	165	31.10
KPS GT 1 x 115 MW	0.12	0.11	115	30.66
AES Kelanitissa - 165 MW	0.54	0.54	165	29.87
Kerawalapitiya DPP 270 MW	0.68	0.68	270	24.48
ASIA Power - 51 MW	0.83	0.81	51	22.04
LakdanaviSapu. - 225 MW	0.05	0.05	225	19.68
ACE - Horana - 24.8 MW	0.89	0.86	24.8	18.84
ACE - Embilipitiya - 99 MW	0.76	0.75	99	18.77
Barge - 60 MW	0.95	0.94	60	18.30
ACE - Matara - 24.8 MW	0.20	0.16	24.8	17.94
Heladhanavi - 99 MW	0.83	0.82	99	16.92
Sapu Old 4 x 18 MW	0.62	0.60	72	13.97
Sapu Ext. 8 x 9 MW	0.84	0.83	72	12.75
Coal Puttalam-300MW	0.68	0.68	300	7.67

Fraction of margin each thermal plant operates in margin has been calculated using the calculated plant factors in Table: 6.11.

Table 6.12: Fraction of margin each plant operates

Plant	Fraction of Margin without Solar PV	Fraction of Margin with Solar PV
KPS GT 5 x 17 MW	0.21	0.20
KPS Combined - 165 MW	0.42	0.42
KPS GT 1 x 115 MW	0.00	0.00
AES Kelanitissa - 165 MW	0.00	0.00
Kerawalapitiya DPP 270 MW	0.05	0.05
ASIA Power - 51 MW	0.15	0.14
LakdanaviSapu. - 225 MW	0.00	0.00
ACE - Horana - 24.8 MW	0.06	0.05
ACE - Embilipitiya - 99 MW	0.00	0.00
Barge - 60 MW	0.06	0.08
ACE - Matara - 24.8 MW	0.00	0.00
Heladhanavi - 99 MW	0.00	0.00
Sapu Old 4 x 18 MW	0.00	0.00
Sapu Ext. 8 x 9 MW	0.00	0.00
Coal Puttalam-300MW	0.00	0.00
Total	0.95	0.94

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After calculating the fraction of margin, the operating cost of the thermal plants operates in margin has been calculated as mentioned in Table: 6.13.

Table 6.13 Operating costs of marginal power plants

Plant	Cost without Solar PV	Cost with Solar PV
KPS GT 5 x 17 MW	11.79	11.21
KPS Combined - 165 MW	13.04	13.19
KPS GT 1 x 115 MW	0.00	0.00
AES Kelanitissa - 165 MW	0.00	0.00
Kerawalapitiya DPP 270 MW	1.24	1.29
ASIA Power - 51 MW	3.32	3.02
LakdanaviSapu. - 225 MW	0.00	0.00
ACE - Horana - 24.8 MW	1.19	0.86
ACE - Embilipitiya - 99 MW	0.00	0.00
Barge - 60 MW	1.07	1.45

ACE - Matara - 24.8 MW	0.00	0.00
Heladhanavi - 99 MW	0.00	0.00
Sapu Old 4 x 18 MW	0.00	0.00
Sapu Ext. 8 x 9 MW	0.00	0.00
Coal Puttalam-300MW	0.00	0.00
Total	31.65	31.02

The reduction of avoided cost due to solar net metering is about Rs.0.64 for the year 2013.

6.7 Prediction of rooftop solar electricity production

According to European Photovoltaic Industry association (EPIA), Global solar power installed capacity growth rate is about 44% in average per year. The table 6.13 shows cumulative installed capacity of solar PV from year 2000.

Table 6.14: Global Solar PV installed capacity

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Year	Cumulative Installed capacity GW	Percentage Increase
2000	1.28	
2001	1.60	25.41
2002	2.05	28.21
2003	2.61	27.51
2004	3.70	41.55
2005	5.09	37.43
2006	6.63	30.36
2007	9.15	37.97
2008	15.80	72.70
2009	23.11	46.30
2010	40.18	73.89
2011	70.17	74.62
2012	99.69	42.07
2013	136.70	37.12

Source: Global Market Outlook for Solar PV published by EPIA

The above data has been presented in a graph as follows. It is obvious that solar PV is exponentially growing.

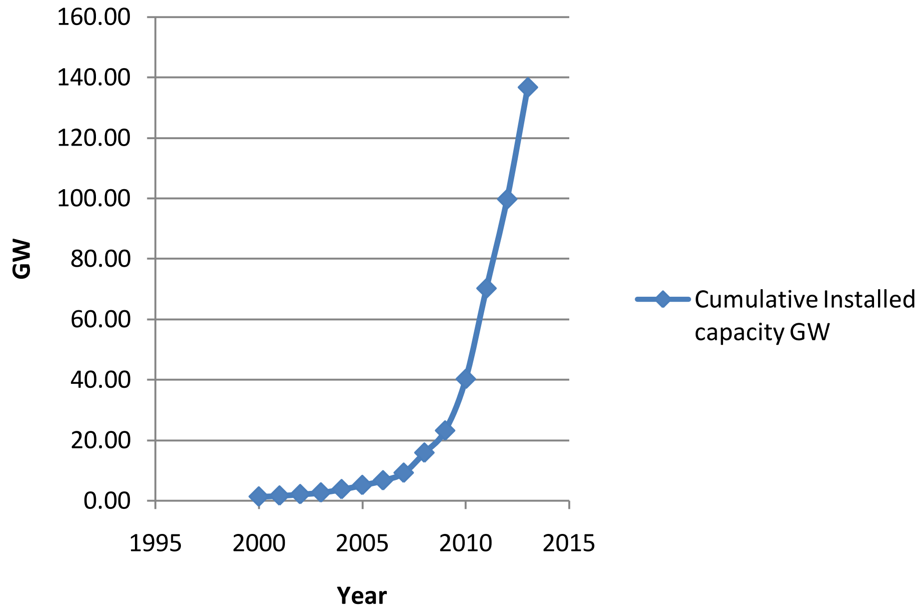

Figure 6.3: Cumulative installed capacity of Solar PV in GW

Source: Global Market Outlook for Solar PV published by EPIA

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According to the report "Global Market Outlook for Solar PV" by EPIA, the average growth rate of solar PV is about 44% per year.

Rooftop solar net metering system has been initiated in Sri Lanka in 2010.Table 6.15 illustrates the addition of rooftop solar capacity to the system from 2010.

