ENERGY, ECONOMIC AND ENVIRONMENTAL ANALYSES OF A SOLAR ENERGY BASED POWER GENERATION UNDER MALAYSIAN CONDITIONS

MD. HOSENUZZAMAN

INSTITUTE OF GRADUATE STUDIES
UNIVERSITY OF MALAYA
KUALA LUMPUR

2016

ENERGY, ECONOMIC AND ENVIRONMENTAL ANALYSES OF A SOLAR ENERGY BASED POWER GENERATION UNDER MALAYSIAN CONDITIONS

MD. HOSENUZZAMAN

DESSERTATION SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF PHILOSOPHY

INSTITUTE OF GRADUATE STUDIES
UNIVERSITY OF MALAYA
KUALA LUMPUR

2016

UNIVERSITY OF MALAYA

ORIGINAL LITERARY WORK DECLARATION

Name of Candidate: **Md. Hosenuzzaman**

Registration/Matric No: **HGF 120004**

Name of Degree: **Master of Philosophy**

Title of Project Paper/Research Report/Dissertation/Thesis ("this Work"):

Energy, Economic and Environmental Analyses of a Solar Energy Based Power Generation under Malaysian Conditions

Field of Study: **Energy**

I do solemnly and sincerely declare that:

(1) I am the sole author/writer of this Work;
(2) This Work is original;
(3) Any use of any work in which copyright exists was done by way of fair dealing and for permitted purposes and any excerpt or extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the Work and its authorship have been acknowledged in this Work;
(4) I do not have any actual knowledge nor do I ought reasonably to know that the making of this work constitutes an infringement of any copyright work;
(5) I hereby assign all and every rights in the copyright to this Work to the University of Malaya ("UM"), who henceforth shall be owner of the copyright in this Work and that any reproduction or use in any form or by any means whatsoever is prohibited without the written consent of UM having been first had and obtained;
(6) I am fully aware that if in the course of making this Work I have infringed any copyright whether intentionally or otherwise, I may be subject to legal action or any other action as may be determined by UM.

Candidate's Signature Date:

Subscribed and solemnly declared before,

Witness's Signature Date:

Name:
Designation:

ABSTRACT

Energy is the driving force for development, economic growth, automation, and modernization. Energy usage and demand are rising globally and researchers have taken this seriously to fulfill future energy demands. Solar energy is the inexhaustible and emission free energy source where the Photovoltaic (PV) is one of the most potential energy system.

This research emphasizes the use of large scale PV installation as a clean energy source to support the energy demand in Malaysia. Discussion also include the 30 MW solar PV power plants and the factors that affecting power generation (cell/module types, efficiency, solar tracking system, shading, dust, life time, solar insolation and cell operating temperature), its installation cost, inverter replacement cost and land price. From the analysis, it is found that when the crystalline silicon module price is RM1.80/W (US$0.50/W), 100% self-financing and the selling price of the produced electricity is RM0.40/kWh, RM0.45/kWh, RM0.50/kWh, and 0.55/kWh, then the Net Present Value (NPV) are RM110.27 million, RM156.69 million, RM203.11 million, and RM249.53 million respectively, the Internal Rate of Return (IRR) of crystalline silicon is 6.8%, 9.2%, 11.4% and 13.5% respectively, the payback period of mono crystalline silicon is 11.4 years, 9.9 years, 8.7 years and 6.3 years respectively. When the crystalline silicon module price is RM1.80/W (US$0.50/W), 50% self-financing and 50% bank loan with 3% interest and loan tenure 15 years, the selling price of the produce electricity is RM0.40/kWh, RM0.45/kWh, RM0.50/kWh, and 0.55/kWh, then the NPV is RM18.06 million, RM16.9 million, RM50.46 million, and RM84.72 million. The IRR% is 1.6%, 4.2%, 6.6%, 8.8%, and the payback periods are 19.7 years, 16.9 years, 12.3 years, and 10.5 respectively. The grid parity is also analyzed and it is found

that the grid parity occur within the year of 2021 to 2022 for crystalline silicon, when module price is RM1.80/W (US$0.50/W). To overcome the negative impacts of fossil fuels on the environment, many countries have been forced to change the environmental friendly alternatives energy sources. Solar energy is one of the best renewable energy sources and has the least negative impact on the environment.

ABSTRAK

Tenaga adalah daya penggerak untuk pembangunan, pertumbuhan ekonomi, automasi dan pemodenan. Penggunaan dan permintaan tenaga semakin meningkat di peringkat global dan penyelidik telah mengambil ini dengan serius untuk memenuhi permintaan tenaga pada masa hadapan. Tenaga solar adalah sumber tenaga diperbaharui dan bersih dari pencemaran di mana Fotovoltaik (PV) adalah salah satu sistem tenaga yang paling berpotensi.

Kajian ini menekankan penggunaan pemasangan fotovoltaik berskala besar sebagai sumber tenaga bersih untuk menyokong permintaan tenaga di Malaysia. Ia juga membincangkan tentang 30 MW loji kuasa solar fotovoltaik dan faktor-faktor yang mempengaruhi penjanaan kuasa (jenis sel / modul, kecekapan, sistem pengesanan solar, teduhan/bayangan, habuk, jangka hayat, solar insolasi dan suhu operasi sel), kos pemasangannya, kos penggantian inverter dan harga tanah. Daripada analisis, didapati apabila harga silikon kristal modul adalah RM1.80/W (US$0.50/W) pembiayaan sendiri sebanyak 100%, dan harga jualan elektrik adalah RM0.40/kWj, 0.45/kWj, 0.50/kWj dan 0.55/kWj, maka NPV RM110.27 juta, RM156.69 juta, RM203.11 juta dan RM249.53 juta masing-masing, IRR% daripada silikon kristal adalah 6.8%, 9.2%, 11.4% dan 13.5%, manakala tempoh bayar balik daripada mono kristal silikon adalah 11.4 tahun, 9.9 tahun, 8.7 tahun dan 6.3 tahun masing-masing . Apabila harga modul silikon kristal adalah RM1.80/W (US$0.50/W), melalului pembiayaan sendiri sebanyak 50% dan pinjaman bank sebanyak 50% beserta facdah sebanyah3% dan tempoh pinjamam selama 15 tahun, dan harga jualan elektrik adalah RM0.40/kWj, 0.45/kWj, 0.50/kWj dan 0.55/kWj, maka NPVs adalah RM18.06 juta, RM16.9 juta, RM50.46 juta, dan RM84.72 juta, di mana IRR adalah 1.6%, 4.2%, 6.6% dan 8.8%, , untuk tempoh bayar

balik selama 19.7 tahun, 16.9 tahun, 12.3 tahun dan 10.5. Pariti grid juga turut dianalisis dalam kajian ini dan didapati pariti grid berlaku dalam tempoh 2021 ke 2022 untuk silikon kristal, Apabila harga modul kristal silikon RM1.80/W (US$0.50/W). Untuk mengatasi kesan negatif daripada bahan api fosil terhadap alam sekitar, banyak negara telah diarah untuk menggunakan sumber tenaga alternatif yang mesra alam sekitar. Tenaga solar adalah salah satu sumber tenaga boleh diperbaharui yang terbaik dan mempunyai kurang kesan negatif terhadap alam sekitar.

ACKNOWLEDGEMENTS

In the name of Allah, the most beneficent, the most merciful, I would like to express my utmost gratitude and thanks to the almighty Allah (s.w.t) for the help and guidance that He has given me through all these years. My deepest appreciation goes to my father, mother, brothers and sisters for their blessings and supports.

I would like to express my deepest appreciation and gratitude to my supervisors, **Professor Dr. Nasrudin Abd Rahim** and **Associate Professor Dr. Jeyraj Selvaraj** for their brilliant supervision, guidance, encouragement and supports in carrying out this research work. I am deeply indebted to them. Special thanks to the UM Power Energy Dedicated Advanced Centre (UMPEDAC), University of Malaya for the financial supports.

Finally, thanks to all in UMPEDAC in helping me and for suggestion, ideas, discussions and advice in completing this research work.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURES

AC	Alternative current
A_{module}	Actual area of module
BOS	Balance of System
CdTe	Cadmium-Telluride
CF	Cash flow
CIGS	Copper Indium Gallium Diselenide
CIS	Copper Indium-Selenide
CPV	Concentrating PV
C-Si	Crystalline silicon
DOE	Department of Energy
E	Solar radiation (1000W/m^2)
E_{bos}	Efficiency of balance of system
EC	Electricity Consumption (kWh)
EFF	Emission factor of fuel (kg/kWh)
EIA	Energy Information Administration
E_{module}	Efficiency of the module
Ep	Electricity produced
EPIA	European Photovoltaic Industry Association
FDI	Foreign direct investment
FiT	Feed in tariff
GCPV	Grid connected photovoltaic
GW	Giga watt
INR	Indian Rupee
IRR	Internal rate of return

I_{solar}	Solar Insolation
LCOE	Levelized Cost of Electricity
Mc-Si	Multi-crystalline silicon
MW	Megawatt
MWh	Megawatt-hour
Nm	Number of module
NOCT	Nominal operating cell temperature
NPV	Net present value
NREL	National Renewable Energy Laboratory
O&M	Operation and Maintenance
PBP	Payback Period
PEGF	Percentage of electricity generated by the specific fuel
P_m	Peak power generation (Watt)
PV	Photovoltaic
R&D	Research and Development
R,d	Discount rate
RE	Renewable Energy
S	Capital investment
SC-Si	Single crystalline silicon
SEDA	Sustainable Energy Development Authority Malaysia
SETP	Solar energy technologies program
STC	Standard Test Condition
SWH	Solar Water Heater
T	Life time of the module
TLCC	Total life cycle cost
TNB	Tenaga National Berhad

T_{ref}	Reference temperature
TWh	Terawatt-hour
USD	United States Dollar ($)
WACC	Weighted Average Cost of Capital
η	Module efficiency
η_{ref}	Reference efficiency

CHAPTER 1: INTRODUCTION

1.1 Background

Energy is the basic elements for economic growth and modernization of a country. Global energy demands are increasing very quickly but most of the energy projections stated that at present and future global energy source are not sustainable. All of the researchers are thinking and working on to arrange or find out the alternative energy sources (Neto et al., 2010; Hasanuzzaman et al., 2012). The electricity generation in Malaysia is largely depended on fossil fuels, mainly from natural gas and coal, which constitute about 85% of the overall generation as shown in Figure 1.1 (EC, 2012). It is also reported that Malaysia could continue to produce of natural gas for 29 years (Ahmad et al., 2011). On the other hand, coal is fully imported from other countries mainly from Indonesia (84%), Australia (11%) and South Africa (5%) (Jaffar, 2009). It is clear that electricity generation in Malaysia is not sustainable and in future, it would be very difficult to fulfill the growing demand of electricity due to the occurrence of fossil fuel depletion issues. The traditional fossil fuel causes a series of serious environment problem such as climate change, global warming, acid rain and greenhouse gases emission. So, Malaysia needs very urgent basis to shift its electricity generation to alternative energy resources. Renewable energy (RE) can be the source of sustainable power generation. Solar energy is one of the alternative energy sources that have significant potential to cover the increasing energy demand in the world (Koch, 2009). Solar energy is one of the renewable energy sources that is derived from the sun through the form of solar radiation. PV conversion is the direct conversion of sunlight into electricity. The PV system has no moving parts that gives long time service and minimum maintenance. PV elements are simple in design and their important feature is construction as stand-alone systems to produce output from micro power to mega power. This system can be used for power source, solar home systems, water pumping, communications, remote buildings, satellites and space vehicles, reverse osmosis plants, and for even megawatt-scale power plants. Solar energy is obviously environmentally advantageous relative to any other energy sources and does not deplete natural resources, no greenhouse gas emission or generates liquid or solid waste products (Solangi et al., 2011; Tsoutsos et al., 2005). The tropical climatic condition in Malaysia is very suitable for the development of solar energy because of the abundant sunlight with the average irradiance 1643 kWh/m^2 per year (Haris, 2008a). Solar energy is one of the most potential energy sources in Malaysia. Malaysia is one of the ASEAN countries that have very good solar irradiations (Huang et al., 2013; Tesea, 2012). The photovoltaic technology has been developed in Malaysia since 1980 (Amin, 2009) and is the fastest growing technology in the world. America, Europe, Australia, China, and Japan, use the technology for development of the country's energy security and reduce the carbon dioxide emissions. The solar insolation range from 1400 to1900 kWh/m^2 and average about 1643 kWh/m^2 per year in Malaysia (Ahmad et al., 2011; Haris, 2008b) where the average sun hours is more than 10 hours (Amin, 2009). It has a promising potential to establish large scale solar power installations. The Malaysian Government has taken a lot of initiatives and built up policies to develop the solar energy system as one of the significant sources of energy in the country. Under the Tenth Malaysian Plan (2011 to 2015), many new strategies upon the Renewable Energy Policy and Action Plan has been taken to achieve a smart target of renewable energy 985 MW by 2015, sharing 5.5% of total electricity generation mix in Malaysia.

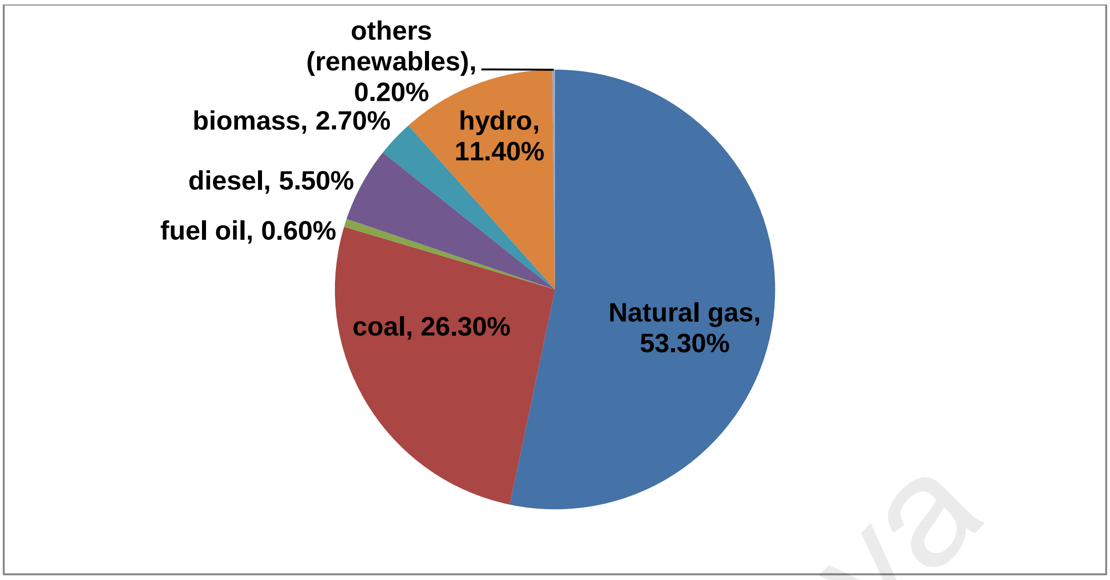

Figure 1.1: Share of electricity generation installed capacity.

(EC, 2012)

Sustainable Energy Development Authority of Malaysia has taken a lot of strategies to increase the awareness, the use of solar energy and consider it as one of the primary sources for energy supply by 2050. Figure 1.2 shows the target set as 985 MW (5.5%) by 2015, 2080 MW (11%) by 2020, 4000 MW (17%) by 2030, and 21.4 GW (73%) by 2050 (Chen, 2012).

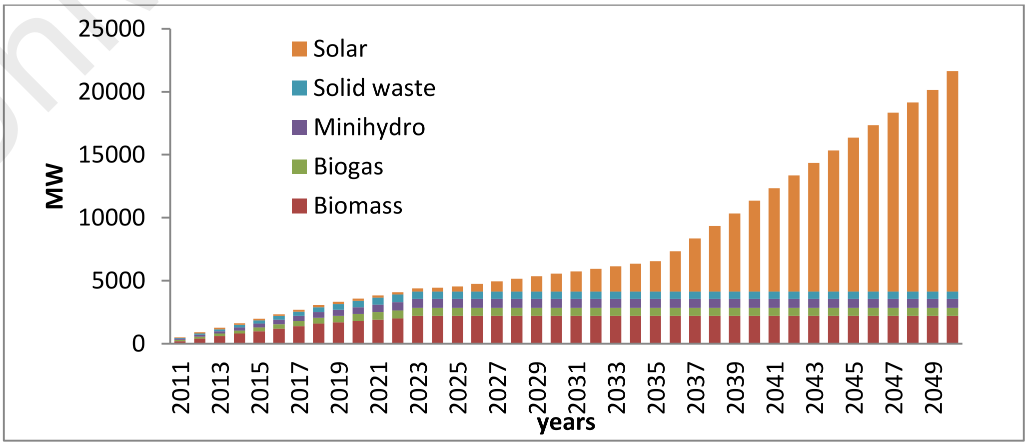

Figure 1.2: In Malaysia solar energy target up to 2050.

(Chen, 2012)

The strategies taken by the Malaysian government and Non-Government organization (NGOs) on solar energy present and future situation to increase its applications of solar energy in Malaysia have been discussed (Mekhilef, 2012). This study also analyzed the consciousness of RE policies, subsidies and a preliminary investigation of public opinion in Malaysia. From this analysis, it was found that the present feed in tariff (FiT) program is good for return of investment as compared to UK, but the return rate is smaller than other investment tools (Sukki, 2011). Solar energy development outlook in Malaysia, building integrated photovoltaic (MBIPV) and its successful initiatives, and FiT scheme have been discussed (Chu, 2012). The potential use of solar PV in Malaysia, the incentives and the RE Act approved by the Malaysian government to confirm future energy supply and safety energy supply, the subsidies for RE, solar irradiation in Malaysia and the five-fuel diversification strategy energy mix has been discussed (Johari, 2012). The growth of solar or photovoltaic (PV) energy technology, implementations and its prospect particularly in Malaysia has been analyzed (Wirun, 2013). SEDA has been taken a lot of strategies to increase the power generation, awareness and set the maximum installation capacity of PV system is not more than 12 kW and 30 MW for individual and no-individual respectively (SEDA, 2014). Feasibility analysis of a PV grid-connected System at University of Malaya Engineering Tower has been studied (Kamali, 2009).

Most of the papers highlighted about the feed in tariff, solar energy past, present and future situation in Malaysia. Very few researchers have investigated the cost benefit analysis and environmental impact of solar photovoltaic energy system in Malaysia. So far, it is found that no specific research has been done to investigate the economic analysis and environmental impact of solar photovoltaic energy system. In this research, solar photovoltaic system power output affecting factors, economic analysis and environmental impact have been investigated. This research also investigates the grid parity year of 30 MW solar PV plants in Malaysia.

1.2 Objective of the research

The objectives of the research are:

- To investigate the economics advantage of PV base power generation
- To analyze the grid parity of solar PV system
- To study the environmental impact of solar PV based power generation system

1.3 Dissertation Organization

This thesis comprises five chapters. The contents of the individual chapters have been outlined as follows:

Chapter 2 contains literature review of the research. In this chapter, a review of the literature on cell technologies, its application in power generation, factors affecting the solar photovoltaic power generation system, global photovoltaic scenario and present scenario of photovoltaic technology in Malaysia have been discussed in details.

Chapter 3 describes the research methodology. Information on the sources of data, formulation used to calculate the different parameter and methodologies used to estimate the different parameters is presented in this chapter.

Chapter 4 contains the results and discussion. The estimated electricity generate from the proposed 30 MW of solar PV plant, net present value (NPV), internal rate of return (IRR %), payback period (PBP), levelized cost of electricity (LCOE), is described with necessary Tables and Figures. It is also described the Grid parity year for 30 MW solar

PV plant in Malaysia, its environmental impact and the amount of different types of gases emission reduction calculated.

Chapter 5 states the conclusion and recommendations of the research. General conclusions, recommendations for future work presented in this chapter.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter contains an overview of other related studies, its approach development and its significance to this study in order to set up the objectives of this research. Literature reviews is an important part of the research that gives the proper direction to conduct the research properly.

The photovoltaic industry is the latest developed industry, which started from 1954, at that time the American Bell Laboratories was started for developing the first silicon solar photocell. From the analysis of world PV industry, it is seen that a significant growth has happened during the last 20 years (Lesourd, 2001). A lot of works and researches are going on to development and proper utilization of the PV technologies. PV technologies, its materials, application of PV technologies, environmental effect, different recent performance and consistency assessment models, grid connection and distribution were analyzed and found that photovoltaic technology is one of the finest ways to harness the solar power (Parida et al., 2011). Different types of PV technologies and different cells (crystalline silicon, thin film, compound and nanotechnology) have been studied and stated that the 3rd Generation of cell technology approach is more focused double, triple junction and nanotechnology to increase the efficiency of the cells at lower cost (Chaar, 2011).

PV base power generation system, financial analysis, internal rate of return, payback period, cash flow, capital investment cost and the operation cost of the PV generation system were investigated in Kiribati, Taiwan. The study showed that by 690 kWp PV system can generate 1178 MWh per year. When the produced electricity is sold at RM1.272/kWh (0.40US$/kWh), the payback period and IRR% is 7.5 years and 11.2% respectively (Chen et al., 2012). At present worldwide status of the PV technology, PV cell materials (e.g. crystalline, thin films, nanotechnology, hybrid solar cell, organic, dye-sensitized) and environmental effect of solar energy base power generation was investigated and found that photovoltaic technology is the fastest growing and environmentally advantageous technology in the world (Tyagi, 2013). The temperature range of 273 to 523K and the effect of temperature on solar cell output performance was investigated and found when the operating temperature of solar cells is increasing, the cell efficiency and power output performance are decreasing (Singh, 2012). The dust effect on solar cell efficiency and output range has been analyzed. This experiment was performed by different qualities of dust (mud, talcum and plastic) with fix radiation. After this experiment, the cell efficiency decreases with the presence of dust but when the radiation level is increased, the effect of dust is decreased (Sulaiman, 2011). Causes of dust and the dust impact on solar cell efficiency and PV output performance was investigated and found that dust decreases the output power of PV panel but this dust effect can be minimized with the incremental of irradiation intensity (Hee, 2012). The potential and the cost-effectiveness of a solar photovoltaic power plant were investigated to meet the energy demand of garment zone at Jaipur India. For this investigation about 2.5 MW capacity of solar PV power plant has been proposed, which requires about 13.14 acres of land area. An off-site proposal for the power plant has also been considered and compared with the on-site option. For the onsite solar PV power plant IRR, NPV @ 10% discount rate, simple payback period and discounted payback period @10% are 11.88%, RM6.35 million (119.52 million INR), 7.73 years and 15.53 years respectively. Where the off-site power plant IRR, NPV, simple payback period and discounted payback period are 15.10%, RM13.29 million (249.78 million INR), 6.29 years and 10.14 years respectively. Levelized cost of energy is RM0.80 (Rs.14.94) and RM0.60 (Rs.11.40) per kWh for on-site and off-site solar PV plants respectively @ 10% discount rate, which is quite attractive (Chandel, 2014).

The grid parity years of solar photovoltaic systems was analyzed for Europe. In this analysis, it was found that the annual electricity generated in Northern and Southern Germany by PV solar energy system is about 780 kWh/kWp and 900 kWh/kWp respectively. The grid parity in South Germany is achieved in the year of 2014 and North Germany will achieve in the year of 2015 under the most positive conditions (Mondol, 2013). The annual electricity generated by solar photovoltaic energy system in Northern and Southern Spain is about 1100 kWh/kWp and 1450 kWh/kWp respectively. The parity year was studied by assuming annual PV system cost decrease rates of 8% and 4%. The results present that the first Residential retail grid parity (RRGP) has been reached in Southern Spain between 2012 to 2013 and Northern Spain has reached in the year of 2014 under the most positive conditions. For unfavorable conditions, i.e. with the PV system cost-decrease rate of 4%, and the electricity price increase rate of 3%, grid parity has been achieved in the year of 2014 for Southern Spain. Northern Spain will achieve the grid parity in the year 2017. Under the most favorable conditions Commercial retail grid parity (CRGP) has been achieved in Southern and Northern Spain in 2011 and 2013 respectively. For unfavorable conditions, grid parity is foreseen to be reached in the year 2015 (Mondol, 2013). The annual electricity generated by solar photovoltaic energy system in the Southern and Northern Italy is about 1350 kWh/kWp and 1100 kWh/kWp respectively. The residential grid parity in Southern and Northern regions in Italy has been achieved in 2013 and 2015, respectively, for commercial applications, grid parity has been achieved between 2011 and 2012 (Mondol, 2013).

In the Central European regions (Belgium, Austria, and Netherlands), the solar conditions are marginal, but the energy cost is high, resulting in grid parity being achieved after the year of 2016, and indicating that PV has a mid-term future as sustainable power source without any subventions (Mondol, 2013). Annual energy output for the selected cities in Malaysia varies about 1170 kWh/kWp to 1600 kWh/kWp for roof-top systems while about 630 kWh/kWp to 830 kWh/kWp for facade systems. The PV based power generation system in Kuala Lumpur would yield around 1000 to 1500 kWh/kWp per year (Chu, 2012). A comparative financial analysis of a non-residential installation of 100 kW solar PV plant in Japan and selected countries in Europe has been performed. For this analysis, solar insolation per year (kWh/m^2/year) and FiT are used to calculate payback period of the solar PV plant. It was found that the average solar insolation (kWh/m^2) in Japan, Germany, Italy and United Kingdom is 1467, 1000, 1533, and 1000 respectively. FiT rate RM/kWh in Japan, Germany, Italy and United Kingdom is RM1.28/kWh (€0.30/kWh), RM0.60/kWh (€0.14/kWh), RM0.73/kWh (€0.17/kWh), and RM0.90/kWh (€0.21/kWh) respectively. Payback period of the plant in Japan, Germany, Italy and United Kingdom is 8.05 years, 14.65 years, 9.26 years, and 9.32 years respectively (Sukk, 2014). Another comparative financial analysis has been done for a residential installation of a 4 kW solar PV plant in Japan and selected countries in Europe. It was found that the average solar insolation (kWh/m^2) in Japan, Germany, Italy and United Kingdom is 1467, 1000, 1533, and 1000 respectively. Payback period of this plant in Japan, Germany, Italy and United Kingdom is 7.67 years, 12.32 years, 13.9 years, and 7.83 years respectively (Sukk, 2014). To meet the energy demand of six major cities in India up to year 2025, solar PV electricity was suggested as the viable solution for meeting future energy demands (Muneeret al., 2005). It was also reported that solar PV system as a reliable substitute to be considered in the Indian process industries, particularly in the garment industry (Gupta, 1989;

Mekhilefet al., 2011). A solar power plant situated in the Kingdom of Bahrain, produced 12 MW (32 kW per day) from PV panels installed at the windows and rooftops of two buildings along with annual CO_2 reduction of 48,000 ton and revenue generation of RM20,496,000 (€4,800,000) annually (Alnaser, 2008).

2.2 Photovoltaic cell and module technology

Photovoltaic (PV) modules are solid-state devices that convert sunlight directly into electricity without an intervening heat engine or rotating equipment. PV system has no moving parts, as a result needs minimal maintenance and has a long time service. Each solar cell needs light absorption properties by which the cell structure absorbs photons and produces free electrons through the PV effect. Electricity is generated from sunlight by the PV effect in solar cells. Sunlight, which is clean energy, on striking a PV cell, donates more energy to some electrons (negatively charged atomic elements) to escalate their energy level and thus free them. A built-in-potential barrier in the cell acts on these electrons to generate voltage which is used to run current through a circuit (Ray, 2010). Figure 2.1 shows the PV effect in a solar cell and Figure 2.2 shows the schematic diagram for the PV systems. A lot of PV cell technologies are available in the market, by proceeding different types of materials. In the future, more cell technologies also will be available in the market. According to maturity level in commercial product and materials used, the PV cell technologies are divided into three generation (IRENA, 2012).

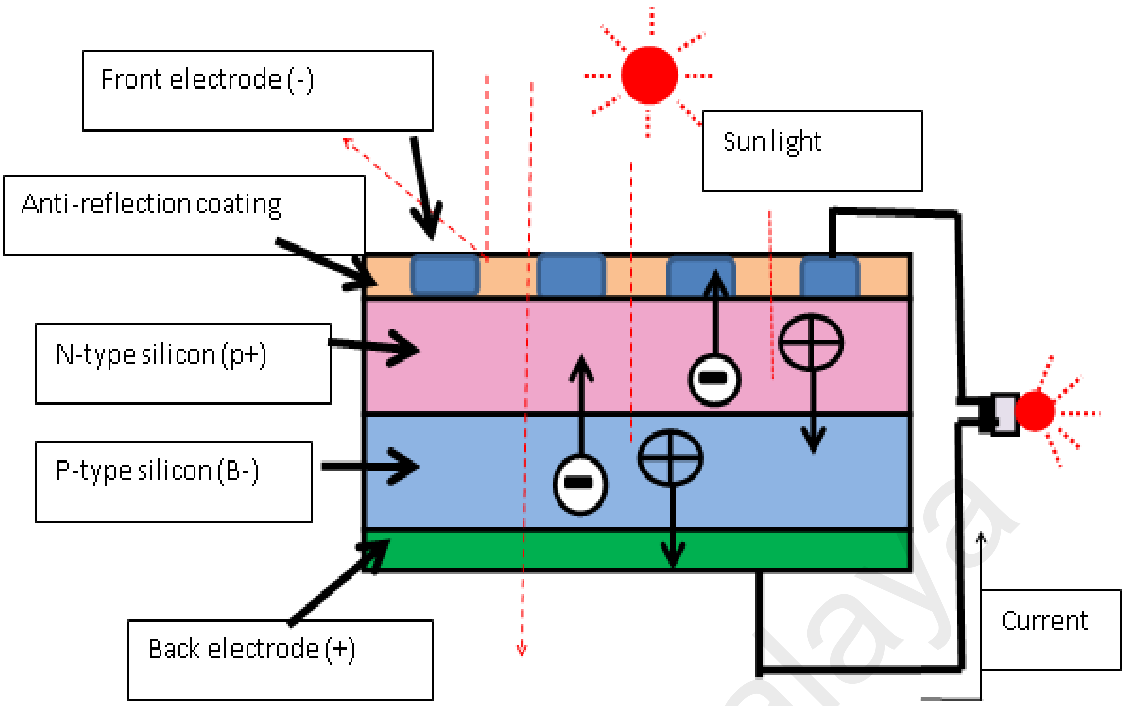

Figure 2.1: The PV effect in a solar cell.

(SE, 2013)

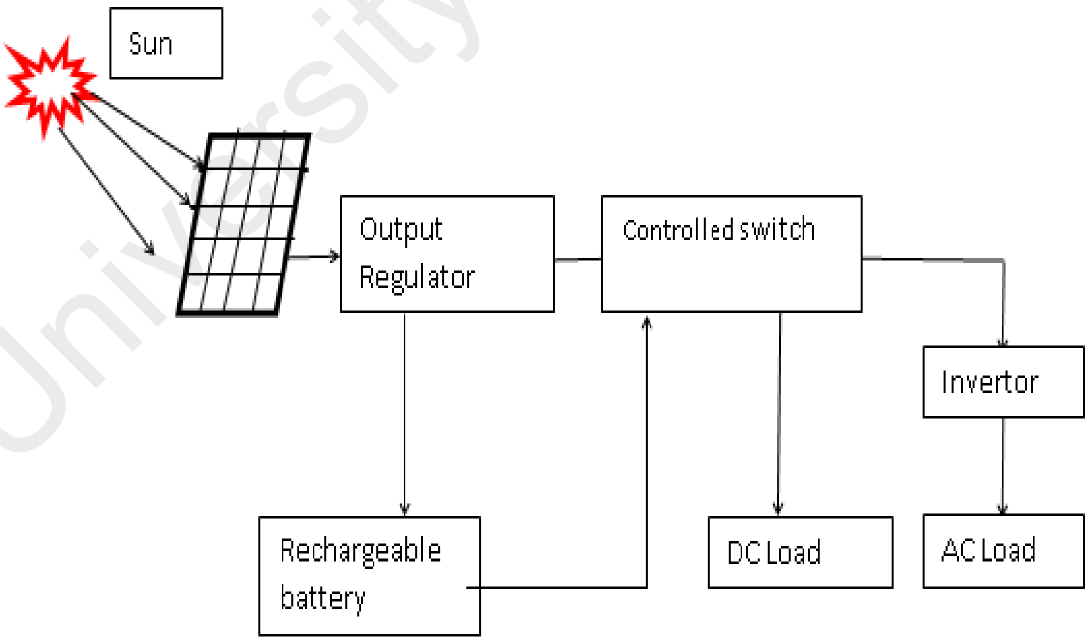

Figure 2.2: Schematic diagram for the PV system

There are two types of crystalline silicon technology: (a) Mono-crystalline (sc-Si), (b) multi-crystalline (mc-Si).

2.2.1 First generation (Crystalline silicon (c-Si) technology)

The international market of photovoltaic is still depended on crystalline silicon based solar cell. This crystalline silicon solar cell occupied about 90% of the PV market (Bagnall, 2008). The global largest commercial PV installation is the crystalline silicon cells and modules at this time. Crystalline silicon technologies are accounted for about 86% of global PV sales in 2010 (SC, 2011). Figure 2.3 shows the different types of cells share percent for PV production. Multi-crystalline solar cell has the highest share of about 53% and Mono crystalline solar cell has the share of about 33%. The efficiency of crystalline silicon modules ranges from 14% to 19%. Crystalline silicon technology is a mature technology, with rapidly cost reductions with modernization of materials and manufacturing processes. Figure 2.4 shows efficiency analysis of three cells (Midtgard, 2010).

2.2.1.1 Mono–crystalline silicone cells

Mono-crystalline silicon cells are the first developed and commercially used cell. This cell is still widely used nowadays. Mono crystalline cell has occupancy about 90% of the PV market and it will be continued until high efficiency and low price cell is manifested. Figure 2.3 shows the production share of different PV cell technologies. Mono-crystalline silicon cells are made from pure mono crystalline silicon. In these cells, the silicon has a single continuous crystalline lattice structure with almost no defects or impurities. In crystalline silicon cell p/n junctions is used. For producing mono crystalline silicon, a single crystal ingot, is ploughed by following the

Czochralski method. The single crystalline silicon solar cell size is mainly 100 to 150 mm-diameter wafer, 100×100 mm pseudo square and 125×125mm pseudo square and the wafer thickness of between 280 to 400 um (Yang, 1999). In laboratory, single-crystalline Silicon cells has efficiency of 24%, and also for this single crystalline silicon, the module efficiency is more than 20% (Yamaguchi, 2001). The highest efficiency of this cell under STC is 24.7% and the complete module efficiency is 20.4%.

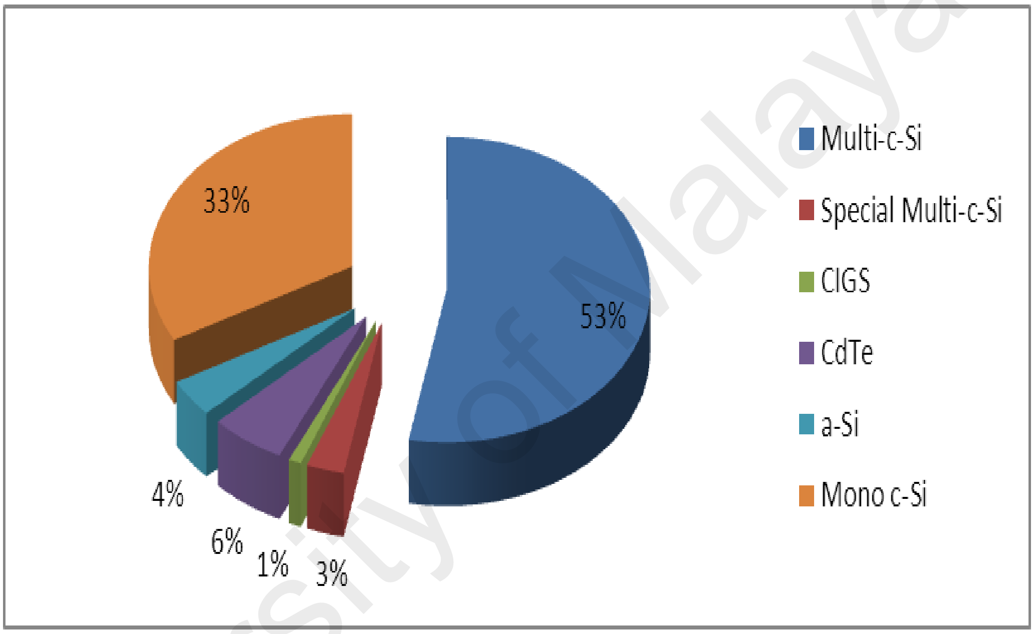

Figure 2.3: Production share of different PV cell technologies.

(Bagnall, 2008)

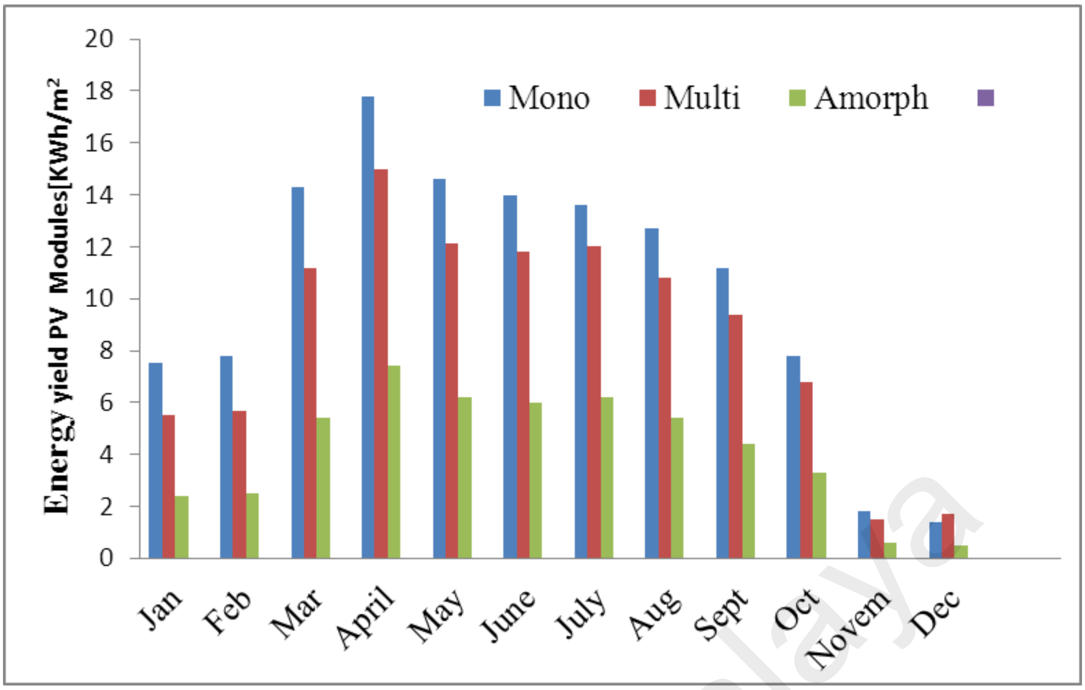

Figure 2.4: Efficiency analysis of three cells.