Table: 6.15 Rooftop Solar Capacity growths in Sri Lanka

Year	kW	GWh /Year
2010	85	1.58
2011	400	3.85
2012	1400	5.40
2013	5950	7.59
2014	6700	10.30

According to the above table, average growth of rooftop solar capacity addition is about 38% per year. It is required to predict the future growth to analyze the avoided cost of rooftop solar net metering during the lifetime of the installed system. It is assumed that 20% of rooftop solar capacity growth for the forecasting purpose. Table 6.16 shows the expected growth of solar PV in Sri Lanka during the lifetime of commissioned Solar Systems. The figures were projected based on the expected development according to the current project pipeline records.

Table: 6.16 Forecasted Rooftop Solar PV Capacity

Year	GWh/Year	Year	GWh/Year
2013	7.59	2023	56.63
2014	12.26	2024	58.38
2015	18.10	2025	60.14
2016	29.78	2026	61.89
2017	42.04	2027	63.64
2018	47.88	2028	65.39
2019	49.63	2029	67.14
2020	51.38	2030	68.89
2021	53.13	2031	70.65
2022	54.88	2032	72.40

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Above data has been plotted in Figure 6.5.

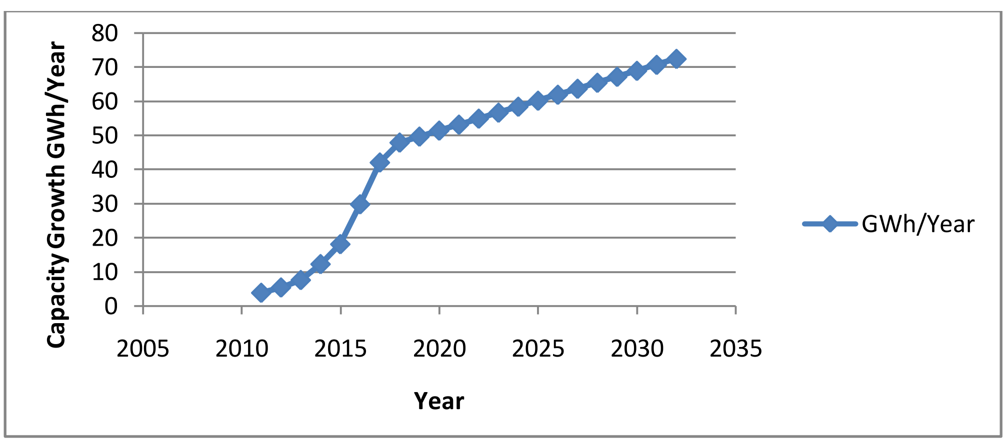

Figure 6.4: Forecasted Solar PV growth in Sri Lanka up to 2033

6.8 Future behavior of existing Thermal Plants

Most of the thermal plants currently operating are old and inefficient. Apart from that, the Independent Power Purchase agreements of thermal plants will be expired in future. Therefore, they will be gradually retired from the system and new plants will be added. Sri Lanka is more focused on coal fired thermal plants as the future energy option since the unit cost of generation compared to oil fired plants is low.

CEB generation planning unit has published the potential plants to be retired and added to the system as mentioned in Table 6.17.

Table 6.17 Additions and Retirements of Thermal Power Plants

YEAR	Thermal ADDITIONS	Thermal RETIREMETS
2015	-	14x7.11 MW ACE Power Embilipitiya, 6x16.6 MW HeladanaviPuttalam, 4x15 MW Colombo Power
2016	-	-
2017	2x250 MW Trinco Coal Power Plant	-
2018	1x250 MW Trinco Coal Power Plant	8x6.13 MW Asia Power, 4x5 MW Northern Power
2019	1x250 MW Trinco Coal Power Plant	5x17 MW Kelanitissa Gas Turbines 4x18 MW Sapugaskanda diesel
2021	2x300 MW Coal Power Plant	-
2022	1x300 MW Coal Power Plant	-
2023	-	1x115 MW Kelanitissa Gas Turbine, 4x9 MW Sapugaskanda Diesel Ext.
2024	1x300 MW Coal Power Plant, 3x35 MW Gas Turbine	163 MW AES Kelanitissa Combined Cycle Plant
2025	1x300 MW Coal Power Plant	4x9 MW Sapugaskanda Diesel Ext.
2027	1x300 MW Coal Power Plant	-
2028	-	-
2029	1x300 MW Coal Power Plant	-
2030	1x300 MW Coal Power Plant	-
2031	1x300 MW Coal Power Plant	-
2032	1x75 MW Gas Turbine	-

Source: CEB Long Term Generation Expansion Plan 2013-2032 prepared by Generation Planning Unit

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In 2015,14x7.11 MW ACE Power Embilipitiya, 6x16.6 MW HeladanaviPuttalam and 4x15 MW Colombo Power plants will be retired from the national Grid while none of the new thermal plants are added to the System.

Table 6.18 shows projected dispatch schedule of Power plants in MW from 2015 to 2032and Table 6.19 shows projected dispatch schedule of Power plants in GWh from 2015 to 2032.

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Plant Name	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Existing Major Hydro	1335	1335	1335	1335	1335	1335	1335	1335	1335	1335	1335	1335	1335	1335	1335	1335	1335	1335
New Major Hydro	0	155	155	182	182	182	182	182	182	182	182	182	182	182	231	231	231	231
Mini Hydro	244	256	279	294	308	320	332	345	354	365	377	389	400	412	414	426	438	450
Sub Total	1579	1746	1769	1811	1825	1837	1849	1862	1871	1882	1894	1906	1917	1929	1980	1992	2004	2016
NCRE - Wind	90	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360	370	380
NCRE - Solar	31	51	72	82	85	88	91	94	97	100	103	106	109	112	115	118	121	124
Small Gas Turbines	85	85	85	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diesel Sapugaskanda	72	72	72	72	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diesel Ext. Sapugaskanda	72	72	72	72	72	72	72	72	36	36	0	0	0	0	0	0	0	0
Gas Turbine No 7	115	115	115	115	115	115	115	115	0	0	0	0	0	0	0	0	0	0
lakdhanavi	23	23	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asia Power	49	49	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KPS Combined Cycle	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165
AES Combined Cycle	163	163	163	163	163	163	163	163	163	0	0	0	0	0	0	0	0	0
Colombo Power	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ACE Power Horana	20	20	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ACE Power Matara	20	20	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heladhanavi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ACE Power Ambilipitiya	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass (Dendro)	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Kerawalapitiya CCY	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270
Puttalam Coal	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825
Northern Power	20	20	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chunnakkam Power Extension	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Sub Total	1933	1933	1933	1801	1644	1644	1644	1644	1493	1330	1294	1294	1294	1294	1294	1294	1294	1294
Coal	0	0	0	0	0	275	550	825	1100	1375	1650	1650	1925	1925	2200	2475	2750	2750
Gas Turbine 75MW	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	150
Gas Turbine 105MW	105	105	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210
Coal Trinco	0	0	0	681	908	908	908	908	908	908	908	908	908	908	908	908	908	908
NCRE Biomass (Dendro)	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80
Sub Total	192	196	305	990	1221	1500	1779	2058	2337	2616	2895	2899	3178	3182	3461	3740	4019	4098

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Plant Name	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Hydro																		
Existing Major Hydro	4112	4112	4112	4112	4112	4112	4112	4112	4112	4112	4112	4112	4112	4112	4112	4112	4112	4112
New Major Hydro	0	366	366	443	443	443	443	443	443	443	443	443	443	443	579	579	579	579
Sub Total	4112	4478	4478	4555	4555	4555	4555	4555	4555	4555	4555	4555	4555	4555	4691	4691	4691	4691
Total NCRE	688	968	1003	1064	1159	1268	1339	1373	1421	1481	1546	1592	1654	1700	1761	1793	1854	1901
Thermal Existing and committed																		
Small Gas Turbines	3	5	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diesel Sapugaskanda	453	455	461	308	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diesel Ext. Sapugaskanda	487	487	490	355	310	239	156	94	37	28	0	0	0	0	0	0	0	0
Gas Turbine No 7	258	249	290	107	79	54	22	9	0	0	0	0	0	0	0	0	0	0
lakdhanavi	140	141	146	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asia Power	326	327	335	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KPS Combined Cycle	494	524	639	245	237	134	105	57	60	34	18	48	28	68	56	48	38	90
AES Combined Cycle	425	467	538	229	197	121	70	52	0	0	0	0	0	0	0	0	0	0
ACE Power Horana	164	164	166	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ACE Power Matara	160	160	164	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass (Dendro)	94	94	94	85	74	58	50	42	31	25	12	28	17	33	25	18	15	40
Kerawalapitiya CCY	1020	1134	1314	594	496	378	301	190	147	111	59	114	58	144	119	113	102	163
Puttalam Coal	4911	4923	4990	4231	4065	4048	4082	4135	4218	4271	4352	4519	4710	4832	4956	5030	5098	5373
Northern Power	137	137	138	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chunnakkam Power Extension	183	183	183	151	140	110	93	65	43	32	20	42	17	51	29	27	27	41
Sub Total	9255	9450	9954	6305	5598	5142	4879	4644	4536	4501	4461	4751	4830	5128	5185	5236	5280	5707
New Thermal Plants																		
Coal	0	0	0	0	0	1278	2421	3640	4699	5761	6877	7584	8714	9511	10602	11916	13241	14089
Gas Turbine 75MV	145	145	159	57	41	32	20	6	10	5	4	8	7	13	11	10	10	10
Gas Turbine 105MV	215	228	524	180	157	109	74	44	46	19	14	45	25	46	41	38	34	110
Coal Trinco	0	0	0	4869	6426	6511	6589	6642	6708	6754	6786	6814	6834	6849	6864	6869	6873	6876
Biomass (Dendro)	82	109	137	140	150	134	130	119	91	84	40	103	59	138	109	81	84	147
Sub Total	442	482	820	5246	6774	8064	9234	10451	11554	12623	13721	14554	15639	16557	17627	18914	20242	21232

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According to Table: 6.16 forecasted Rooftop Solar PV Capacity for year 2015 is about 18.10 GWh.

Table 6.20 shows the projected total Plant Dispatch capacity of each thermal plant for year 2015 considering two scenarios.

Table 6.20 Projected total Plant Dispatch capacity of each thermal plant 2015

Plant	**GWh (Without Solar PV)**	**GWh (With Solar PV)**
ASIA Power - 51 MW	326	307.9
Kerawalapitiya DPP 270 MW	1020	1001.9
AES Kelanitissa - 165 MW	425	406.9
Coal Puttalam-300MW	4911	4892.9
Sapu Ext. 8 x 9 MW	487	468.9
Sapu Old 4 x 18 MW	453	434.9
KPS Combined - 65 MW	494	475.9
KPS GT 1 x 115 MW	258	239.9
GT 75 MW	145	126.9
GT 105 MW	215	196.9
Nothern Power 20MW	137	118.9
Lakdhanavi	140	121.9
Ace Power Horana	164	145.9
Ace Power Matara	160	141.9
Nothern Power Extension 24MW	183	164.9
Total	9518	9264.9

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By using above projected plant dispatch capacity, plant factors have been calculated.

Table 6.21 Calculated plant factors for projected total Plant Dispatch schedule

Plant	Plant Factor without Solar PV	Plant Factor with Solar PV	Capacity MW	Cost Rs/kWh
GT 75 MW	0.14	0.13	75	53.21
GT 35 MW	0.01	0.01	35	51.34
Nothern Power Ext. 24MW	0.74	0.74	24	43.67
Nothern Power 20MW	0.75	0.75	20	42.6
KPS Combined - 165 MW	0.46	0.46	165	31.1
KPS GT 1 x 115 MW	0.26	0.26	115	30.66
AES Kelanitissa - 165 MW	0.21	0.21	165	29.87
Kerawalapitiya DPP 270 MW	0.35	0.35	270	24.48
ASIA Power - 51 MW	0.62	0.62	51	22.04
Sapu Old 4 x 18 MW	0.67	0.67	72	13.97
Sapu Ext. 8 x 9 MW	0.76	0.76	72	12.75
Coal Puttalam	0.68	0.68	300	7.67

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Table 6.22 shows the fraction of Margin each plant operates in margin calculated using the above plant factors.