(Midtgard, 2010)

2.2.1.2 Multi-Crystalline silicon cells

Research and improvement of solar cells was mainly dependent to polycrystalline silicon (poly-Si) solar cells (Yamaguchi, 2001). In the manufacturing process of multi-crystalline silicon cells, melted polycrystalline silicon is thrown into ingots, which is later cut into small and narrow wafers and combined into complete cells. Crystalline silicon can give higher efficiency by mixing only a small amount of material. This cell is used widely and showing the efficiency around 14% to 19% (Green et al., 2004). The cell production technologies are as follows (Jungbluth, 2005):

1) Etching: By this step the wafers are treated by chemicals, so that, the microscopic damage and sawn parts are removed from the surface of the wafer.

2) Doping: When the etching is finished then the doping step is started. Doping process is essential because the system wafer is activated on photoactive PN junction. Doping process is normally done by phosphorous.

3) Screen printing: The front and backside of the wafer is needed to Screen printing for the properties of collecting electron and metallization.

4) Coating: This step is the most important for the wafer. Here light absorbing covering is given on the front size of the wafer to increase irradiation and efficiency.

5) Checking: This is the last step of the cell production. The produced cell needs to be checked of its quality based on the electrical properties means efficiency. Figure 2.5 shows the steps of production of silicon-based PV modules.

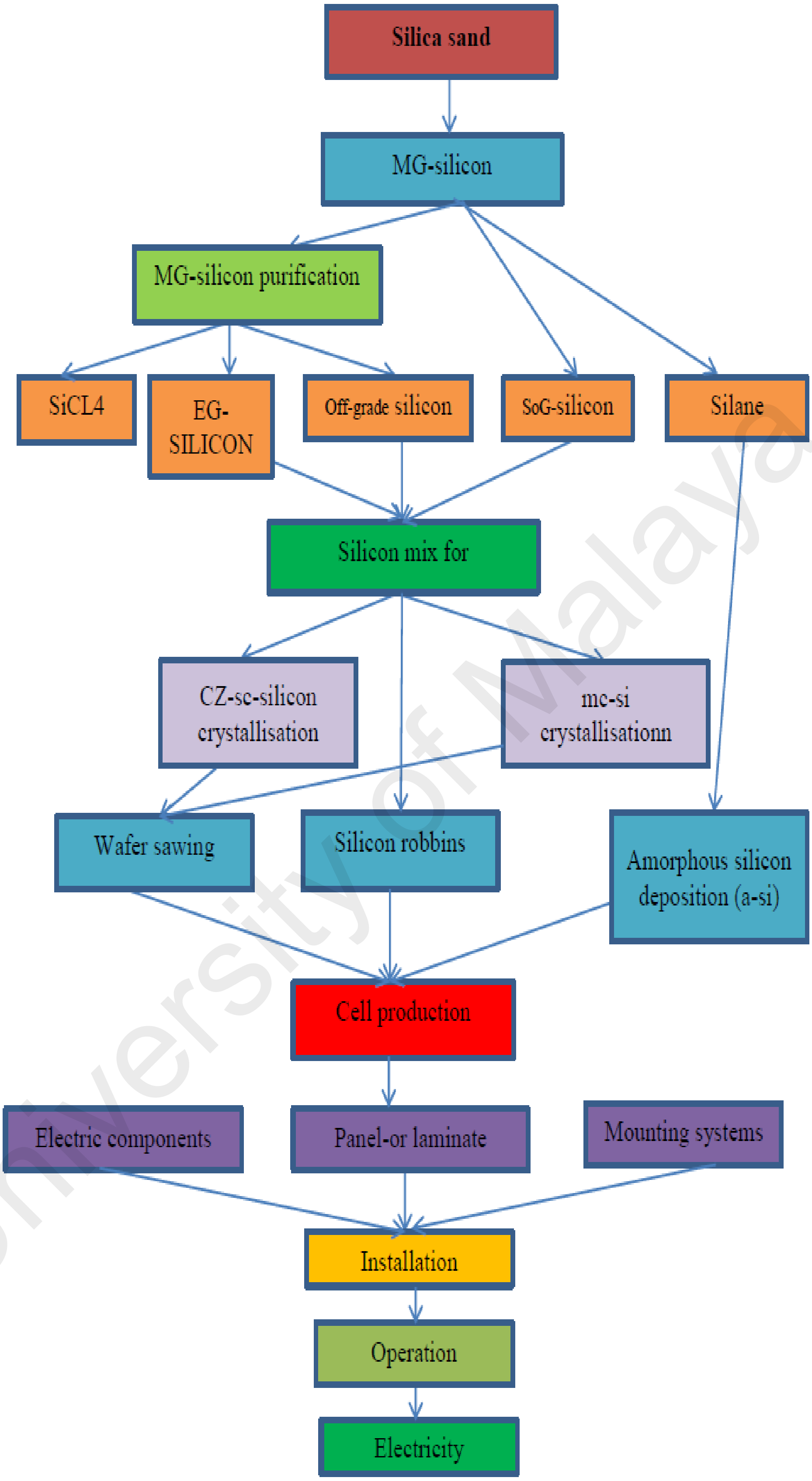

Figure 2.5: Steps of production of silicon-based PV modules

2.2.2 Second-generation (Thin-film technology)

Thin-film technology is generally when a small seam of semiconductor ingredients are given to a solid backing material. The semiconductor ingredient layers are smaller than 10µm thick compared to silicon wafers which tend to be more than hundred microns thick. Furthermore, the possible films are deposited on stainless steel substrate to allow the creation of flexible PV module. As a result, the production cost is lower due to the high throughput deposition process as well as the lower cost of materials. Normally as thin film cell elements, the following elements are used, such as like cadmium telluride (CdTe), Gallium arsenide (GaAs), titanium dioxide (TiO_2) and copper indium diselenide (CuInSe2). Production procedure of thin film photovoltaic panel for producing (CdTe and CIS) thin film PV module is done by forming photo active P/N junction with two semiconductor materials: CdTe or CdS and CuInSe2. This element is directly gathered in the very thin sheets on a cleaned substrate glass that means of a vacuum vaporization process. A P/N junction is formed in series connection by means of a series of auto mated laser and mechanicals cribbing processes. To make the finished form of the module, another protective glass pane is attached on top of the module (Raugei, 2007). Steps of production of thin film modules is shown in Figure 2.6 (Jungbluth, 2005).

Thin–film technology is classified into three types:

(a) Amorphous (a-Si) and micromorph silicon (a-Si/μc-Si)

(b) Cadmium-Telluride (CdTe)

(c) Copper- Indium-Selenide (CIS) and Copper-Indium- Gallium-Diselenide (CIGS).

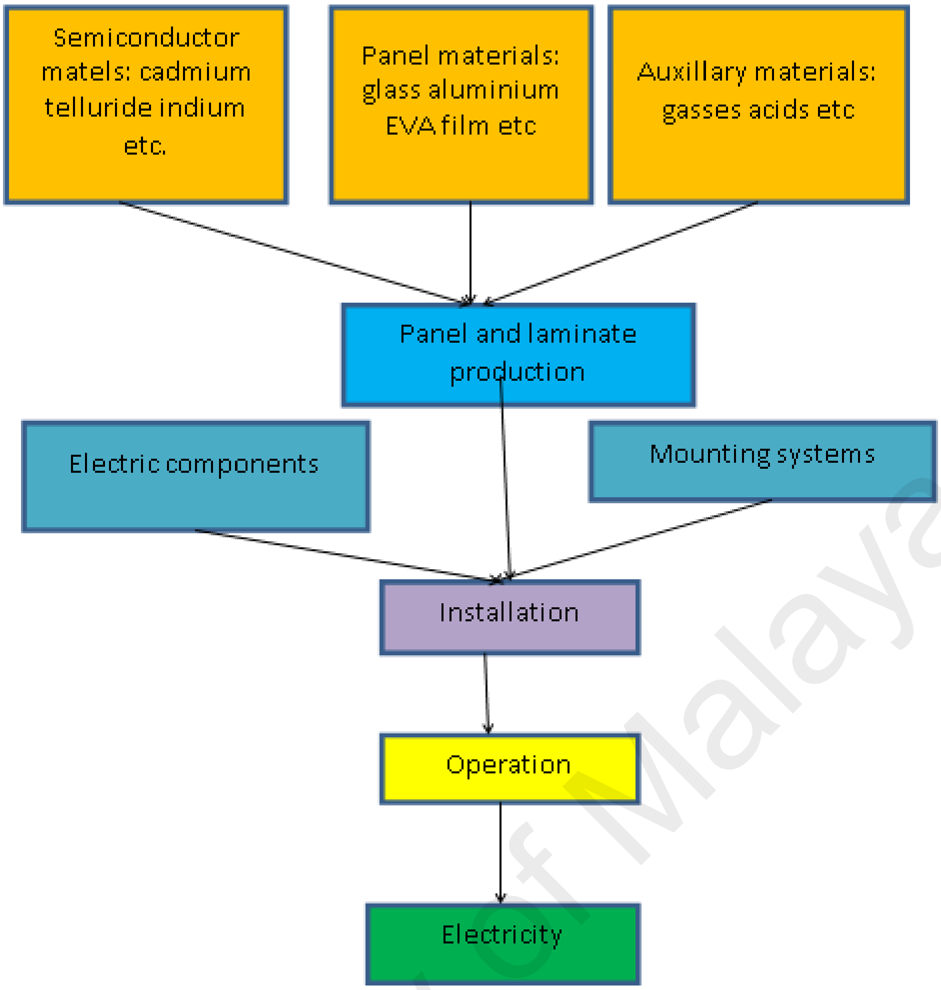

Figure 2.6: Steps of the production of thin film PV modules.

(Jungbluth, 2005)

2.2.2.1 Amorphous silicon

Amorphous silicon technology is an un-crystalline technology which is one of the oldest and most popular thin-film technology (Carlson, 1976). This technology is developed from crystalline silicon technology. The normal nature of silicon atom is that they can free move from each other (Markvart, 2001). The nature of freely movement in the atomic structure of silicon has a great advantage for electronic properties as band-gap. This band-gap (1.7eV) is higher than crystalline silicon (1.1eV). There are advantages of higher band-gap to support a-silicon cells to absorb the visible part of spectrum highly than the infrared parts of the spectrum. The crystalline silicon solar cell substrates are (1) tandem junction, (2) glass or flexible SS, and (3) double and triple junctions. These substrates have different properties as well as different performance (Hashimoto, 2003). A hybrid a-Si/poly-Si thin-film cell is under development where the efficiency is about 14%, low-cost and stable (Yamaguchi, 2001).

For reduction of silicon consumption, a novel sliver cell is made on sole crystal silicon cells. For same size solar panel, this cell offers 10 to 20 times less of silicon requirement than others. This cell is also suitable for large scale production, and needs 20 to 42 times fewer wafers per MW than other wafer-based cell (Franklin, 2007; Zhang et al., 2011). To increase the efficiency of a new multi-junction a-Si device, micro morph thin film is developed to capture the short wavelength to long wavelength from solar irradiation (Franklin, 2007). Many PV junctions are added and designed in this cell. The upper layer is made by ultrathin layer of a-Si and used to capture the shorter wavelengths and the microcrystalline silicon is used to convert longer wavelength.

2.2.2.2 Cadmium telluride

Cadmium telluride (CdTe) technology is attractive and popular thin film technology. This technology is most suitable for large-area module production. The module needs CdS thickness 0.05 µm and a CdTe thickness 3.5 µm. CdTe highest efficiency is about 16% (Yamaguchi, 2001). CdTe has the band-gap 1.45eV that is known as ideal band-gap and also has high direct absorption coefficient. CdTe technology is widely used for high volume production. Different country in the world already has used CdTe for high volume production (e.g. USA 40 MW, Germany 10 MW, Abu Dhabi, UAE 5 MW). For this technology, hetero-junction is used that is proved by First Solar (F. Solar) and Antec Solar (A. Solar). The toxicity of cadmium (Cd) and some other environmental effect is the problem for this technology. However this technology is extremely popular because of manufacturing process efficiency, competitive price and availability of raw material as such telluride (Te) (Hashimoto, 2003). Schematic diagram of CdTe cell is as shown in Figure 2.7 (Hashimoto, 2003).

Glass Superstrate
Front contact (ITO/ZnO)
Cds (Cadmium sulfide) n-type layer
CdTe p-type layer
Back contact

Figure 2.7: Schematic diagram of CdTe cell.

2.2.2.3 Copper indium gallium diselenide

Chalcopyrite compound materials likes $CuInSe_2$ has extraordinary high optical absorption co-efficiency. $CuInSe_2$ is a good semiconductor materials with band-gap of 1.02 eV and most suitable for photovoltaic device application. To increase the band-gap, the compound semiconductor formulation, gallium and sulfur are added. Ga is added about 25–30% to produce Cu $(In,Ga)Se_2$ (CIGS) band-gap is about 1.15–1.20 eV (Yamaguchi, 2001). Moreover, by using the selenide better uniformity properties is achieved. CIGS is the multi-layer thin-film composites that are defined as a multi faced hetero-junction module. This cell has best efficiency of about 20% with CIGS (Repins, 2008) and big structure modules efficiency is about 13%. Maximum stated methods are used: sputtering, “ink” printing and electroplating (Basol, 2008; Eldada, 2008). Indium shortage is a great problem for this technology, because indium is widely used for indium tin oxide (ITO), a transparent oxide, computer screens and many others

(Yamaguchi, 2001). Schematic diagram of CIGS cell is shown in Figure 2.8 (Hashimoto, 2003).

ZnO transparent oxide
Cds buffer layer or (indium sulfide)
CIGS (absorber)
Mo contact layer
Glass

Figure 2.8: Schematic diagram of CIGS cell

2.2.3 Third-generation PV technology

Currently, first and second generation solar cells are used widely in industry but they do not offer the most efficient and cost effective product. It is hoped that the third generation solar cell can overcome these problems. But this technology is at the primary stage and different development is going on for commercial used. Multi-junction concentrating PV has achieved very good efficiency 44.7%. Nanotechnology is one of the technology that could be used in photovoltaic panels and provide higher efficiency level demanded by industry at a reasonable cost. Some third-generation PV technologies are beginning to be commercialized, but it remains to be seen how successful they will be in taking market share from existing technologies. Table 2.1 Generation of solar cells, cell efficiency and application area (Yamaguchi, 2001).

There are four types of third-generation PV technologies,

(a) Concentrating PV (CPV),

(b) Dye-sensitized solar cells (DSSC),

(c) Organic solar cells

(d) Novel and emerging solar cell concepts (IRENA, 2012).

Table 2.1: Generation of solar cells, cell efficiency and application area. (Yamaguchi, 2001)

Generation	Solar cell materials	Conversion efficiency (%)	Radiation resistance	Reliability	Cost	Uses area
I (Crystalline Si)	Single-crystal Si	24.7	a	c	b	Terrestrial, space
	Poly-crystal Si	19.7	a	c	b	Terrestrial
II (Thin-Film)	Amorphous Si	14.6	a	a	c	Consumer, Terrestrial
NEXT (Advanced Thin Film)	Poly-Si thin film	16.1	a	b	c	Terrestrial
	II-VI Compound thin film	18.7	c	b	b	Terrestrial
	Concentrator tandem	32.5	c	b	b	Terrestrial, space
Space	GaAs	25.6	b	c	a	Space
	InP	22.0	c	c	a	Space
	Tandem	33.4	b	c	a	Space
New Materials	TiO_2	11		a	c	Terrestrial
	Organic	2		a	c	Terrestrial
	Carbon	3.4		b	c	Terrestrial

Note: c Excellent; b good; a fairly good

2.3 Photovoltaic power generation

These systems are the combination of many elements like cells, mechanical and electrical mountings, and connections. On a clear day, when the sunlight irradiation is happen, electric power is generated and this power is rated as peak kilowatts (kWp) (Parida et al., 2011). Photovoltaic power generation system is built-up with a number of solar cells, batteries, inverter, charge and discharge controller, solar tracking control system and other equipment components (Jin, 2011). The schematic representation of solar photovoltaic power generation system is shown in Figure 2.9. Some important equipment and their function are as follows.

2.3.1 Batteries

Battery is an important element for continuation supply of solar energy, which is produced by the PV power generation systems.

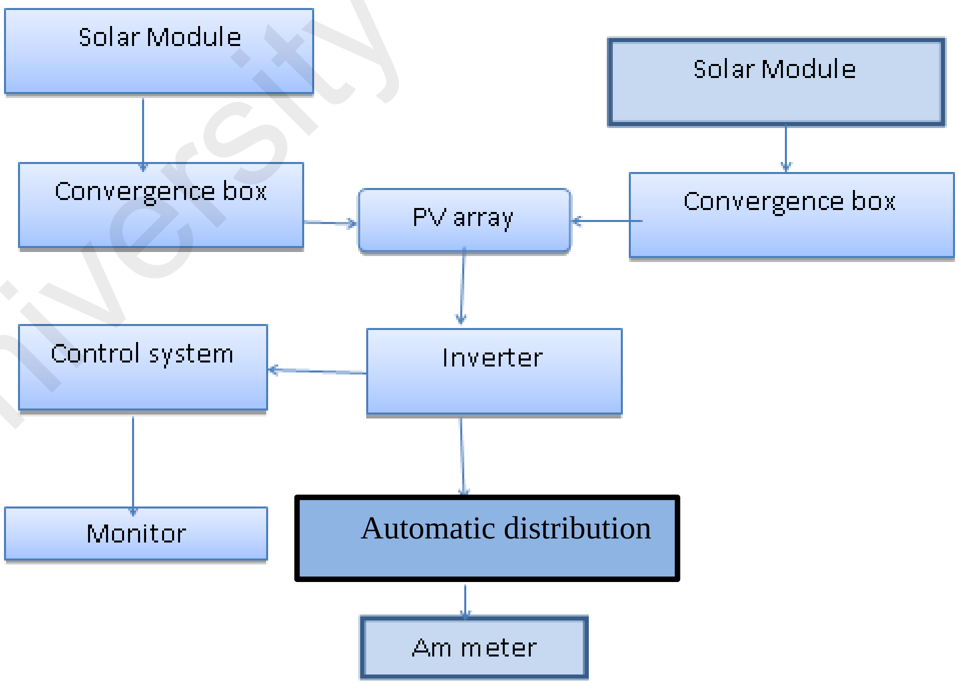

Figure 2.9: Schematic representation of photovoltaic power generation system. (Jin, 2011)

The following features are essential for the batteries:

i) Never Auto-discharge

ii) Life time must be high

iii) Have high -discharge capacity

iv) High charge storage capacity

v) Minimum maintenance

vi) Operating temperature varying range must be high

vii) Prices must be low

2.3.2 Charge and discharge controller

This device is used for control the overcharge or over discharge of the battery. This function is done automatically. How many times the battery charge and discharge and how much the battery discharges are the major factors for the battery life time.