Table 6.22 Fraction of margin each plant operates

Plant	Fraction of Margin without Solar PV	Fraction of Margin with Solar PV	Capacity MW	Cost Rs/kWh
GT 75 MW	0.14	0.13	75	53.21
GT 35 MW	0.00	0.00	35	51.34
Nothern Power Extension 24MW	0.60	0.59	24	43.67
Nothern Power 20MW	0.01	0.01	20	42.60
KPS Combined - 165 MW	0.00	0.00	165	31.10
KPS GT 1 x 115 MW	0.00	0.00	115	30.66
AES Kelanitissa - 165 MW	0.00	0.00	165	29.87

Kerawalapitiya DPP 270 MW	0.00	0.00	270	24.48
ASIA Power - 51 MW	0.00	0.00	51	22.04
Sapu Old 4 x 18 MW	0.00	0.00	72	13.97
Sapu Ext. 8 x 9 MW	0.01	0.01	72	12.75
Coal Puttalam	0.00	0.00	300	7.67
Total	0.76	0.74		

Fraction of margin has been multiplied by the variable cost of each plant to obtain the avoided cost with and without rooftop solar net metering. The result is shown in Table 6.23.

Table 6.23 Avoided cost of each thermal plant with and without Rooftop Solar contribution.

Plant	Avoided Cost without Solar PV	Avoided Cost with Solar PV
GT 75 MW	7.19	7.13
GT 35 MW	0.00	0.00
Nothern Power Extension 24MW	26.42	26.32
Nothern Power 20MW	0.48	0.46
KPS Combined - 165 MW	0.00	0.00
KPS GT 1 x 115 MW	0.00	0.00
AES Kelanitissa - 165 MW	0.00	0.00
Kerawalapitiya DPP 270 MW	0.00	0.00
ASIA Power - 51 MW	0.00	0.00
Sapu Old 4 x 18 MW	0.00	0.00
Sapu Ext. 8 x 9 MW	0.12	0.15
Coal Puttalam	0.00	0.00
Total	34.20	34.06

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Table 6.24: Reduction of avoided cost due to rooftop solar net metering

Year	Avoided cost Without Solar PV Rs/kWh	Avoided cost With Solar PV Rs/kWh	Reduction of Avoided Cost Rs/kWh
2012	31.655	31.611	0.044
2013	32.305	32.241	0.064
2014	33.677	33.586	0.091
2015	34.206	34.064	0.142
2016	31.78	31.585	0.195
2017	29.005	28.785	0.22
2018	27.235	26.941	0.294
2019	25.108	24.753	0.355
2020	24.354	23.889	0.465
2021	23.454	22.953	0.501
2022	21.655	21.045	0.61
2023	20.77	20.072	0.698
2024	19.612	18.837	0.775
2025	18.023	17.142	0.881

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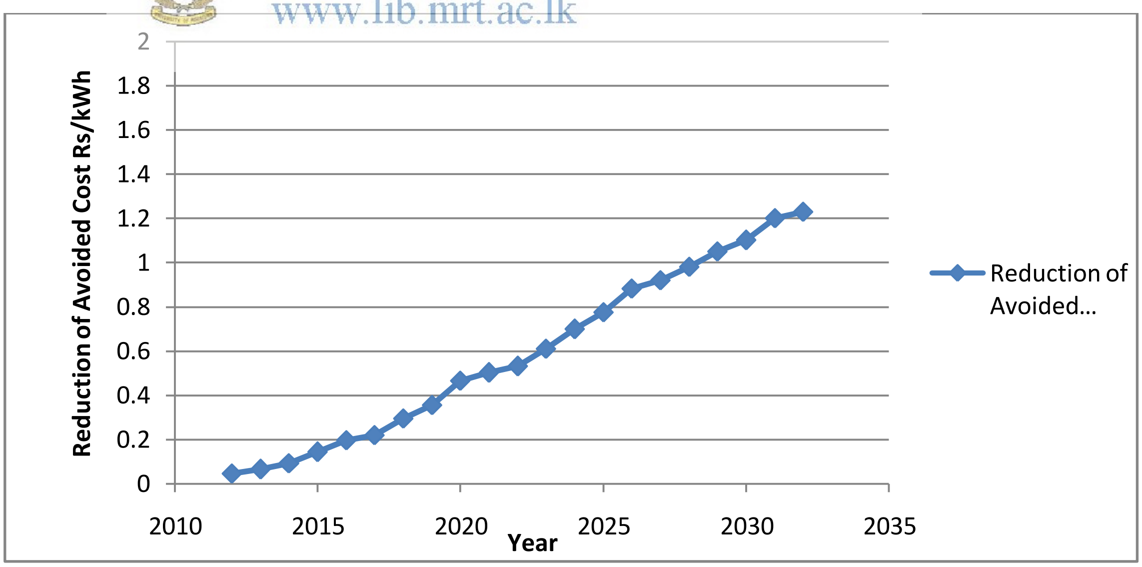

Figure 6.5 Reduction of total Avoided cost over the lifetime of Solar System

The reduction of avoided cost is increasing gradually even though the contribution of rooftop solar generated energy to the national grid is exponentially increasing. The reason for this variation can be justified by studying the expected share of future energy supply by source as indicated in Table 6.25.

Table 6.25: Expected share of energy supply by source

Year	Hydro	NCRE	Thermal	Coal
2015	4112	390	4786	4911
2020	4555	713	1369	11837
2025	4555	855	167	18015
2030	4691	989	335	23815

According to the generation expansion plan prepared by CEB for 2015-2032, the expected share of Coal in electricity generation is exponentially increasing and contribution of fuel fired plants is rapidly reducing. Therefore, future electricity market is dominated by Coal power.

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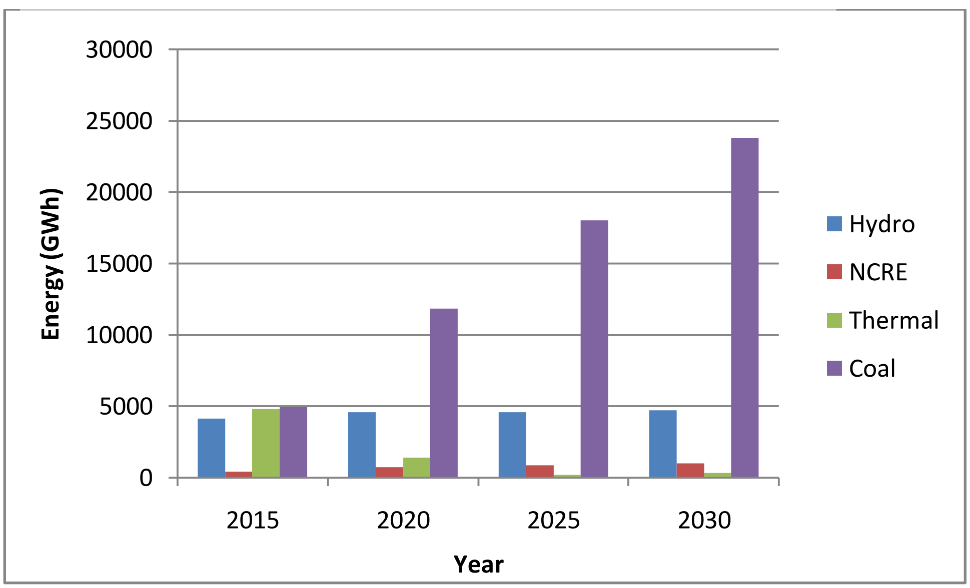