2.3.3 Inverter

The inverter is used to convert the DC into AC. Both PV and battery power are DC and the load is normally AC. So, inverter is one of the most important elements for photovoltaic power generation systems. There are two types of Inverter namely, square wave inverter and sine wave inverter. Square wave inverter is used for small project, capacity less than hundred watts. This inverter is not in high demand because of high harmonic presence. However, it is low cost and simple design. On the other hand, sine wave inverter price is high but the inverter can used for different types of load (Chen, 2009).

2.4 Factors affecting solar photovoltaic power generation

Photovoltaic cells efficiency is limited by many losses, a few of them are controllable and a few of them are not controllable. Today, PV panels convert energy from sunlight into electric energy within the range of 12% - 19% of solar radiation (Mekhilef et al., 2011; Sánchez, 2010). It has been assumed that these PVs work in tropical temperatures, with pre-photovoltaic losses (dirt and shadows) of 8%, system losses (cable and inverter losses of 5% and maintenance downtime of 6%), tilt and orientation losses of 5%, module losses of 50% and thermal losses of 10% (Erge, 2003). This gives an overall solar energy to electricity conversion efficiency of 17%.

2.4.1 Solar angle and Tracking system

The maximum absorption of solar radiation occurs when the panel surface is perpendicular to the direct sun's rays (θ=0). The higher direct irradiance on a surface perpendicular to the solar radiation causes the increased energy yield. During days with high direct radiation, tracking can achieve energy gains over horizontal orientation in the order of 50% in summer and up to 300% in winter. The advantage of the trackers is early morning and late afternoon, as a result of more power can be produced (Figure 2.10). A single axis tracker produced about 20 to 25% of power and dual axis tracker produced more than 30% (as shown in Figure 2.11) more power can be produced, depending on latitude. Trackers are more benefited in zone that received the sunlight directly. The tracker system produced more power because of two main causes. First, when a solar panel is perpendicular to the sunlight, it receives more light on its surface than if it were angled. Second, direct light is used more efficiently than angled light. To increase the intensity of the sunlight falling on the panel's surface, it is important to adjust the orientation of the panel with respect to the direction of the sun, Figures 2.12 and 2.13. There are two parameters which are taken into consideration. The first is the maximum variation in the sun's angle between the equinoxes and the summer and winter solstice (*b*), which is 23.45 degrees. The second parameter is the azimuth angle (*a*), which is the angle between the plane of the panel and due south. The best module arrangement is related to the actual weather forecasting, the power supply and that location latitude (Figure 2.13).

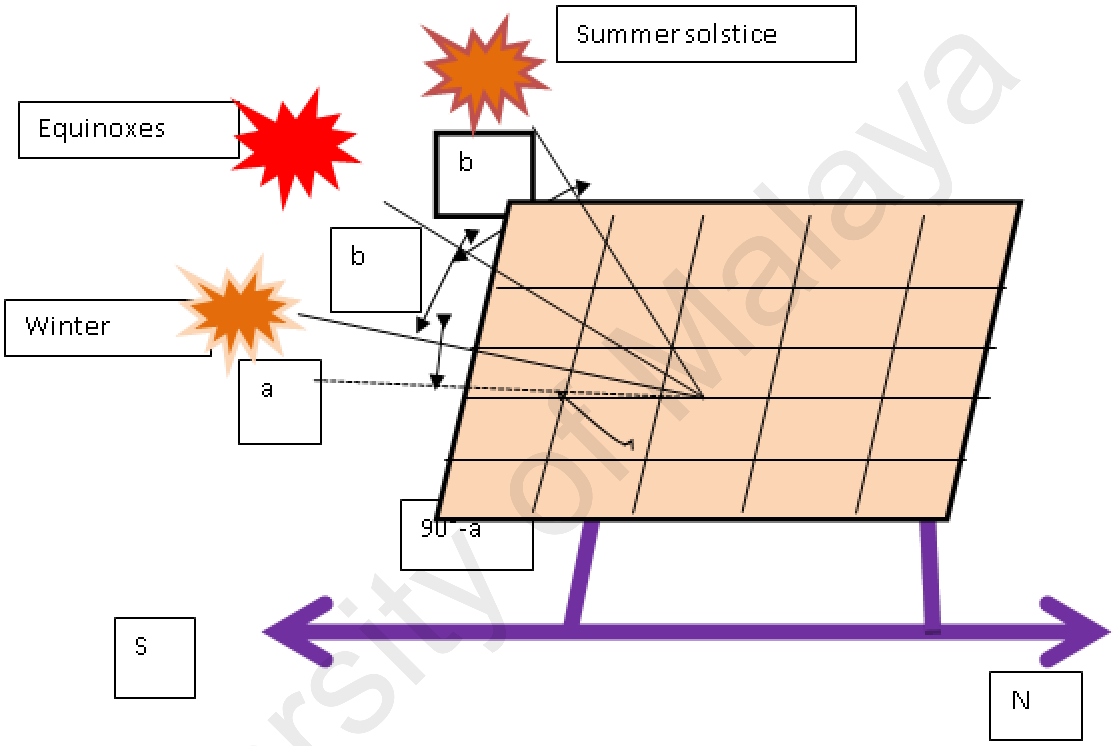

Figure 2.10: Insolation received with respect to change in sun angles.

(Lynn, 2010)

Generally the highest output performance of PV panel gathered at low latitudes, especially when the angle of latitude matched with the tilt angle of panel and the direction of module position at in the southern hemisphere (due north) or in the northern hemisphere (due south). At upper latitudes, the highest output power is gained when tilt angles is very close to minus 10 to 15° latitude angle.

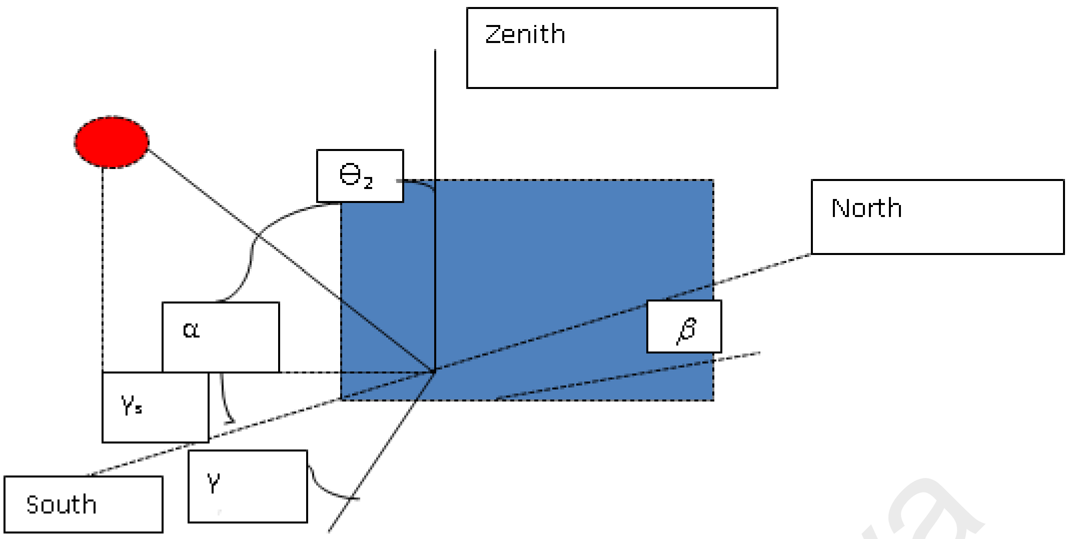

Figure 2.11: Sun angles used in the nomenclature.

(Duffie, 2013)

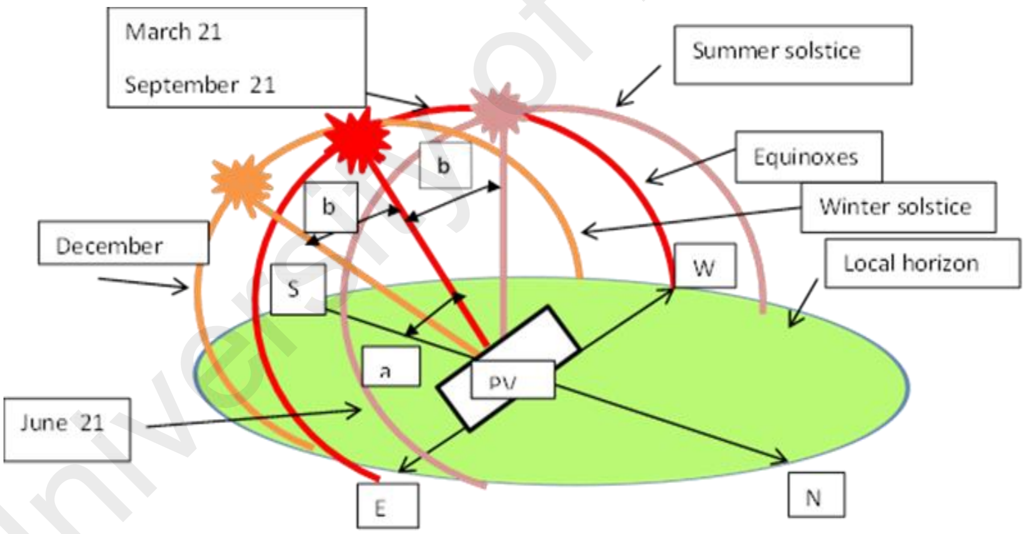

Figure 2.12: Solstice changing along the year.

(Lynn, 2010)

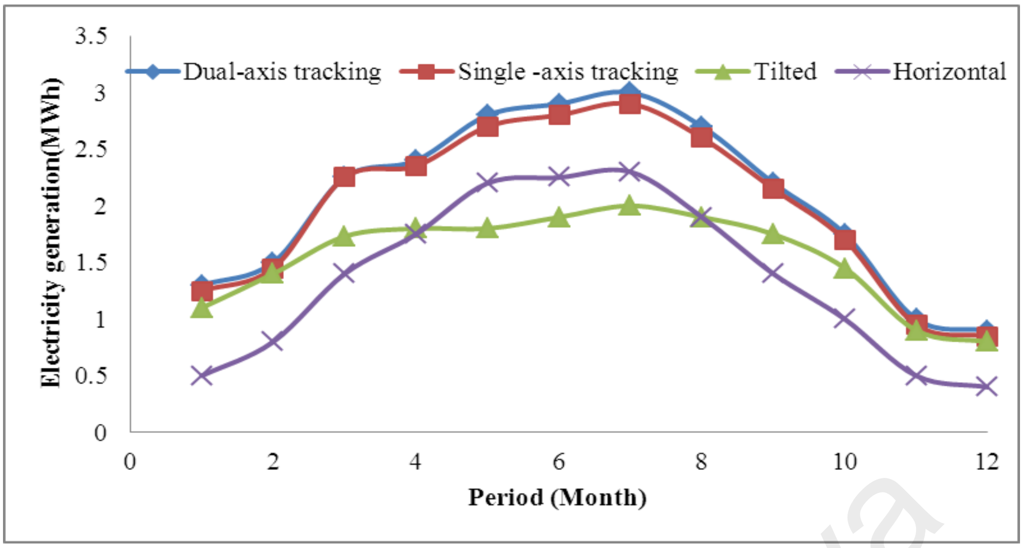

Figure 2.13: Monthly electricity generation.

2.4.2 Shading

A solar panel's electrical output is very sensitive to shading. The power loss depends on the area of the panel that is shaded and the type of shading. There are two types of shading sources: hard and soft sources. A shadow dispersed due to items like a chimney, vent etc. from a far distance diffuses the sun light falling on the module and contributes to soft source shading. Hard sources resist the light to reach to the surface of the solar cells. Tree leaves, bird droppings, snow, and thick dust or other impurities at the surface of the module contribute to hard source shading. Consider a panel which has only half shading of a cell or cells. The shaded cells could be half of a single cell or a row of cells half shaded horizontally or vertically (as shown in Figure 2.14). Since the cells are connected in series, and thus carry the same current, the power output will be the same for all of the configurations shown. The half shaded cell will reduce the current and thus the power for entire series string of cells. So the amount of power losses is about 50% for this case which is proportional and equivalent to the shaded area of PV panel (KS, 2011). If the solar cell is shaded completely, it will consume power rather than generation and acts as a load.

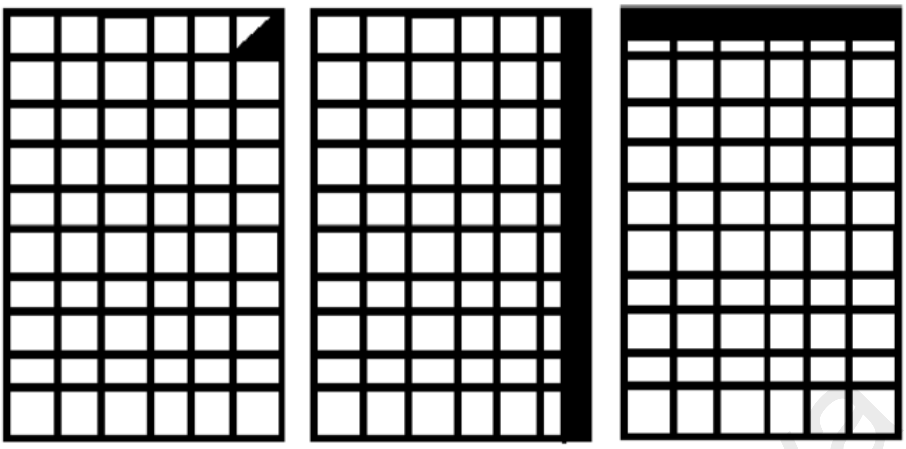

Figure 2.14: Examples of partial-cell shading that reduce module power by one-half. (KS, 2011)

The panel will route the power around that series string. Even if only one cell in a series string is completely shaded, as shown in Figure 2.15, it will cause the panel to reduce its power level to one half of its full available value If a row of cells, such as at the bottom of a module is fully shaded, the power output may drop to zero. It is advisable to avoid partial shading and shading if possible.

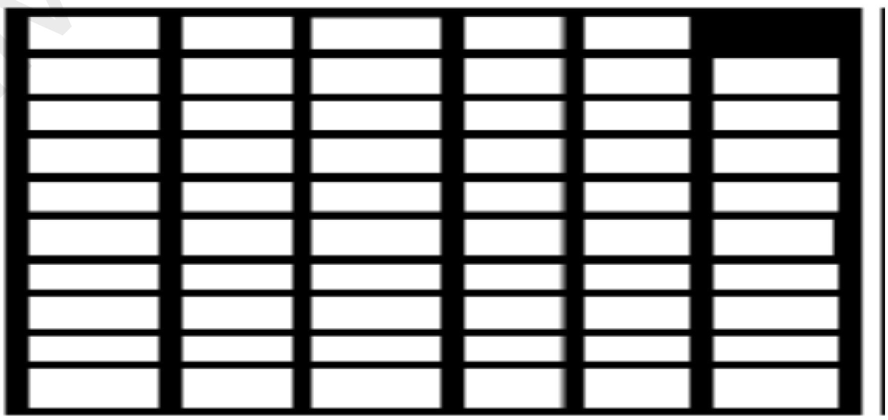

Figure 2.15: Effect of shading on output power.

(KS, 2011)

2.4.3 Dust

Dust on PV module has bad effect on PV efficiency because of dust may resist the incoming irradiance to reach onto the PV module (Tyagi et al., 2013). A major problem facing with sand accumulation, from a lot of experiment shows that at least 50% of solar module efficiency reduces for dust on PV module in one month only (Maranda, 2004; Marian, 2005). Investigation of dust effect on PV module power generation shows that a significant amount of energy reduction for the dust on the module surface and module efficiency was lower than clear surface. This study also indicates that dust decreases the output power of PV panel but this dust effect can be minimized with the increment of irradiation intensity (Kaldellis & Kapsali, 2011). Sulaiman et al. (2011) performed an investigation about the output performance of PV module at fixed radiation intensity with various dust quality such as talcum, mud and plastic. With the presence of dust, the power generation by the PV module is shown in Table 2.2. From Table 2.2, when irradiation 301 W/m^2, power generation with talcum powder is 3.22 W, 4.12W for plastic and with mud it was 3.42 W. When irradiation 340 W/m^2, power generation with talcum powder is 1.73 W, 3.62 W for no plastic and with mud it was 3.49 W.

Table 2.2: PV panel power output with various types of dust and fixed radiation intensity.

(Sulaiman, 2011)

Condition	**225 W/m^2**	**301 W/m^2**	**340 W/m^2**
No plastic	4.25	4.12	3.62
clean plastic	4.25	3.75	3.16
Mud	3.84	3.42	3.49
Talcum	3.55	3.22	1.73

To get better performance, the solar module surface must be clean. Manually hand cleaning element by water with detergent is used once a week on the panel. On the other hand, an automatic spry nozzle is retrofitted at the top to wash surface module. Some producer uses robot for washing the surface of PV panel. However, water washing is the easiest and cost effective way to clean the module surface where about 5 to 6 liter of water is needed (Mohamed, 2012).

2.4.4 Effect of operating temperature on PV output

Working temperature of solar module is the key variable for the PV conversion process. The PV efficiency decreases with the increasing of working temperature of PV module. The cell temperature acts as a critical factor that causes the efficiency and power output of the module to decrease. This cause the band gaps to shrink with the increasing of temperature. That is why a much reduction of Voc will occur (Shenck, 2011). By absorbing high irradiation the flow of electric charge increases form valence band to conduction band (Dincer, 2010). The temperature effect on mono-crystalline solar cells is higher than polycrystalline silicon and thin film solar cells. Mono crystalline silicon solar cell and thin film solar cell efficiency decreases by 15% and 5%, respectively (Kumar & Rosen, 2011). One investigation on the performance of PV module performance in between 273 to 523 K module temperature was performed. The efficiency of solar cell for three cases with the increment of cell temperature and reverse current flow across the cell shows that the efficiency, Voc as well as fill factor decreases. The band gap reduced at the same time with the increment of temperature. As a result, the tendency of Voc to decrease and raises the Jsc with the raising temperature of PV cells causes the drop of overall efficiency of photovoltaic cells (Singh & Ravindra, 2012).

The power conversion efficiency of the solar cells can be written as:

$$\eta_c = \frac{p_{\max}}{p_{in}} = \frac{I_{\max} \times v_{\max}}{I(t) \times A_C} \tag{2.1}$$

Where Imax and Vmax are the maximum current and maximum voltage, I(t) is intensity of solar irradiation and Ac is the PV cell area (Tiwari, 2010).

It has shown that the temperature of solar cell is dependent on weather variables like solar radiation (I(t)) and the ambient temperature (Ta) etc. The correlation between the efficiency and solar cells operating temperature can be described by the following equations.

$$\eta_C = \eta_{ref}[1 - \beta_{ref} \times [T_a - T_{ref} + (T_{NOCT} - 20) \times \frac{I(t)}{I(t)_{NOCT}}] + \gamma \log_{10} I(t)] \times 100 \tag{2.2}$$

Where ηT_{ref} is the electrical efficiency of PV module at 1000 W/m^2 solar irradiation and standard reference temperature (T_{ref}). Two main material properties such as, βref is the temperature coefficient which is equivalent to 0.0045K and γ and is the irradiation coefficient which is equivalent to 0.12 for c-Si based PV solar cells (Notton, 2005). The operating temperature of PV cells is calculated in open circuit condition 20°C ambient temperature, 1 m/s wind speed and 0.8 kW/m^2 irradiation. The value of TNOCT is generally about 45°C. The operating temperature of PV module could be assumed due to variation of irradiance and ambient temperature. Here the author assumed that βref is 0.0045K, η_{ref} is 12% and T_{ref} is 25°C. A linear correlation consists between module efficiency and ambient temperature (as shown in Figure 2.16). Reduced temperature shows higher efficiency. Table 2.3 shows the standard testing condition performance and negative temperature coefficients of different types of cells (Seng, 2010).