Figure 6.6 Share of energy supply by source

The average unit cost of generation of Coal fired plant is about Rs: 7.50. It is the least unit cost of generation among other sources. Therefore, the cost of electricity for the consumer will be reduced and the electricity bill will be reduced. Ultimately, the saving due to rooftop solar net metering will be reduced. According to Figure 6.5, the reduction of avoided cost will become constant after year 2032.Therefore it can be concluded that the installation of rooftop solar net metering is beneficial as long as the feeding of national grid is dominated by high cost fuel fired thermal plants only.

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Chapter 7

DISCUSSION

The main objective of this study to conduct a cost benefits analysis of Solar Net Metering concept on Consumer and Utility Point of view. Consumer category that gets the highest benefit from implementing roof top solar net metering has been identified and the avoided cost due to rooftop solar net metering concept to the utility was determined.

The study results in several outcomes.

Key Findings of the research are listed as follows.

- Net Metering is economical for monthly average consumption exceeds 190 kWh. Those consumers can meet their investment within the lifetime of the installed solar system.
- When the monthly consumption exceeds 290kWh, the consumer can meet the cost of investment within 10 years.

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- It is profitable for high end consumers.
- Profit increases with the increase of local consumption.
- Future energy market of Sri Lanka will be dominated by mainly Coal and Hydro power. The contribution of Thermal plants to the national energy requirement is rapidly decreasing. Therefore avoided cost from high cost fuel burned plants is reducing. Due to the increased interest on rooftop solar, reduction of avoided cost is rapidly increasing. But the rate at which the reduction of avoid cost increasing is decreasing and it becomes constant after 20 years. However, rooftop solar electricity generation cannot replace any marginal plant during the period of study concerned.

There are several studies on this topic based on several countries such as Kenya, Califonia Germany and India which has high potential for Solar PV. They also have concluded that rooftop solar net metering is not economical for the consumers having less monthly consumption of electricity and the avoided cost to the utility is significantly low for the next 20 years since the system is dominated by large scale Hydro and thermal plants.

There is no detailed study for Sri Lanka in this particular area of study. The outcome of the research provides important and useful information for consumers, electricity utilities as well as the policy makers in energy sector.

It is required to increase the share of renewable energy in power generation to 20% by 2010 and to increase green electricity generation in Sri Lanka at relatively low cost to utilities. Rooftop Solar net metering is a way to allow participation of larger consumer groups in green energy production.

It is essential to promote rooftop solar net metering in Sri Lanka by eliminating the short comings of the excising system. The initial cost of installation is still high for solar systems. As an example the 1Kw unit costs about Rs: 650,000.Therefore average people in Sri Lanka can't afford this high cost. It is required to propose loan schemes to purchase solar systems. The government should reduce the tax on solar systems. It is also important to promote solar panel manufacturing within the country.

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Chapter 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Future Research Areas

The study is focused only on the domestic consumer category. The effect of rooftop solar net metering for Industry, Hotel and General purpose consumer categories should be studied. Solar systems installed by them should have somewhat better economics for several reasons:

•Commercial enterprises pay higher effective rates for electricity than residential customers.

• Commercial tariffs include a significant capacity charge.

• Commercial or industrial solar systems are larger and initial per kW cost of installation is lower.

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It is recommended to develop an incentive scheme to promote low end consumers for Solar Net Metering. It is suggested to propose consumer and utility benefited tariff structure. The research has been done assuming that the fuel cost is constant throughout the period of concern. But fuel cost is rapidly increasing and very complex to predict the behavior of future fuel cost. It is important to analyze the avoided cost with variation of fuel costs during the lifetime of solar panel. Hence study the effect of solar net metering with the variation of unit cost of generation of thermal plants. Different load patterns can be considered and analyse how the benefits vary accordingly. It is possible to examine different PV technologies and how benefits change.

While the concept of net metering is simple, the implications of net metering are anything but simple. In an extreme example, if every home had rooftop solar generation that exactly offset their usage, the utility would have no usage-based revenue. The utility would only have revenue from fixed tariff charges such as metering and billing fees. Then it will be a problem to bear the cost of maintaining the grid. Therefore it is vital to assess this scenario via future researches.

8.2 Conclusions

Solar energy is the most abundant energy resource on earth. But it is of poor competency in economic currently in the starting stage of Solar PV electricity generation. The initial investment of Solar PV power plant is much higher than that of fossil power plant, conversely the Operation and Maintenance costs is quite lower. Taking the life cycle cost and a reasonable payback of investment into consideration, price of on-grid PV power vary with several factors, such as the local solar resource, efficiency of PV system, technical lifetime of PV plant, price of PV modules and so on, most of which are improvable by technological innovation.

There is no doubt that Solar PV electricity generation is expanding very rapidly due to dramatic cost reductions. PV is a commercially available and reliable technology with a significant potential for long-term growth in nearly all world regions. Achieving this will require more concerted policy support, and a long-term focus on R&D to reduce costs and ensure PV readiness for rapid deployment, while also supporting longer-term technology innovations.

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It is required to promote consumers to invest money on rooftop solar systems. Establishing a mechanism to provide solar panels in subsidiary rates and provide import tax exceptions will encourage the consumers. Then it will overcome the barrier of high initial cost. All banks should be advised to encourage the home loan seekers to install rooftop solar PVs. If the energy injected by the consumer is more than the energy consumed, such surplus energy should be carried forward for pre defined time period. If it is still not consumed, the customer should be paid by the utility. It is important to attract the private sector participation in solar energy sector.