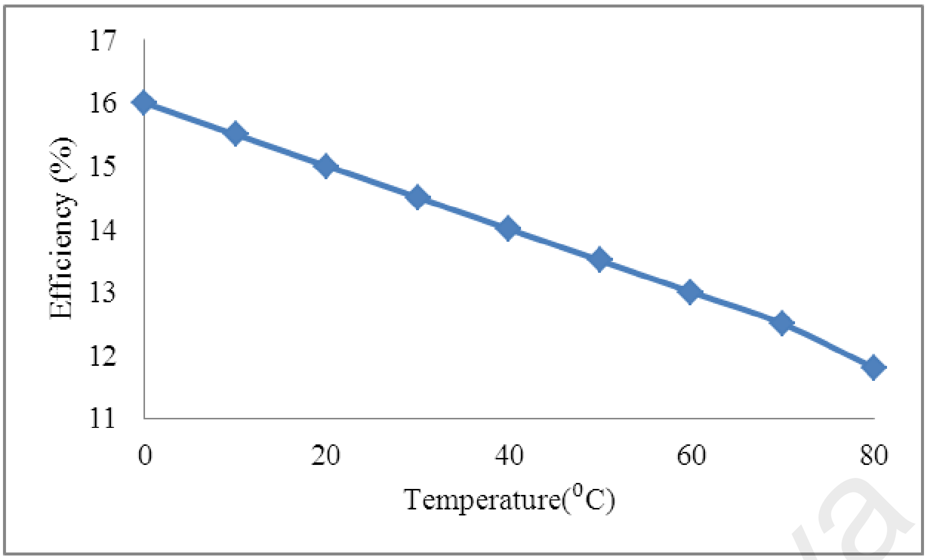

Figure 2.16: Photovoltaic cell efficiency versus temperature

Table 2.3: Effect of standard testing condition on PV cells performance.

(Seng, 2010)

Type	STC Performance (%)	Temp. Coefficient
Mono-crystalline	12.5-15	-0.4 to -0.5
Poly –crystalline	11-14	-0.4 to -0.5
Amorphous-Si	11-13	-0.35 to -0.38
CIGS	10-13	-0.32 to-0.36
Cadmium Telluride	9-12	-0.25

Agroui (2012) investigated the temperature effect on multi-crystalline PV modules with the temperature range and irradiance range of 61°C to 75°C and the 780 W/m^2 to 1250 W/m^2 respectively. This investigation indicates that in this situation the PV modules lost at least of 35% efficiency, and 18% of the output power compared with the standard testing conditions. Figure 2.17 shows the temperature effect on different types of solar cell.

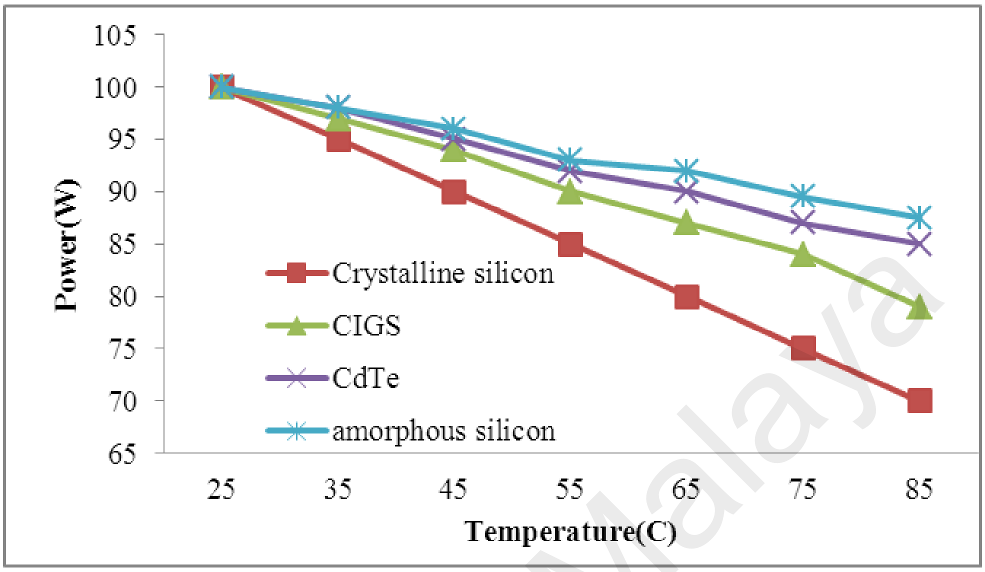

Figure 2.17: Effect of temperature coefficient on PV module types.

(Seng, 2010)

The electrical efficiency of PV module also dropped due to many losses. Some of those losses are integrated to the PV device and few of those can be minimized. For this reasons by decreasing PV cell temperature does not show an effective change in increasing the efficiency. That is why, it is essential to maintain PV operating temperature at Nominal Operating Cell Temperature (NOCT) condition. For controlling the temperature of the module, different cooling system is used such as air cooling, water cooling etc.

2.4.5 Photovoltaic Cell/module efficiency effect on PV module electricity output

The photovoltaic solar cell efficiency is an important factor for the photovoltaic technology. The efficiency of a cell has a great effect for establishing the technology in the market and commercially used. For increasing the efficiency of the solar cell a lot of research and work is going on. Solar cell efficiency is the ratio of electrical output of a solar cell to the incident energy in the form of sunlight. Solar cell conversion efficiency is the percentage of the solar energy that is converted into electrical energy. Cell efficiency is calculated by dividing a solar cell's power output (in W) at its maximum power point by the P_m input light (E, in W/m^2) and the actual surface area of the solar cell (Ac in m^2)

$$\eta = \frac{P_m}{E \times A_C} \tag{2.3}$$

Where η stands for the conversion efficiency (0-100%), Pm stands for peak power generation (W), E represents solar irradiance per area (standard 1000 W/m^2). Ac for the surface area of the solar cell/panel (m^2). In this sense, for the standard E in one square meter of PV cell area, the generated output for a 17% efficient PV surface will be 170 W/hour. By convention, solar cell efficiencies are measured under standard test conditions (STC). STC means a temperature of 25 °C and an irradiance of 1000 W/m2 with an air mass 1.5 (AM 1.5) spectrums. Different cell has already performed very good efficiency. Mono-crystalline solar cell efficiency has 24.7%, poly crystalline solar cell has 20.3% efficiency and the thin-film cell has 19.9% of efficiency in 2010 (Tyagi et al., 2013). Different PV cells and module manufacturing companies and their maximum module efficiency details are described in Table 2.4.

Table 2.4: PV manufactures companies and module efficiencies.

(Tyagi et al., 2013)

Company	**Module Type**	**Efficiency**
Suntech power	Mono crystalline	15.30 to 15.70
	Polycrystalline	14.50 to 14.80
Yingli solar	Mono crystalline	15.30 to 16.20
	Polycrystalline	14.10 to 15.00
Trina solar	Mono crystalline	14.50 to 15.20
	Polycrystalline	13.70 to 15.00
Canadian solar	Mono crystalline	13.70 to 15.26
	Polycrystalline	12.65 to 14.12
Sharp	Mono crystalline	14.4
	Thin film	10
Hanwha solar one	Polycrystalline	13.60 to 15.10
	Mono crystalline	13.30 to 15.30
Jinko solar	Polycrystalline	14.05 to 15.27
	Mono crystalline	14.36 to 15.59
LDK solar	Mono crystalline	14.49 to 15.67
	Polycrystalline	13.32 to 15.67
Solar world	Polycrystalline	14.31
	Mono crystalline	14.31

Suntech Power Company achieved the efficiency of 15.30% to 15.70% for mono crystalline solar module and the efficiency of 14.50% to 14.80% for polycrystalline solar module. The Yingli solar company achieved the efficiency of 15.30% to 16.20%

for mono crystalline PV module. The highest conversion efficiency of poly-crystalline module is 13.32% to 15.67% that is achieved by LDK solar.

$$P_m = \eta \times E \times A_C \tag{2.4}$$

Table 2.5 shows PV modules efficiency (%) target up to 2030 (IEA, 2010).

Table 2.5: PV modules efficiency target.

(IEA, 2010)

Technology	**2010-2015**	**2015-2020**	**2020-2030**
Crystalline silicon	Single crystalline -21%	Single crystalline - 23%	Single crystalline - 25%
	Multi crystalline -17%	Multi crystalline - 19%	Multi crystalline - 21%
Thin film	Thin film si-10%	Thin film si-12%	Thin film si-15%
	Copper indium gallium(di) selenide (CIGS)-14%	CIGS-15%	CIGS-18%
	Cadmium-telluride(CdTe): 12%	CdTe-14%	CdTe-15%

2.4.6 Life time affecting the PV module electricity output

The performance of a PV module will decrease with life time of the module. The degradation rate of the module efficiency is higher in the first year upon initial exposure to light and then stabilizes. Module efficiency degradation rate is depended on the quality of materials used in manufacture, the manufacturing process, the quality of assembly and packaging of the cells into the module, and also maintenance quality of the module. PV modules electrical output decreasing rate is from 0.3% to 1% per annum. For crystalline modules, a generic cell efficiency decreasing rate of 0.5% per annum is often considered applicable. Maximum banks consider the degradation rate of 0.5% per annum (LSP, 2013). Figure 2.18 shows the effect of life time on solar module efficiency.

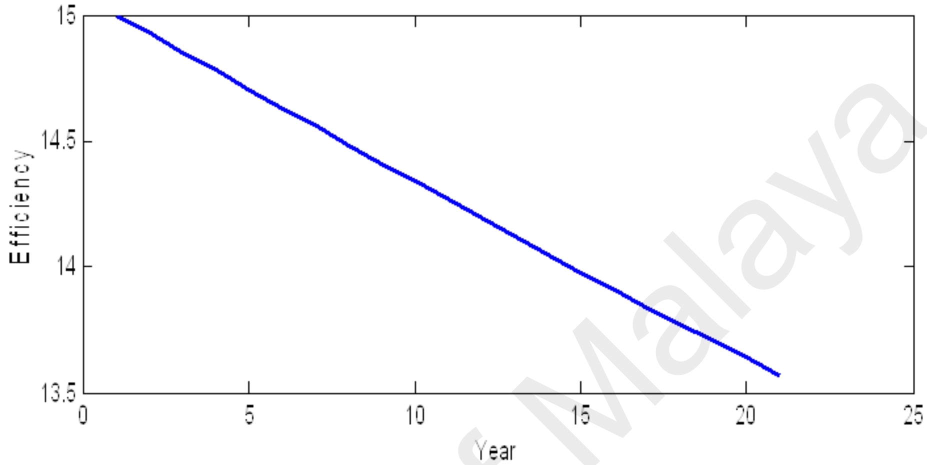

Figure 2.18: Life time affected the module efficiency

In the PV system, electricity generation is directly proportional to module efficiency. So PV base electricity production is also affected by PV module life time. Figure 2.19 shows the life time effects on the electricity produced.

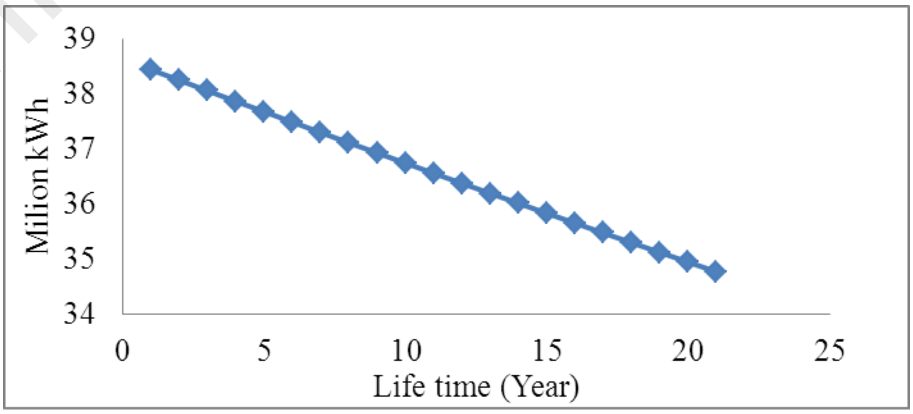

Figure 2.19: Life time affected the electricity produced

As a result operational life time of photovoltaic module is increasing. Table 2.6 shows the PV module operational lifetime increases target up to 2030. In 2020 to 2030 the module operational life time would be 35 years. That has the direct effect on photovoltaic electricity generation, as shown in Figure 2.20.

Table 2.6: PV module operational life time increases target up to 2030. (IEA, 2010)

Time	2010-2015	2015-2020	2020-2030
Operational life time (years)	25	30	35

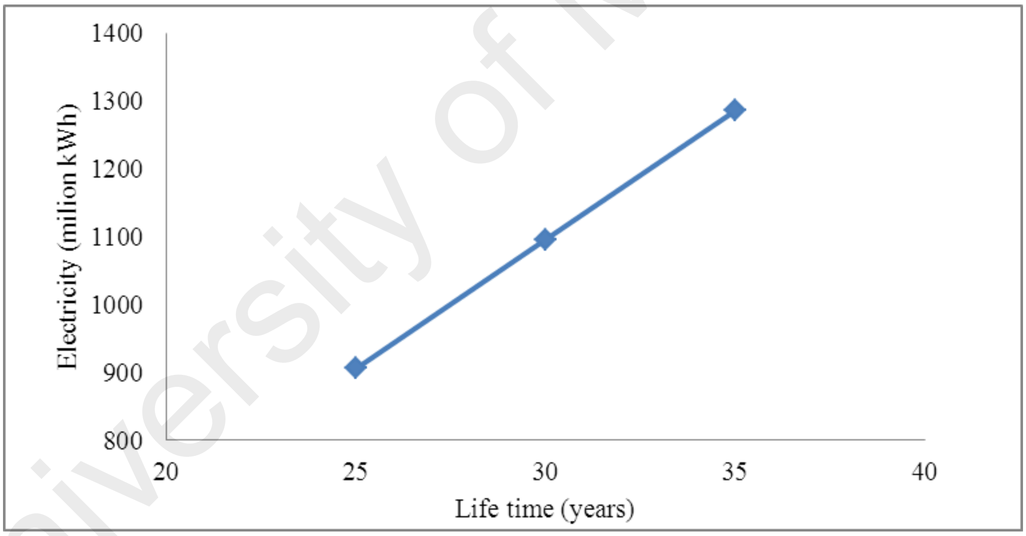

Figure 2.20: Effect of life time on Electricity output

2.4.7 Effect of radiation on PV module electricity output

When the solar irradiance increases, the PV module efficiency also increases because more photons are hitting the module surface. Many electron-hole pairs can be generated, so the level of irradiance increase thus will produce more electricity (Kumar & Rosen, 2011). Figure 2.21 shows the effect of insolation on electricity output.

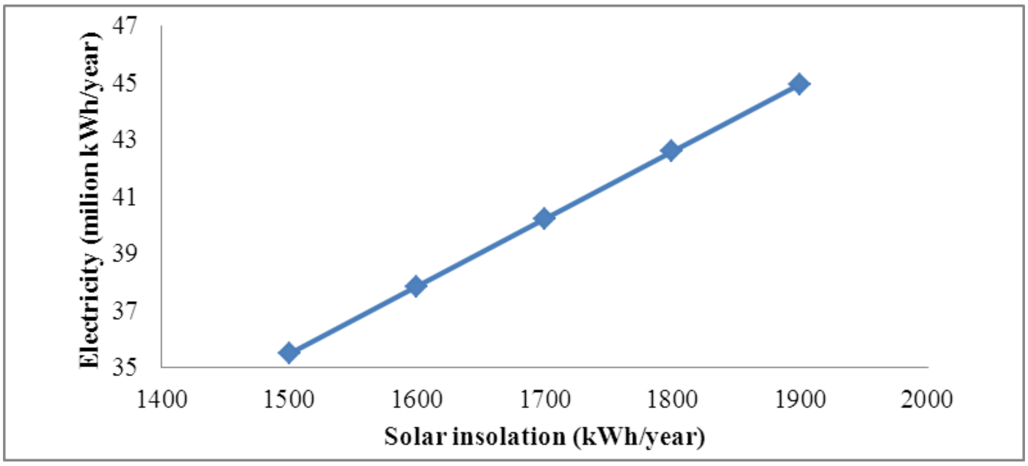

Figure 2.21: Effect of insolation on electricity output

2.5 Global photovoltaic technology scenario

Solar photovoltaic is a sustainable energy source (Pearce, 2002). At present, PV is a rapidly growing renewable energy technology and will play a major role for producing global electricity in the future. Worldwide total of PV installation in 2000 was 1.8 GWp and 2011 was 71.1 GW with the growth rate of 44% per year. In the year 2011, about 27.7 GW has been installed (EPIA, 2013b). The installation capacity 71.1 GW is enough to produce 85 TWh/year of electricity (EPIA, 2012a). By the end of 2012, the installed capacity 100 GW milestone was acquired (RI, 2013). The total global photovoltaic installation capacity is capable to produce 110 TWh/year electricity (EPIA, 2013b). This electricity is enough to meet the demand of about more than 20 million households in the world and this amount of electricity is covering only 0.5% of global electricity demand (EPIA, 2012a). The EPIA/Greenpeace Solar Generation Advanced Scenario, 2010 shows that by the year 2030, the global photovoltaic installation capacity would be 1,845 GW and produce about 2,646 TWh/year of electricity. It is expected that the photovoltaic power system will supply about 20% of global demand electricity by the year of 2050 (EPIA, 2013c). There are about more than 100 countries using the solar photovoltaic system in the world (REN21, 2011).

Global grid connected installation is also increasing rapidly, as shown in Table 2.7. In 2010 global grid connected installation capacity was 40 GW.

Table 2.7: Global grid connected installation capacity.

(Martinot & Sawin, 2009; REN21, 2009; REN21, 2011)

Year	**Installation capacity (GW)**
2007	7.6
2008	16
2009	23
2010	40

Most of the installation systems are ground mounted (stand alone and grid-connected) and integrated. The integrated system may be with farm Integrated, graze Integrated and building Integrated. At present public research programs on renewable energy systems is the burning issue in the energy section. Last year, renewable energy and energy efficiency sector reported that new investments for renewable energy sectors are RM836.34 billion (US$263 billion), where R&D department has spent about RM82.044 billion (US$25.8 billion). New investments for solar photovoltaic system have increased about 44% and the amount is about RM407 billion (US$128 billion) (PELE, 2012). Table 2.8 shows Global PV installation capacity up to 2013 and Table 2.9 shows the global PV power generation capacities up to 2050.

Table 2.8: Global PV installation up to 2013.

(EPIA, 2013b)

Year	Installation capacity (GW)
2005	5.4
2006	6.9
2007	9.5
2008	16.2
2009	23.6
2010	40.7
2011	71.1
2012	102.2
2013	139

Table 2.9: Evolution of the PV power generation capacities up to 2050

(PELE, 2012)

Year	2010 (GW)	2015 (GW)	2020 (GW)	2030 (GW)	2035 (GW)
Total installations	70				
Greenpeace (reference scenario)		88	124	234	290
Greenpeace (evolution scenario)		234	674	1764	2420
IEA present policy		60	161	268	314
IEA new policy		112	184	385	499
IEA 450 ppm Scenario		70	220	625	901
IEA PV system Roadmap		76	210	872	1330

This table represents the different condition of the Greenpeace and EREC study, and IEA World Energy picture and the IEA PV system future plane.

A lot of photovoltaic system power stations have been built and most of them are in Europe (Lenardic, 2015). In the world the largest photovoltaic (PV) power plants are in USA, the Agua Caliente solar project with the capacity of 247 MW. In India, the Charanka solar park project has capacity of 214 MW, In China, the Golmud solar park Project has capacity of 200 MW). In Canada, the Sarnia photovoltaic power plant has capacity of 97 MW. In Germany, the Brandenburg-Briest solar park has capacity of 91 MW, Finow tower solar park has capacity of 84.7 MW. The Eggebek Solar Park has capacity of 83.6 MW. The Senftenberg solar park has capacity of 82 MW and the Finsterwalde solar park has capacity of 80.7 MW, In Thailand, the Lopburi solar farm has capacity of 73.16 MW, In Italy, the Montalto di Castro Photovoltaic Power Station has capacity of 84.2 MW and Rovigo Photovoltaic Power Plant has capacity of 72 MW. There are also many large plants is under construction.

2.6 Photovoltaic Technology in Malaysia

Malaysia is a country in the Southeast Asia which comprises Peninsular Malaysia, Sabah and Sarawak (both of which make up East Malaysia) separated by the South China Sea. It has a total area of 329,847 km^2 (CIA, 2010). The tropical climatic condition in Malaysia is favorable for the development of solar energy due to abundant sunshine with the average irradiance per year of 1643 kWh/m^2 (Haris, 2008a). Malaysia, Thailand, Vietnam and the developing countries are using the technology as an alternative energy source. In Malaysia, the solar insolation is very high and it's ranging from 1400 to1900 kWh/m^2 (Ahmad et al., 2011). It has a promising potential to establish large scale solar power installations. In case of Foreign Direct Investment

(FDI), Malaysia has earn a lot of investment, amounting to a total of RM 13.8 billion in the solar field and according to solar PV manufacturers, Malaysia was in position number three in the world in 2011 (Chu, 2012). The increase of FDI in solar also increase the quality of solar equipment, lower pricing, availability of equipment, and jobs in the field of solar PV (Mendonca, 2010). It is also interesting to understand public opinion regarding PV issues in Malaysia. Figure 2.22 and Figure 2.23 is the ample evidence of people awareness about solar photovoltaic technology in Malaysia. Haw et al. (2009) have performed an analysis of public willingness to pay for electricity from Renewable energy sources. From this survey it was found that 51.4% people is ready for electricity generation from Renewable energy source Figure 2.22.

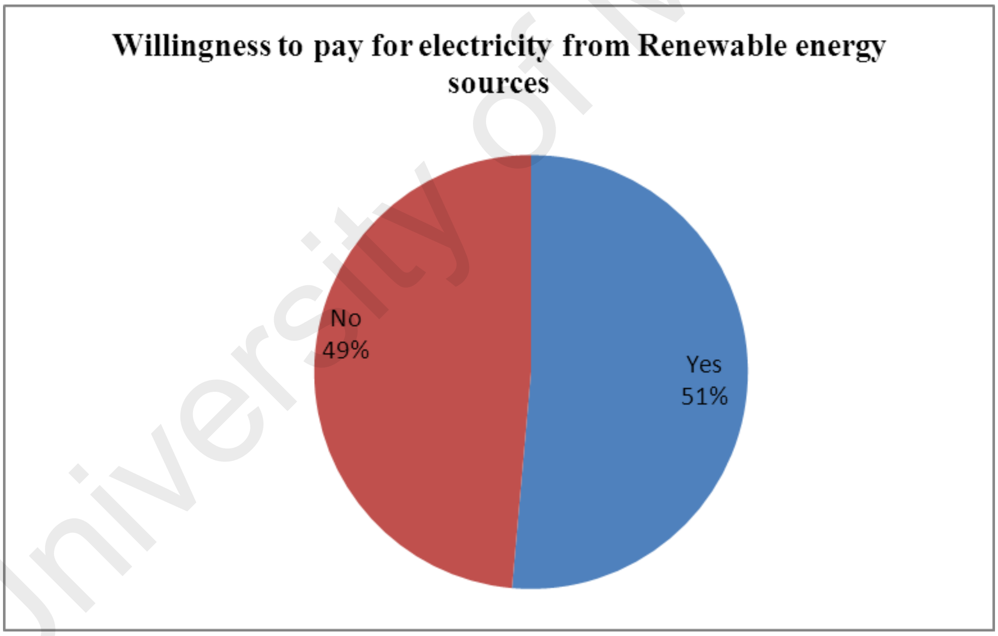

Figure 2.22: Willingness to pay for electricity generation from Renewable energy source

(Chen, 2012).

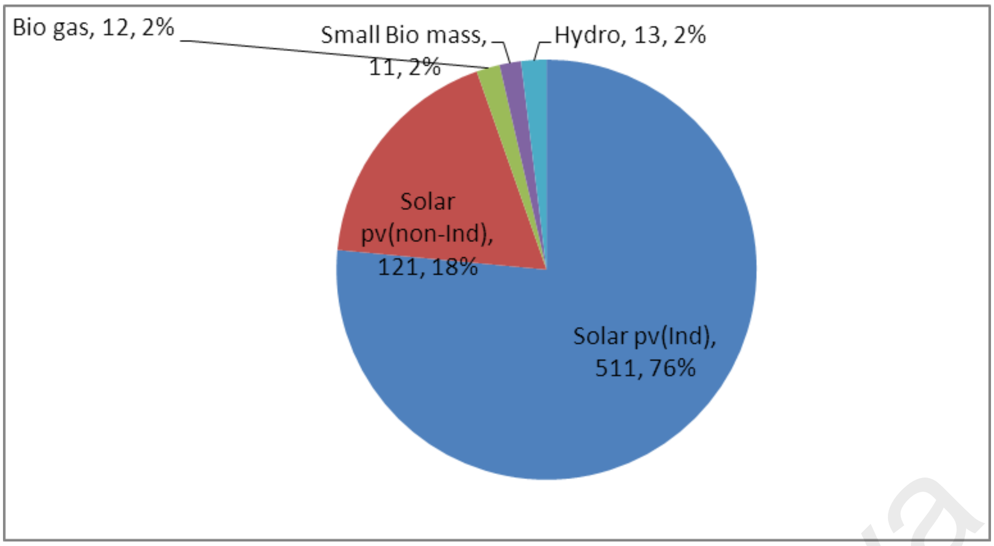

Figure 2.23: Approved capacities of RE.

(Chen, 2012)

2.6.1 Smart target for RE in Malaysia

SEDA has taken a lot of strategies to increase the use of renewable energy and make it as one of the main sources for energy supply up to 2050. The target set as for is 2020 - 2080 MW (11%), 11.3 TWh (9%) and in 2050 is about 21.4 GW (73%), 44.2 TWh (24%) (Chen, 2012).

2.6.2 Key players in solar energy development

Energy security, policy and how the plan to be activated were suggested and presented by different organizations, such as government, non-government organizations and industrial sectors. For solar PV development in Malaysia, the Malaysian PV industry association (MPIA) was formed in May 2006. This organization is working for proper development, public awareness, successful and sustainability in the execution of solar PV in Malaysia. Energy Commission (EC) is formed after the Malaysian EC Act 2001 and is working to control, apply and encourage all matters related to the electricity and gas supply industry. The MEGTW was established in April

2009. The MEGTW is controlling all the matter of energy, green technology and water functions. For electricity generation, transmission and supply activities in Peninsular Malaysia, Sabah and Sarawak, the countrywide main companies are Tenaga Nasional Bhd. (TNB), Sabah Electricity Sdn. Bhd. (SESB) and Syarikat SESCO Berhad (SESCO). On the other hand, electricity generation and supply is also handled by different private power producers, dedicated power producers and co-generators. For scientific and economic research and development for RE and EE, Standards and Industrial Research Institute of Malaysia (SIRIM) is another one of the organization. Malaysian Industrial Development Authority (MIDA) is also working in energy sector for investment, upgrading the manufacturing and services sectors including solar PV development and investments.

2.6.3 PV developments programs, initiatives and policies in Malaysia

SEDA has taken a lot of strategies to increase the PV installation, public awareness for emission reduction and achieve the SEDA target and make it one of the main sources for energy supply up to 2050. Program such as 1) showcase and demonstration, 2) SURIA 1000, and 3) SURIA for Developers have been implemented.

2.6.3.1 BIPV showcase and demonstration programme

The main objectives of BIPV showcase program are to create awareness from the people about the BIPV system in Malaysia. For BIPV system, the government has declared 100 kWp and 160 kWp capacity under incentive advantage. Successful BIPV scheme examples are MEC-GEO office 92 kWp BIPV system, at Petaling Jaya SMK school 4.4 kWp BIPV system, and at Monash University, Malaysia 7.36 kWp BIPV system.

2.6.3.2 SURIA 1000 program

SURIA 1000 program was formed at 2006. The main target of this program is to install GC-BIPV systems 1200kWp by 2010. According to Rooftop Program in Germany and Sunshine program in Japan, SURIA 1000 permits homes and offices to be fixed with solar PV roofs to produce electricity from sunlight. This is the first financial help for PV program in Asia-Pacific by the government of Malaysia (GoM). This program offers two times in every year. In 2006, 30% of the total installation cost was carried out by this program. The amount would be about RM 28,000 (US$ 8700) (SO, 2006). For making the PV system cheaper, the government also offer discount. The first call announced up to 75% discount for the PV system price and the discount decreased 5% for the 2nd call. Under SURIA 1000 program first five calls reveals that total achieved of 612 kWp in PV capacity where the target was 450 kWp (MBIPV, 2009).

2.6.3.3 SURIA for Developers program

The SURIA for Developers program gives chance for the property developers to build up housing development project which incorporates BIPV. This program has announced the financial support was about RM3 million (US$927,000) and the target was 340 kWp of BIPV installation. The program runs from July 2007 to January 2008. The developers also share their different perceptions about BIPV, cost of solar BIPV and architectural drawing. The following three developers who participate and work properly are i) Setia Eco. Park in Shah Alam, Selangor which develops 5 kWp PV systems cost over RM170, 000 (US$52500) of 39 bungalows, (ii) Putrajaya Perdana at location Precinct 16 of Putrajaya, which offers average 5.4 kWp PV modules in 15 bungalows, and (iii) Amarin Wickham at U-Thant area of Kuala Lumpur which incorporates PV cells into the sunshade on the roof of its condominium (SHM, 2008).

2.6.3.4 Other key PV development initiatives under MBIPV

The other PV development programs under MBIPV are as following: public awareness program. At the same time, a program for the student to study about the solar energy (MBIPV, 2007), in Universiti Teknologi MARA which is a PV monitoring centre from 2006 has been set up. Others such as, built up PV business progress program, training program for PV in 2008 named approved service provider, and a national PV conference for sharing knowledge on solar PV technology, its present condition, progress and policies. The smart target for GC-PV capacities in Malaysia until 2020 is to install a total of 20 MWp .There are a lot of policies that have been taken to support solar PV in Malaysia, namely (i) fiscal incentives, (ii) intellectual property protection, (iii) investment grants, and (iv) Net-metering (MBIPV, 2006; Oliver, 1999). Table 2.10 shows the summary of BIPV incentive projects.

Table 2.10: Summary of BIPV incentive projects.

MBIPV category	Target capacity (kWp)	Awarded capacity (kWp)	Operational capacity (kWp)
Showcase	125	140	140
Demonstration	205	391	323
SURIA 1000	1215	1524	488
Total	1545	2055	951

2.7 Environmental Impact

2.7.1 Global CO_2 emission scenario

Nowadays, global warming and climate change is a burning issue all over the world. The anthropogenic driver of climate change is raising the density of greenhouse gases (GHG) in the world surface. Carbon dioxide (CO_2) is one of the most important elements of GHG, and the global raising of CO_2 density are mainly for traditional fossil fuel use and land use change (IPCC, 2007). Economic development and population increase are the main conduct backing forces for raising energy consumption and CO_2

emissions (Fong, 2007; IGES, 2004). Growth rates for major emitter countries in 2012 were China is 5.9%, USA is 3.7%, EU28 is 1.3%, and India is 7.7% and in 2012 carbon dioxide emissions breakdown is coal is 43%, oil is 33%, gas is 18%, cement is 5.3% and gas flaring is 0.6% (GCE, 2013). Tables 2.11 show the Global CO_2 emission from 2006 to 2012.

Table 2.11: Global CO_2 emission from 2006 to 2012.

(GCE, 2013)

Year	CO_2 emission (billion metric tons/ year)
2006	30.7
2007	31.5
2008	32.2
2009	32.1
2010	33.7
2011	34.8
2012	35.6

The world is not capable to absorb this big amount carbon at the rate at which it is producing by fossil fuels. As a result, increasing the volume of CO_2 in the environment causes the increase of global warming. If CO_2 emissions are continuing at the same rate, the acidification, global warming also will be continued (Abbasi & Abbasi, 2010; Saidur et al., 2011). The Intergovernmental Panel on Climate Change (IPCC) also reported that the global warming will continue to increase unless we shift quickly to clean energy and cut emissions. Emissions of greenhouse gases grew 2.2% per year between 2000 and 2010, compared with 1.3% per year from 1970 to 2000.

The Intergovernmental Panel on Climate Change (IPCC) has revealed that eleven of the last twelve years (1995 to 2006) rank among the 12 warmest years in the instrumental record of global surface temperature since 1850, and total about 0.76°C temperature increase from 1850 to 1899 and 2001 to 2005 (IPCC, 2007).

2.7.2 Energy payback period (EPBP)

EPBP is the time in years needed to recover the energy use for fabrication of a PV system and decommissioning the PV system at the end of its life time (Table 2.12). Energy payback period is an important parameter that is used to indicate the amount of benefits it brings for the environment.

Table 2.12: Energy needs for the fabrication of different PV system components. (Seng et al., 2008)

Components	Energy needs
Mono-crystalline silicon module and frames	47 MJ/Wp
Polycrystalline silicon module and frames	35 MJ/Wp
Amorphous silicon module and frames of	23 MJ/Wp
Ground mounted PV system supporting structure	1700 MJ/m2
Roof top PV system supporting structure	500 MJ/m2
cabling and Inverters	1 MJ/W

Figure 2.24 shows the EPBP of roof mounted different PV technologies at different places. It is shown that EPBP of mono crystalline silicon at different places is from 3.2 years to 4.4 years, EPBP of poly crystalline silicon module at different places from 2.2 years to 3 years and the EPBP of thin film module is in the range of 1.89 to 2.6 years, where thin film module EPBP is lower than mono-crystalline and polycrystalline PV system.

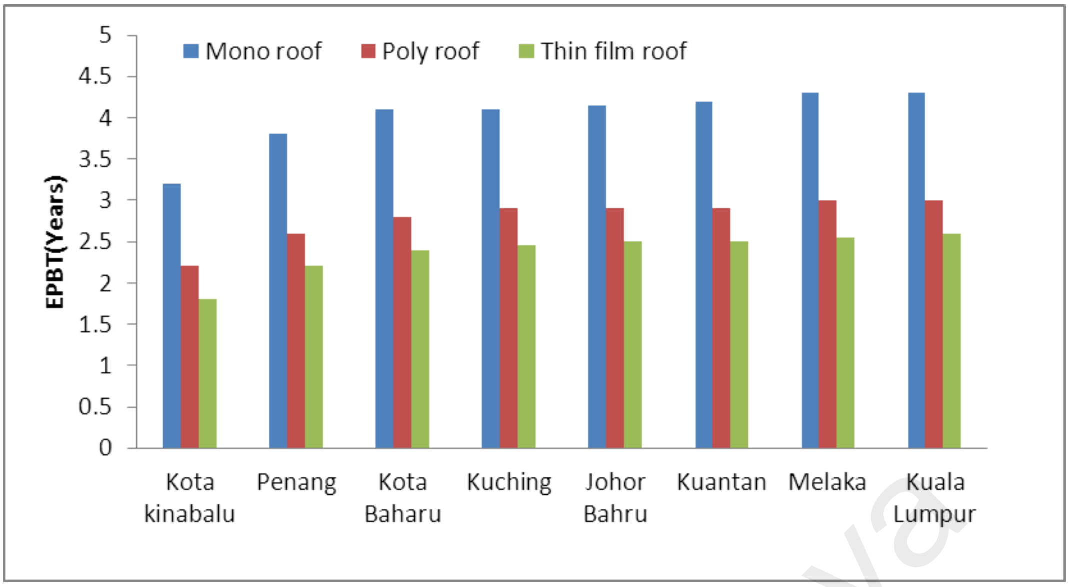

Figure 2.24: EPBP of rooftop PV systems at different cities in Malaysia.

(Seng et al., 2008)

2.7.3 Hazardous materials

Silicon hazardous material needs purification. At the same time, other toxic chemicals (e.g. diborane and phosphine, are needed for doping the silicon). Very small amount of gas are used for this process. In microelectronic industry, these materials are frequently used, so very good control and monitoring system is available. Silane and phosphine are flammable gases and highly toxic. In the normal usage manufacturing processes, these gases are not dangerous. For any accident or leakage, dangerous emissions of the gases can happen. Common materials such as aluminium and copper are connected with the standard industrial hazards. As PV module is transported from one place to another places and sometime long distances, about 0.1% to 1% of the emissions came from transport. It is concluded that the following hazardous materials are emitted during fabrication of PV module and supporting structure, such as: Silica dust, Diborane, Silanes, Solvents and Phosphine (Dubey, 2013). Many of the findings in the recent literature suggest that while some substances used in manufacturing PV solar cells are considered toxic, they do not pose a risk because they are used in small quantities (EPRI, 2003). PV energy is often viewed as having very minimal waste because there is none produced during operation. With the increase in manufacturing of PV systems, the potential risks and consequences of the use of heavy metals and other chemicals in PV cell production are garnering attention. In addition, the waste created by the decommissioning of the solar modules at the end of their useful lives cannot be ignored. Currently, many solar companies meet or exceed national and international standards for handling and mitigating hazardous materials. Companies are engaged in research and development to use less hazardous materials with the aim of further reducing the environmental impact of manufacturing. For example, companies are modifying processes to eliminate the use of hazardous gases or lessen their concentrations and switch to more environmentally friendly alternatives. Lead was initially used as a solder to connect crystalline silicon cells into modules; however, advances in manufacturing have now led to lead-free solder to connect its cells (CG, 2012). The decommissioning of PV modules is seen as an environmental challenge for the solar industry. To address this challenge, PV cycle, an international PV industry program that is addressing the recycling challenge in Europe, has been established. The first large-scale dismantling facility for end-of-life modules was introduced in Europe in 2009 under PV cycle. The PV cycle target is to collect at least 65% of modules at the end-of-life, with 85% of the module content to be recycled (Raugei, 2012).

2.7.4 Human health and well-being

Table 2.13 lists the impacts to human health and well-being from solar energy in forested regions. Most of the impacts are beneficial, because of reduction of poison emissions that are emitted from the burning of traditional fossil fuels. Currently, a study indicates that 49% of lakes and reservoirs in the U.S. carrying fish with higher amount of mercury (Hg) than safety amount of mercury (Hg) (US-EPA, 2009). Solar PV system emitted 50 to 1000 times less direct mercury (Hg) than conventional electricity generation system, i.e., ~0.1 g Hg/ GWh as compared to ~15 g Hg /GW h from coal (Fthenakis et al., 2008; Meij, 2007). In the US, about 65% of the mercury (Hg) in lakes and reservoirs comes from burning of conventional fossil fuels. CdTe module that is made by CdTe, which is emitted cadmium (Cd) ~0.02 g /GWh, during generating clean electricity is 100 to 300 times less than emissions from coal power generation (Fthenakis et al., 2008; Meij, 2007). Emissions of CO_2, NOx, SO_2, CO and other gases from solar PV based power generation system are smaller than those from conventional fossil fuel based power generation system (Fthenakis et al., 2008). These toxics gases and others particulates has great bad effect on human health.