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Appendix A- Sample Data Collection

Capacity of the Solar System: 6.11 kW

Jul-12		Aug-12		Sep-12		Oct-12		Nov-12		Dec-12	
Date	Energy (Wh)	Date	Energy (Wh)	Date	Energy (Wh)	Date	Energy (Wh)	Date	Energy (Wh)	Date	Energy (Wh)
9/7/2012	5,471.17	18/08/2012	12,606.88	1/9/2012	27,504.91	1/10/2012	26,702.89	1/12/2012	8,427.86	1/12/2012	25,080.03
10/7/2012	21,087.80	19/08/2012	29,677.33	2/9/2012	23,128.75	2/10/2012	27,478.54	2/12/2012	15,029.56	2/12/2012	16,857.43
12/7/2012	24,033.69	20/08/2012	25,530.18	3/9/2012	14,354.21	3/10/2012	28,080.65	3/12/2012	18,102.12	3/12/2012	24,351.69
12/7/2012	21,833.12	21/08/2012	26,335.37	4/9/2012	25,616.04	4/10/2012	28,586.75	4/12/2012	27,516.50	4/12/2012	25,180.90
13/07/2012	17,318.05	22/08/2012	8,979.56	5/9/2012	27,690.68	5/10/2012	27,944.28	5/12/2012	21,205.10	5/12/2012	25,240.51
14/07/2012	20,512.65	23/08/2012	28,812.48	6/9/2012	19,339.73	6/10/2012	30,863.98	6/12/2012	22,459.51	6/12/2012	25,353.70
15/07/2012	25,614.94	24/08/2012	6,919.07	7/9/2012	22,371.63	7/10/2012	31,601.93	7/12/2012	25,231.35	7/12/2012	26,742.28
16/07/2012	7,079.20	25/08/2012	23,705.38	8/9/2012	28,249.70	8/10/2012	30,790.60	8/12/2012	24,902.08	8/12/2012	26,698.83
18/07/2012	20,406.24	26/08/2012	26,552.48	9/9/2012	26,207.84	9/10/2012	29,901.85	9/12/2012	28,851.22	9/12/2012	25,879.02
19/07/2012	25,306.16	27/08/2012	27,697.21	10/9/2012	884.8404	10/10/2012	22,266.13	10/12/2012	26,621.92	10/12/2012	22,208.65
20/07/2012	2,292.17	28/08/2012	27,654.19	12/9/2012	25,452.90	12/10/2012	25,341.84	12/12/2012	27,741.56	12/12/2012	21,682.83
22/07/2012	17,887.50	29/08/2012	29,850.92	12/9/2012	17,467.69	12/10/2012	19,947.60	12/12/2012	26,329.78	12/12/2012	19,634.64

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23/07/2012	14,398.35	30/08/2012	28,083.48	13/09/2012	21,879.04	13/10/2012	28,583.40	13/12/2012	26,317.59	13/12/2012	16,925.91
24/07/2012	23,173.98	31/08/2012	24,454.45	14/09/2012	20,741.87	14/10/2012	20,449.14	14/12/2012	25,961.35	14/12/2012	12,312.26
25/07/2012	22,326.57			15/09/2012	18,512.33	15/10/2012	31,079.15	15/12/2012	26,745.71	15/12/2012	9,703.45
26/07/2012	21,250.30			16/09/2012	18,910.46	16/10/2012	31,969.40	16/12/2012	27,679.81	16/12/2012	20,924.15
27/07/2012	24,513.82			17/09/2012	30,467.73	17/10/2012	26,608.60	17/12/2012	27,671.55	17/12/2012	22,816.60
28/07/2012	3,936.75			18/09/2012	29,815.81	18/10/2012	30,597.62	18/12/2012	26,202.31	18/12/2012	24,007.22
				19/09/2012	29,998.45	19/10/2012	32,257.08	19/12/2012	20,926.32	19/12/2012	16,098.58
				20/09/2012	29,330.04	20/10/2012	23,697.79	20/12/2012	16,234.73	20/12/2012	9,317.68
				21/09/2012	17,123.87	21/10/2012	25,122.45	21/12/2012	12,976.91	21/12/2012	14,076.78
				22/09/2012	26,337.32	22/10/2012	20,996.03	22/12/2012	22,813.29	22/12/2012	12,852.13
				23/09/2012	29,964.82	23/10/2012	22,843.23	23/12/2012	21,360.72	23/12/2012	9,033.52
				24/09/2012	29,539.63	24/10/2012	26,875.64	24/12/2012	16,192.06	24/12/2012	22,799.93
				25/09/2012	30,747.90	25/10/2012	19,480.18	25/12/2012	7,636.51	25/12/2012	23,145.63
				26/09/2012	27,614	26/10/2012	28,496.20	26/12/2012	21,336.96	26/12/2012	22,289.71
				27/09/2012	20,592.05	27/10/2012	24,651.84	27/12/2012	21,887.48	27/12/2012	18,173.26
				28/09/2012	30,638.88	28/10/2012	22,463.52	28/12/2012	14,613.39	28/12/2012	21,398.69
				29/09/2012	30,184.43	29/10/2012	20,604.61	29/12/2012	27,374.29	29/12/2012	23,741.05