Table 2.13: Effects of solar energy on human health and well-being relative to traditional U.S. power generation.
(Turney, 2011)

Impact types	Advantage relative to conventional power	Beneficial or detrimental	Remarks
Exposure to hazardous chemicals			
Emission of Hg	Decrease emissions	Positive	30 times less emission from solar
Emission of Cd	Decrease emissions	Positive	150 times less emission from solar
Emission of other toxics	Decrease emissions	Positive	Solar emits much less
Emission of particulates	Decrease emissions	Positive	Solar emits much less
Others impacts			
Noise	Decrease noise	Positive	Less mining noise, less train noise
Recreational resources	Decrease pollution	Positive	Cleaner air: cleaner fishing
Visual aesthetics	Same as fossil fuel	Neutral	Solar firms vs. open pit mines
Climate change	Decrease change	Positive	25 times less emission from solar
Land occupation	less occupied	Neutral	Less

2.7.5 Land use for PV installation

Indirect land use is linked to materials and energy use during PV manufacturing. Fthenakis and Kim (Fthenakis et al., 2009) assessed the life cycle inventories of PV modules, power plants and their components, and determined that indirect land use was insignificant compared with direct land use. This study found indirect land use was 18.4 m^2/GWh for multi-crystalline silicon, 18 m^2/GWh for mono-crystalline silicon and 15 m^2/GWh for ribbon silicon. Additional land use for BOS manufacturing was determined to be 7.5 m^2/GWh. The study was based on an insolation of 1 800 kWh/m^2 per year and a 30 year power plant lifespan, the land use under average Canadian insolation would be higher. Figure 2.25 shows the land use of different types of energy resources, where hydroelectric and wind technologies occupied maximum land use compared to Nuclear and PV technologies.

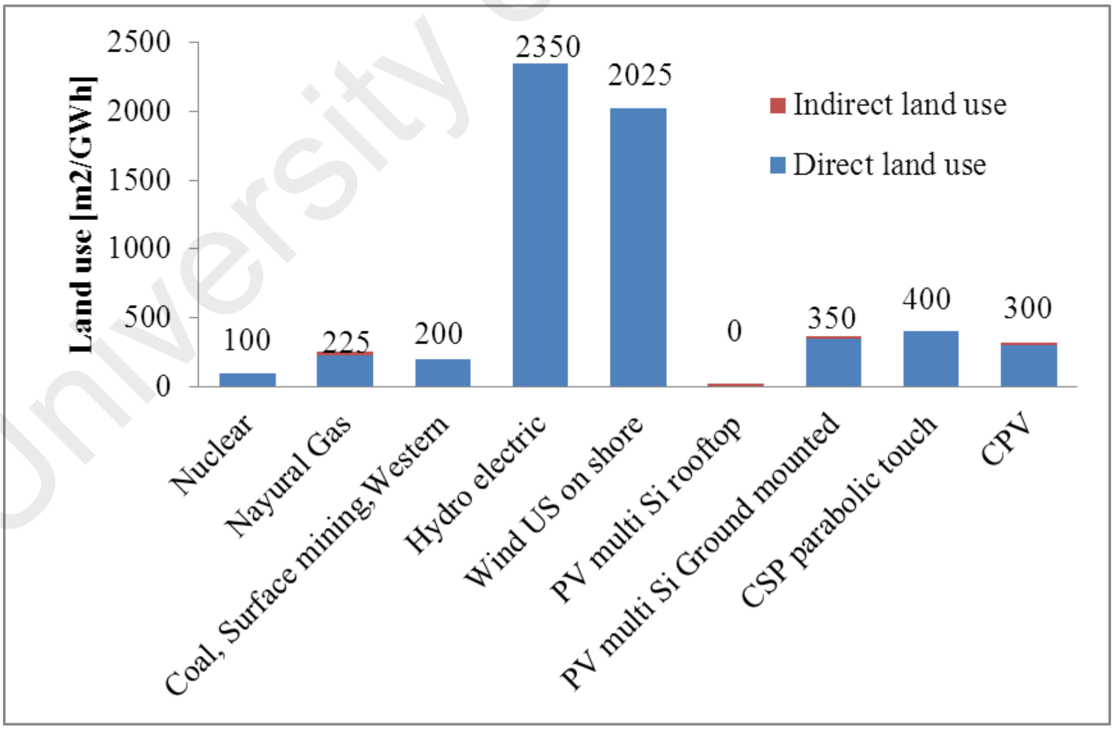

Figure 2.25: Land use (m^2/GWh) by energy generating technologies.

(Fthenakis et al., 2009)

A typical ground-mounted PV configuration occupies more land than just the PV module area. Enough land is needed for access and maintenance as well as to avoid shading. Many solar project developers flatten the landscape and erect fences around major solar plants. During the environmental impact studies and planning, it is best practice for developers to move endangered or threatened species off a disturbed land. Developers may also set aside pristine parcels of land to compensate for the loss of the habitat (Kammen, 2011). Soil erosion rates for PV solar farms (ground mounted) depend largely on the type of ground cover. PV projects that are sustainably developed and used soil conservation techniques, such as elevated PV modules with grass cover under foot, can reduce soil erosion to negligible rates (Graebig, 2010; GREA, 2010). For example, Graebig (Graebig, 2010) reported that grass cover fields, which are not tilled, can reduce soil losses to 0.08 t/ha per year. Land use for renewable energy sources, such as PV, is distinct in that renewable energy sources use land statically (passively), whereas conventional fuel sources use resources extracted from the land during their operation and maintenance phase. Another benefit of PV power plants is that they can be located on marginal lands and brown fields. They can also be used on higher-quality lands in conjunction with grazing livestock and crops (Fthenakis et al., 2009). Rooftop PV installations use the least land of any of the PV technologies, as they are situated on land already disturbed by the building on which they are installed (Kammen, 2011). Sustainable land use by solar farms has important benefits in decreasing effects on local plant and wildlife habitat.

2.7.6 Water used for PV technology

Water is used for cleaning and cooling silicon wafers, glass, cells and modules and for preparing chemical solutions. Production of semiconductor materials and the purification of silicon also use water indirectly, in the form of large amounts of thermoelectric power, which relies on water-cooling systems (Fthenakis et al., 2010). No water is used during the operation of PV systems, except when modules are cleaned to remove dust or dirt (EPIA, 2012c). Water is used in the end-of-life phase (e.g., decommissioning and recycling). While overall water use is low, the manufacturing of silicon-based PV requires more water than that of thin film CdTe (Fthenakis et al., 2010). For silicon-based PV, water consumed throughout the manufacturing of a system is approximately 200 L/MWh (Fthenakis et al., 2010). Most of this water is used in the production of high-purity silicon. For multi-crystalline and mono-crystalline silicon PV, 66% and 68%, respectively, of the upstream water use is accounted for in silicon production (Kammen, 2011). Water is used for cooling in the fabrication of the cells, including contact forming and edge isolation. Indirect water withdrawals for silicon-based PV systems are related to producing cast-silicon and growing single crystals (Fthenakiset al., 2010). For thin-film CdTe PV, there is a lower PV material requirement in manufacturing. As shown in Table 2.14, water consumption is lower than for silicon PV, at approximately 0.8 L/MWh (Fthenakis et al., 2010).

Table 2.14: Water consumptions for different PV technologies during manufacturing and plant construction.

(Fthenakis et al., 2010)

Types of PV	On-side (L/MWh)	Upstream (L/MWh)
Multi-crystalline silicon	200	1470
Mono crystalline silicon	190	1530
CdTe	0.8	575
Frame(based on multi-crystalline silicon PV)	NA	64
BOS (Ground mounted PV)	1.5	210

During the operation and maintenance of PV systems, water is in some cases used to wash dust and dirt off modules, as cell efficiency is reduced when the modules are dirty

(Kammen, 2011). It has been estimated that water use during PV operations in the United States is 15 L/MW h for cleaning (Fthenakiset al., 2009). Figure 2.26 shows the water consumption for various power generation technologies where hydroelectric power plant needs 5300 L/MWh, Coal recirculating needs 3100 L/MWh. On the other hand for PV power generation needs only 15 L/MWh water.

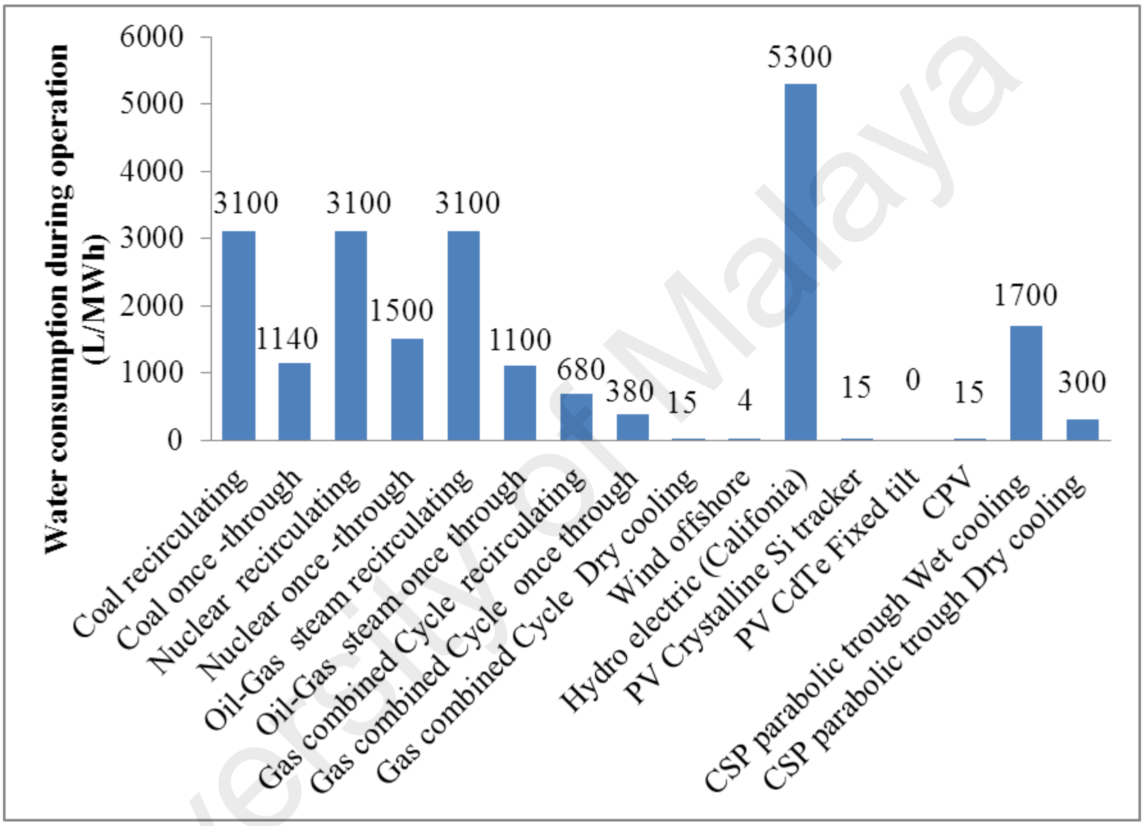

Figure 2.26: Water consumption for different power generation technologies.

(Fthenakis et al., 2010)

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

The aim of this chapter is to describe the facilities development to conduct the research. This chapter also discusses about system design, the formulation and other related procedure.

3.2 System design for 30 MW solar photovoltaic plants

The grid-connected PV system has been focused to support the supply of increasing energy demand (Fawcett, 2008; Svensson, 2007). This study mainly focuses on the analysis of the development of 30 MW solar photovoltaic plants in Malaysia. The PV system is composed of 120000 crystalline silicon modules and every panel has peak production watts (Wp) of 250. Each PV panel has an area of 1.6368 m^2 (the real area is equal to 1.46 m^2 (AMU)). The real area occupied by the system is 175200 m^2. The efficiency of the cells is 17% for crystalline. The BOS efficiency is 96% that includes the estimation of the efficiency of the inverter (98%) and other factors such as the losses of electric connection cables (90%) (Infantes, 2006). Table 3.1 shows the module specification. Figure 3.1 shows the schematic diagram of the PV plant.

Table 3.1: Crystalline silicon module specification

Power (W)	**250**
Module dimension (mm)	1650*992*50
Cell size (mm)	156*156
Cell type	10*6
Efficiency %	15
Module actual area (m^2)	1.46
No. of PV panel/module	128000
Total Module actual area (m^2)	186,880

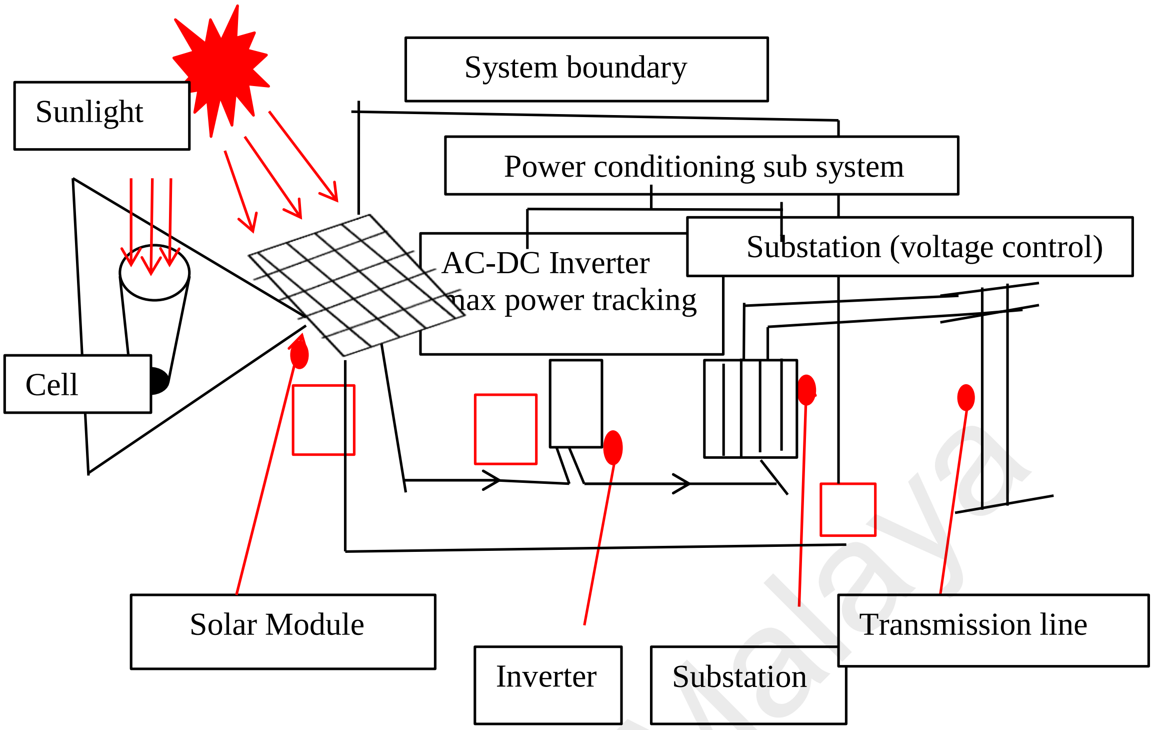

Figure 3.1: Schematic diagram of the PV plant

3.2.1 Land requirement for the plant and land price

The land area estimated for 1 MW of PV plant of crystalline cell is about 3.5acres. Total land requires about 105 acres. Land price per acre is RM30, 000 (ML, 2014). Total land price is as shown in Table 3.2.

Table 3.2: Land price for 30 MW PV plants

Total land require	**105 acre**
price per acre	RM30,000
Total land price	RM3,150,000

3.2.2 Cost Breakdown of PV Systems

Cost reduction of photovoltaic system is very helpful for commercially established technology (IRENA, 2012). The global and U.S. photovoltaic technology installed capacity has increased very rapidly in last few years due to decreasing PV price and government subsidies and incentives. The U.S. Department of Energy's (DOE) Sun Shot has taken a target to calculate PV price without government subsidies. It could be achieved by decreasing the cost of photovoltaic electricity generation system up to 75% within 2012 to 2020 (Feldman, 2012). Australian solar pioneer Stuart Wenham forecast about solar module price that it would fall 50% with in 2020, also 80% decrease for the last few years (CT, 2013). The cost of PV system consists of two components, i.e. 1) the module cost and 2) the Balance of System (BOS) cost. Normally, the module costs are in the range of 40-60% of the total PV system costs. The total system installation costs include the cost for site preparation, the system design and engineering, the authorization and the installation labor (Dahlan, 2014). The cost breakdown for a commercial PV system includes 50 to 60% for PV modules (TF and c-Si, respectively), 10% for the Inverter, 23-32% for installation of BOS and about 7% for engineering and procurement (EPIA, 2011a). DOE (2012) analyzed and found that acquiring the "US$1/W" for PV technology needs module price of US$0.50/W, BOS and installation price of US$0.40/W and power electronics price of US$0.10/W as shown in Figure 3.2 (DOE, 2012).

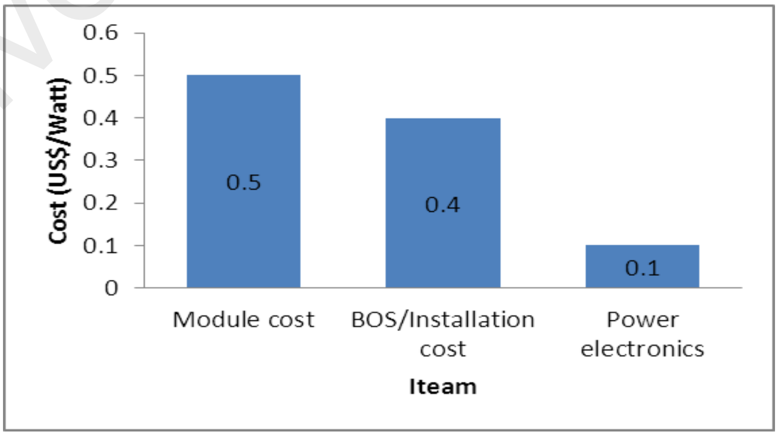

Figure 3.2: Cost breakdown for a commercial PV system.

(DOE, 2012)

3.2.2.1 Solar PV Module price/cost

The PV module cost is calculated on the basis of costs of raw materials, silicon prices, silicon processing and cell manufacturing cost, and module organization costs. Generally PV module cost is 40% to 60% of total PV system. The cost depends on the project size and PV module types. Accurate data on global average PV module prices are difficult to obtain and in reality there is a wide range of prices, depending on the cost structure of the manufacturer, market features and module efficiency. Table 3.3 shows the module prices from different suppliers. Figure 3.3 shows the Module price decreasing scenario from 1975 to 2014. Table 3.3 shows solar module spot prices in the month of March 2014-2015.