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Jan-13		Feb-13		Mar-13		Apr-13		May-13	
Date	Energy (Wh)	Date	Energy (Wh)	Date	Energy (Wh)	Date	Energy (Wh)	Date	Energy (Wh)
1/1/2013	24,721.52	1/2/2013	26,545.97	1/3/2013	27,296.36	1/4/2013	27,440.67	1/5/2013	23,803.38
2/1/2013	24,101.18	2/2/2013	25,577.65	2/3/2013	29,000.48	2/4/2013	28,595.23	2/5/2013	25,884.46
3/1/2013	23,772.31	3/2/2013	26,753.65	3/3/2013	28,980.03	3/4/2013	29,186.99	3/5/2013	28,264.28
4/1/2013	18,470.42	4/2/2013	24,987.37	4/3/2013	25,456.25	4/4/2013	28,322.90	4/5/2013	28,250.83
5/1/2013	10,777.68	5/2/2013	26,662.39	5/3/2013	28,620.49	5/4/2013	29,417.13	5/5/2013	26,483.58
6/1/2013	21,067.75	6/2/2013	22,487.32	6/3/2013	27,460.79	6/4/2013	28,543.80	6/5/2013	23,922.37
7/1/2013	27,089.07	7/2/2013	18,303.72	7/3/2013	25,560.66	7/4/2013	27,226.06	7/5/2013	25,646.18
8/1/2013	26,372.83	8/2/2013	22,082.23	8/3/2013	25,219.23	8/4/2013	27,949.07	8/5/2013	26,625.28
9/1/2013	24,966.71	9/2/2013	22,819.48	9/3/2013	26,163.04	9/4/2013	29,389.36	9/5/2013	26,085.66
10/1/2013	26,557.09	10/2/2013	6,854.45	10/3/2013	23,970.27	10/4/2013	25,919.78	10/5/2013	26,735.42
11/1/2013	25,033.99	11/2/2013	23,138.35	11/3/2013	24,762.33	11/4/2013	26,528.66	11/5/2013	25,066.88
12/1/2013	26,346.50	12/2/2013	30,638.06	12/3/2013	25,611.49	12/4/2013	10,826.21	12/5/2013	25,389.80
13/01/2013	28,014.19	13/02/2013	29,115.69	13/03/2013	18,770.55	13/04/2023	30,260.13	13/05/2013	24,257.17
14/01/2013	26,651.17	14/02/2013	22,302.73	14/03/2013	28,377.73	14/04/2013	30,328.21	14/05/2013	26,424.59
15/01/2013	29,679.49	15/02/2013	11,794.55	15/03/2013	21,934.25	15/04/2013	26,242.85	15/05/2013	25,098.91
16/01/2013	27,927.18	16/02/2013	24,027.04	16/03/2013	27,185.23	16/04/2013	25,991.95	16/05/2013	25,613.32
17/01/2013	23,132.69	17/02/2013	25,206.83	17/03/2013	26,819.18	17/04/2013	28,435.90	17/05/2013	25,482.65
18/01/2013	26,765.93	18/02/2013	26,713.93	18/03/2013	29,580.61	18/04/2013	18,287.60	18/05/2013	22,193.39
19/01/2013	27,412.14	19/02/2013	25,319.23	19/03/2013	29,830.52	19/04/2013	27,346.48	19/05/2013	21,588.91
20/01/2013	26,711.18	20/02/2013	26,714.24	20/03/2013	28,866.85	20/04/2013	12,980.40	20/05/2013	23,598.23

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21/01/2013	25,428.41	21/02/2013	26,123.93	21/03/2013	27,321.70	21/04/2013	22,723.23	21/05/2013	22,186.78
22/01/2013	21,279.73	22/02/2013	22,103.58	22/03/2013	28,544.47	22/04/2013	26,026.23	22/05/2013	23,458.54
23/01/2013	25,625.89	23/02/2013	23,155.54	23/03/2013	27,534.91	23/04/2013	4,672.73	23/05/2013	24,425.45
24/01/2013	24,398.61	24/02/2013	26,355.66	24/03/2013	27,069.56	24/04/2013	11,163.10	24/05/2013	23,622.56
25/01/2013	27,372.18	25/02/2013	26,598.48	25/03/2013	29,118.59	25/04/2013	18,427.21	25/05/2013	15,166.08
26/01/2013	27,939.06	26/02/2013	25,138.20	26/03/2013	28,007.21	26/04/2013	13,645.22	26/05/2013	17,211.27
27/01/2013	23,078.85	27/02/2013	19,202.83	27/03/2013	29,925.11	27/04/2013	28,480.08	27/05/2013	22,693.03
28/01/2013	27,003.29	28/02/2013	20,114.12	28/03/2013	29,265.55	28/04/2013	26,557.04	28/05/2013	65.7952
29/01/2013	24,483.60	29/02/2013	18,499.94	29/03/2013	28,921.22	29/04/2013	19,281.36		
30/01/2013	26,543.95			30/03/2013	28,070.64	30/04/2013	6,788.45		
31/01/2013	26,404.34			31/03/2013	26,717.72				

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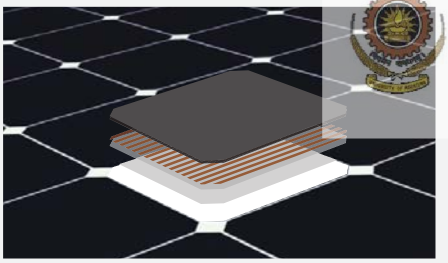
- **20.4% efficiency**
Ideal for roofs where space is at a premium or where future expansion might be needed.
- **High performance**
Delivers excellent performance in real world conditions, such as high temperatures, clouds and low light.[1,2,3]
- **Proven value**
Designed for residential rooftops, E-Series panels deliver the features, value and performance for any home.



Maxeon™ Solar Cells: Fundamentally better.
Engineered for performance, designed for durability.

Engineered for peace of mind

Designed to deliver consistent, trouble-free energy over a very long lifetime.[4,5]

Designed for durability

The SunPower Maxeon Solar Cell is the only cell built on a solid copper foundation. Virtually impervious to the corrosion and cracking that degrade Conventional Panels.[4,5]

#1 Ranked in Fraunhofer durability test.[10]
100% power maintained in Atlas 25+ comprehensive PVDI Durability test.[11]

HIGH PERFORMANCE & EXCELLENT DURABILITY

E20 - 327 PANEL

E20 SERIES

HIGH EFFICIENCY[6]

Generate more energy per square meter

E-Series residential panels convert more sunlight to electricity producing 36% more power per panel,[1] and 60% more energy per square meter over 25 years.[3,4]

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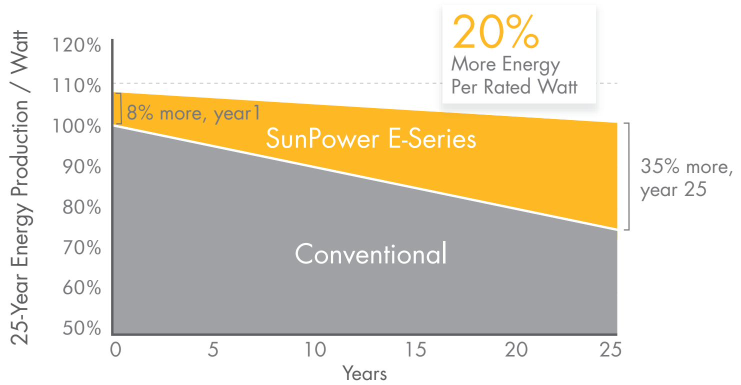
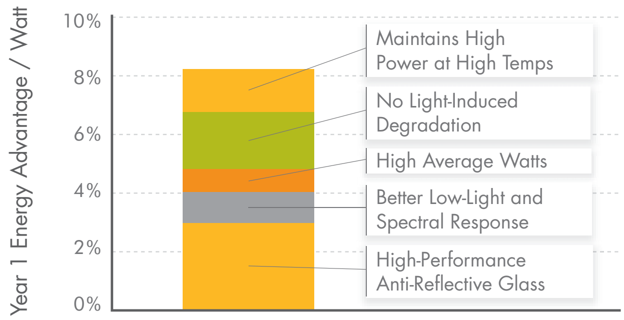
HIGH ENERGY PRODUCTION[7]

Produce more energy per rated watt

High year one performance delivers 7-9% more energy per rated watt.[3] This advantage increases over time, producing 20% more energy over the first 25 years to meet your needs.[4]





MOST ENERGY PER WATT
1
PHOTON
2012 FIELD TEST

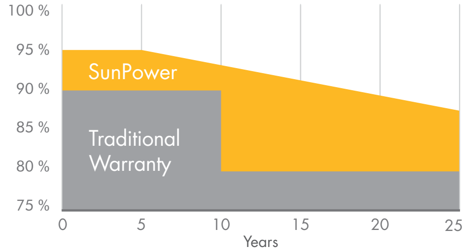
SUNPOWER

MORE ENERGY. FOR LIFE.™

E-SERIES SOLAR PANELS

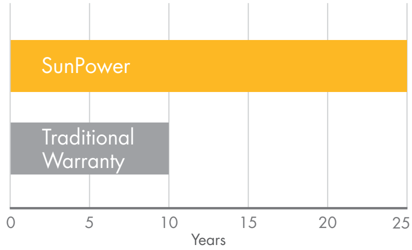
SUNPOWER OFFERS THE BEST COMBINED POWER AND PRODUCT WARRANTY

POWER WARRANTY



More guaranteed power: 95% for first 5 years, -0.4%/yr. to year 25.[8]

PRODUCT WARRANTY



Combined Power and Product defect 25 year coverage that includes panel replacement costs.[9]

ELECTRICAL DATA

	E20-327	E19-320
Nominal Power[12] (Pnom)	327 W	320 W
Power Tolerance	+5/–0%	+5/–0%
Avg. Panel Efficiency[13]	20.4%	19.8%
Rated Voltage (Vmpp)	54.7 V	54.7 V
Rated Current (Impp)	5.98 A	5.86 A
Open-Circuit Voltage (Voc)	64.9 V	64.8 V
Short-Circuit Current (Isc)	6.46 A	6.24 A
Max. System Voltage	1000 V IEC & 600 V UL	
Maximum Series Fuse	20 A	
Power Temp Coef.	–0.38% / °C	
Voltage Temp Coef.	–176.6 mV / °C	
Current Temp Coef.	3.5 mA / °C	

OPERATING CONDITION AND MECHANICAL DATA

Temperature	– 40°C to +85°C
Max load	Wind: 2400 Pa, 245 kg/m² front & back Snow: 5400 Pa, 550 kg/m² front
Impact resistance	25mm diameter hail at 23 m/s
Appearance	Class A
Solar Cells	96 Monocrystalline Maxeon Gen II
Tempered Glass	High transmission tempered Anti-Reflective
Junction Box	IP-65 Rated
Connectors	MC4
Frame	Class 1 black anodized (highest AAMA rating)
Weight	18,6 kg

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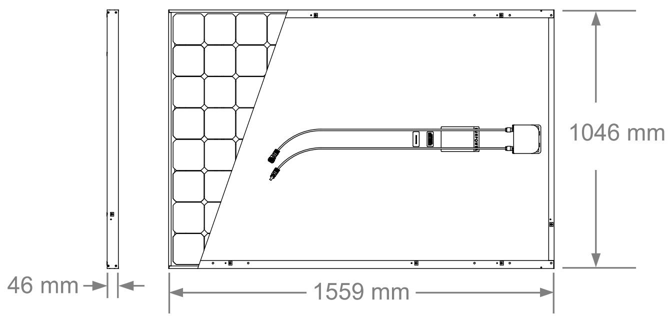
TESTS AND CERTIFICATIONS

Standard tests	IEC 61215, IEC 61730, UL1703
Quality tests	ISO 9001:2008, ISO 14001:2004
EHS Compliance	RoHS, OHSAS 18001:2007, lead free, PV Cycle
Ammonia test	IEC 62716
Salt Spray test	IEC 61701 (passed maximum severity)
PID test	Potential-Induced Degradation free: 1000V[10]
Available listings	TUV, MCS, UL, JET, KEMCO, CSA, CEC, FSEC



REFERENCES:
1 All comparisons are SPR-E20-327 vs. a representative conventional panel: 240W, approx. 1.6 m², 15% efficiency.
2 PVEvolution Labs "SunPower Shading Study," Feb 2013.
3 Typically 7-9% more energy per watt, BEW/DNV Engineering "SunPower Yield Report," Jan 2013.
4 SunPower 0.25%/yr degradation vs. 1.0%/yr conv. panel. Campeau, Z. et al. "SunPower Module Degradation Rate," SunPower white paper, Feb 2013; Jordan, Dirk "SunPower Test Report," NREL, Oct 2012.
5 "SunPower Module 40-Year Useful Life" SunPower white paper, Feb 2013. Useful life is 99 out of 100 panels operating at more than 70% of rated power.
6 Out of all 2600 panels listed in Photon International, Feb 2012.
7 8% more energy than the average of the top 10 panel companies tested in 2012 (151 panels, 102 companies), Photon International, March 2013.
8 Compared with the top 15 manufacturers. SunPower Warranty Review, Feb 2013.
9 Some exclusions apply. See warranty for details.
10 5 of top 8 panel manufacturers were tested by Fraunhofer ISE, "PV Module Durability Initiative Public Report," Feb 2013.
11 Compared with the non-stress-tested control panel. Atlas 25+ Durability test report, Feb 2013.
12 Standard Test Conditions (1000 W/m² irradiance, AM 1.5, 25° C).
13 Based on average of measured power values during production

See http://www.sunpowercorp.com/facts for more reference information.
For more details, see extended datasheet: www.sunpowercorp.com/datasheets. Read safety and installation instructions before using this product.
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