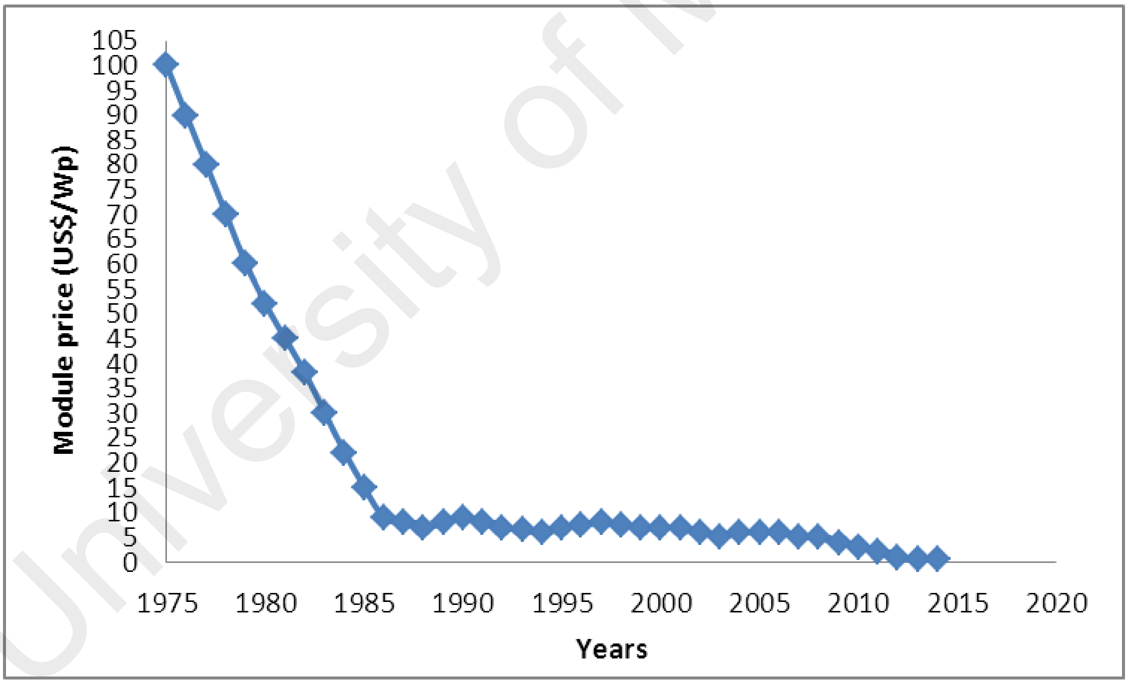

Figure 3.3: Module price decreasing scenario from 1975 to 2014.

(EC, 2013; Solarbuzz, 2012; Maycock, 2011)

Table 3.3: Solar Module price (US$/W) from different suppliers.

Type of cell	Place of Origin	Model Number	Efficiency	price (US$/W)	Reference
Monocrystalline Silicon	China	HSPV, 300Wp 156 M-72	16%	0.63 to 1.0	SHLSC, 2014
Polycrystalline Silicon	China	RS6S-300P	16.30%	0.5 to 0.75	SP, 0214b
Polycrystalline Silicon	China	BCT300-24	17%	0.55 to 0.7	SP, 2014a
Monocrystalline Silicon	China	HPSM-300W	17%	0 .73 to 0.85	SP, 2014c
Monocrystalline Silicon	China	JOYSOLAR-300W	17.3%	0.40 to 0.70	SPPA, 2015
Monocrystalline Silicon	China	HT280W	17.0%	0.30 to 0.60	HT, 2015

By the end of 2012, the "best in class" module price had dropped to US$ 0.50/W, and was expected to drop to US$0.36/W by 2017 (GTS, 2013). The learning rate of PV module and PV system level makes no difference between global and local learning. Therefore, the world module price and the world system price are used in this study to estimate the solar grid parity year for Malaysia.

3.2.2.2 Inverter, BOS and Installation cost

Capital cost is the sum of BOS costs and installation cost of the PV system. The BOS costs are largely depended on the type of the installation. For utility-scale PV plants, and a simple grid connected system, the cost can be as low as 20% and for an off-grid system, it can be as high as 70%. A standard utility-scale ground-mounted system is about 40% of the total system cost (IEA PVPS, 2009).

The inverter, BOS and installation costs include:

- The inverter, which converts the direct current (DC) PV output into alternating Current (AC);

- The Mounting and racking components of the PV system;
- The combiner box and miscellaneous electrical components;
- Site preparation and labour costs for installation and grid connection;
- System design, permit fees, installer overhead, management and any up-front financing costs.

The inverter is one of the important components of a PV system. It converts the DC electricity from the PV modules into AC electricity. The size and numbers of inverters required are determined on the basis of the installed PV capacity and system design options. Sometime inverters price is of 20% of total installed system costs. At present, inverter cost varies from RM0.72/W to RM1.80/W (USD0.20/W to USD0.50/W), depending on the installation capacity (Photon, 2014). Larger systems tend to have lower inverter costs per unit of capacity, such as systems in the 10 to 100 kW range having costs of between RM0.72/W to RM1.80/W (USD0.20/W to USD0.5/W). However, some of the most competitive inverters for small-scale applications (<5 kW) can rival those costs, as the range in 2010 was RM0.90/W to RM3.60/W (USD0.25 to USD1.0/W) (Photon, 2014). Table 3.4: Cost breakdown of 30 MW PV plants.

Table 3.4: Cost breakdown of 30 MW PV plants

Items	**Percentage (%)**
Module price (US$/W)	40-50
Inverter price	25
BOS+ Installation cost	23-32
Engineering +Procurements	7
Total	100
US$ 1= RM 3.60	Date (02.03.2015)
EURO 1= RM 4.10	Date (02.03.2015)

Table 3.5 shows the 30 MW PV plant module cost, balance of system cost and land price. Table 3.6 shows the yearly operation and maintenance cost and inverter replacement cost.

Table 3.5: 30 MW plant cost calculation.

Item	**Crystalline silicon module price RM 1.8/W (US$ 0.50/W)**
Module cost (40% of total cost)	54,000,000
Inverter price (25% of total cost)	33,750,000
BOS cost (35% of total cost)	47,250,000
Land price RM30,000/acre (3.5acres/MW for crystalline silicon)	3,150,000
Total project cost RM	138,150,000

Table 3.6: Operation& maintenance and inverter replacement cost calculation.

	Crystalline silicon module price RM 1.80/W (US$ 0.50/W)
Operation and Maintenance cost RM (1% of module cost, BOS cost and land price)	1,381,500
Insurance RM per year (0.4% of module cost, BOS cost and land price)	552,600
2 times inverter replacement cost	67,500,000
Total cost	69,434,100

3.3 Data collection

3.3.1 Solar insolation in Malaysia

Malaysia has favorable climatic conditions for the development of solar energy. Malaysia is one of the ASEAN countries that has very good solar irradiations average which is about 1643 kWh/m^2 per year (i.e. range from 1400 to1900 kWh/m^2) with sun hours than 10 hrs (Ahmad et al., 2011; Amin, 2009; Haris, 2008b; Tesea, 2012). Table 3.7 shows the average value throughout the year of solar insolation of different place in Malaysia (Mekhilef, 2012).

Table 3.7: Solar insolation in Malaysia (average value throughout the year).

Location	**Average value (kWh/m^2)**
Kuching	1470
Bandar Baru Bangi	1487
Kuala Lumpur	1571
Petaling jaya	1571
Seremban	1572
Kuantan	1601
Johor Baru	1625
Senia	1629
Kota Baru	1705
Kuala terengganu	1714
Ipoh	1739
Taiping	1768
George Town	1785
Bayan Lepas	1809
Kota Kinabalu	1900

3.3.2 Feed in tariff (FiT) rate in Malaysia for PV technology

SEDA has taken a lot of strategies to increase the awareness, the use of solar energy and to consider it as one of the primary sources for energy supply up to 2050. The target set for 2015 is at 985 MW (Chen, 2012). Feed in Tariff (FiT) is one of the main elements for economic support for the photovoltaic owner. Table 3.8 shows the Revised FiT for Solar PV effective from March 2014. Table 3.8 also shows that the maximum capacity of PV system is not more than 30 MW.

Table 3.8: Revised FiT for Solar PV effective from March 2014.

(SEDA, 2014)

Description	**FiT rate for 2014 (RM/kWh)**	**Degression rate**
Basic Fit rates having capacity of:		
Individual:		
1.Up to 4KW	1.018	10%
11.More than 4 KW and up to 12 KW	0.994	10%
Non-individual		
i.Up to and up to 4 kW	1.018	10%
ii. More than 4 KW and up to 24KW	0.994	10%
iIi. More than 24 KW and up to 72 KW	0.85	10%
iv. More than 72 KW and up to 1 MW	0.82	10%
v. More than 1MW and up to 10MW	0.68	10%
vi. More than 10MW and up to 30 MW	0.61	10%

3.4 Formulations for Electricity production, NPV, IRR%, payback period, Capital Recovery Factor and LCOE of photovoltaic system.

3.4.1 The estimated AC electricity produced by photovoltaic system

According to the available data, the AC electricity produced in a year can be estimated by equation 3.1 (Cucchiella, 2012).

$$E_p = I_{Solar} \times E_{Module} \times E_{BOS} \times A_{Module} \times N_M \quad (3.1)$$

Where Ep is the produced electricity, I_{solar} is solar insolation, E_p is the module and balance of system efficiency.

Supplier warranty for photovoltaic module lifetime is 25 years (SHS, 2014; SP, 2014c).

Total electricity produced in (T=25) years can be estimated by equation 3.2.

$$E_p = I_{Solar} \times E_{Module} \times E_{BOS} \times A_{Module} \times N_M \times T \quad (3.2)$$

3.4.2 Net present value (NPV)

Net present value (NPV) represents the sum of the total cash flows (CF) of the project reduced to the present value by the discounting. S is the project initial cost, the NPV is found by the Equation 3.3 (Rosenzweig, 2010).

$$NPV = -S + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \ldots + \frac{CF_n}{(1+r)^n} = -S + \sum_{j=1}^{n} \frac{CF_J}{(1+r)^j} \quad (3.3)$$

3.4.3 Internal rate of return (IRR)

Internal rate of return is the discount rate which reduces the net present value of the Investment project to zero (Rosenzweig, 2010). It is calculated in the following fashion. The IRR is calculated by the Equation 3.4 with the NPV to be zero.

$$NPV = -S + \sum_{j=1}^{n} \frac{CF_J}{(1+IRR)^j} = 0 \quad (3.4)$$

3.4.4 Payback period (PBP)

Payback period represents the number of periods (years) in which it is necessary to realize such a net cash flow of the investment project, so as to retrieve the total value of the realized investment within the scope of the life span of the project. When S is the initial cost, Tp (PBP) payback period of the project is calculated by the Equation 3.5 (Rosenzweig, 2010).

$$\sum_{n=0}^{T} S_n = \sum_{n=1}^{T_p} CF_n \tag{3.5}$$

3.4.5 Capital Recovery Factor (CRF):

A Capital Recovery Factor (CRF) converts a present value into a stream of equal annual payments over a specified time, at a specified discount rate i (interest).The value of an equal payment (A) to be made in each of n periods here is given by:

That is, A = P x CRF

$$CRF = \frac{[i(1+i)^n]}{[(1+i)^n - 1]} \tag{3.6}$$

Where, CRF is the capital recovery factor and P is the total loan amount,

3.4.6 Levelized cost of energy (LCOE)

LCOE is the ratio of an electricity-generation system costs (i.e. installed cost plus lifetime operation and maintenance (O&M) costs) to the electricity generation by the system over its operational lifetime. The LCOE is very sensitive to installed system cost, PV panel orientation, O&M costs, system lifetime, local solar resource and climate, financing terms, taxation, policies etc. (DOE, 2012).

The LCOE can be calculated by the following equation:

$$LCOE = \frac{TLCC}{\left(\sum_{n\to 1}^{N} Q_n \big/ (1+d)^n\right)} = \frac{\left(\sum_{n\to 0}^{N} C_n / (1+d)^n\right)}{\left(\sum_{n\to 1}^{N} Q_n / (1+d)^n\right)} \tag{3.7}$$

Where C_n is the cost for year n, Q_n is the energy output for the year n, d is the discount rate, and N is the analysis period. The discount rate appears in Eq. 3.6 to compensate for the time value in the currency. Branker et al. (2011) reported in a survey of studies of PV LCOE. In this study, they didn't clearly mention the discount rate but the value is 5% to 10% in most studies. In this paper 6% has been used as the rate used by the IEA (2012) to compute LCOEs.

3.4.7 Emission reduction calculation:

During electricity generation by fossil fuel, emission occurred and emission reduction is calculated according to fuel type, percentage of electricity generated by that fuel and emission factor of the specific fuel. Table 3.9 shows the emission for a unit electricity generation by different types of fuel and Figure 3.4 shows the Primary energy generation mix in Malaysia in 2012.

The emissions for electricity generation are estimated as:

$$Emission = EC \times PEGF \times EFF \tag{3.8}$$

Where: EC=Electricity consumption (kWh), PEGF=Percentage of electricity generated by the specific fuel, EFF=emission factor of fuel (kg/kWh).

Table 3.9: Emission of different fuels for unit electricity generation. (Mahlia, 2010)

Fuel	**Emission factor (kg/kWh)**			
	CO_2	**SO_2**	**NO_x**	**CO**
Coal	1.18	0.019	0.005	0.0002
Petroleum	0.85	0.016	0.003	0.0002
Gas	0.53	0.0005	0.0009	0.0005
Hydro	0.00	0.00	0.00	0.00

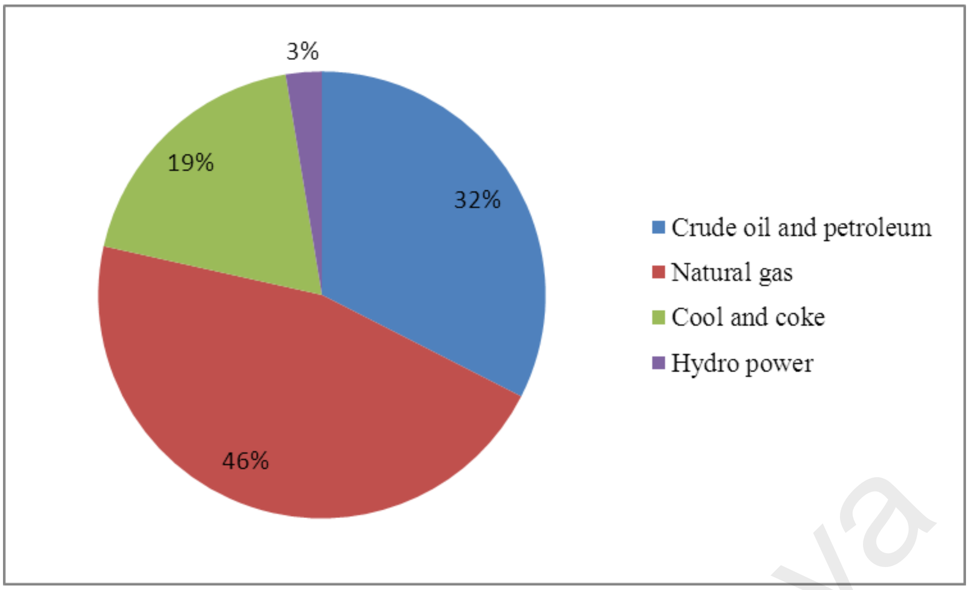

Figure 3.4: Primary energy generation mix in 2012.

(EC, 2012)

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

The aim of this chapter is to describe the results and discussion of the analysis. The estimated electricity generation from the proposed 30 MW of solar PV plant, net present value (NPV), internal rate of return (IRR%), payback period (PBP), levelized cost of electricity (LCOE), are described with necessary Tables and Figures. It is also described the Grid parity year for 30 MW solar plant in Malaysia, environmental impact of PV technology and the amount of different types of gases emission reduction.

4.2 Economic analysis of 30 MW power plants

4.2.1 Near future price trends

PV is the rapidly growing renewable energy technology and plays an important role for producing global electricity. Worldwide total PV installation was 1.8 GWp in 2000 and 67.4 GW in 2011 where the growth rate is about 44% per year (EPIA, 2012b). By the end of 2012, the installed capacity 100 GW milestone was acquired (RI, 2013). Table 4.1 shows the yearly and cumulative installation from 2004-2012. Solar PV technology in 2011 produced 118 TWh of electrical power. The PV modules learning rate for the module price is from 20% to 22%, where for crystalline silicon is about 19% to 20% and for thin films 23% to 24%. Each time the cumulative installed capacity has doubled, PV module cost has decreased by 20% to 22% (EPIA, 2011b; Kersten, 2011). PV modules on a global scale usage shows explanatory variable, with an average learning rate of 20.0% (Tour, 2013). Table 4.2 shows the learning rate of global and different countries from1965 to 2010.

Table 4.1: PV yearly and cumulative installation from 2004 to 2012. (EPIA, 2013a).

	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
ROW (Rest of the World)	29	10	105	42	76	80	284	508	1095
MEA (Middle East and Africa)	1	n/a	n/a	1	1	22	46	121	410
China	10	8	10	20	40	160	500	2500	5000
America	104	106	150	213	346	543	1029	2179	3758
APAC (Asia Pacific)	282	303	324	271	535	742	1583	2672	4769
Europe	707	984	992	2028	5710	5830	13622	22411	17159
Yearly total installation	1133	1411	1581	2575	6708	7377	17064	30391	32191
Cumulative installation	2860	4271	5852	8427	15135	22512	39576	69967	102156

Table 4.2: Learning rate of global and different countries from1965 to 2010.

(Tour, 2013)

Reported by	Study area	Period of study	Learning rate (%)	Data sources
Maycock & Wakefield (1975)	Global	1965-1973	20.0%	n.a
Tsuchiya(1992)	Japan	1979-1988	19.0%	n.a
Williams and Terzian (1993)	Global	1976-1992	18.4%	Strategies Unlimited
Cody and Tiedje (1997)	US	1976-1988	22.0%	Maycock
Tsuchiya (1999)	Japan	1979-1998	17.7%	n.a
IEA (2000)	Global	1976-1984	16.0%	EU-Atlas and Nitsch(1998)
		1987-1996	21.0%	
Harmon (2000)	Global	1968-1998	20.2%	Maycock
Williams (2002)	Global	1976-2000	20.0%	Strategies Unlimited
Parente et al. (2002)	Global	1981-2000	22.8%	Maycock
		1981-1990	20.2%	
		1991-2000	22.6%	
Poponi (2003)	Global	1976-2002	25.0%	Maycock
		1989-2002	19.5%	
Schaeffer (2004)	Global	1976-2001	20.0%	Strategies Unlimited
		1987-2001	23.0%	
	Germany	1992-2001	10.0%	Photex database
Papineau (2004)	Germany	1992-2000	15.0%	Extool Project. IEA
	Switzerland	1992-2000	10.0%	
	US	1992-2001	32.0%	
	US	1992-2001	20.0%	US DOE
Nemat (2006)	Global	1978-2001	26.0%	Maycock
		1976-2001	17.0%	Strategies Unlimited
Van Sark (2006)	Global	1976-2001	20.6%	Strategies Unlimited
		1981-1990	16.6%	
		1991-2000	29.6%	
Swanson (2006)	Global	1979-2005	19.0%	Strategies Unlimited
Van Sark (2008)	Global	1976-2006	20.6%	Strategies Unlimited
Breyer et al.(2010)	Global	1976-2003	22.8%	Strategies Unlimited
		1976-2010	19.3%	

Table 4.2 indicates that PV learning rate is about 20%. So, it is clear that PV cost decreasing rate is more than 10% annually. For achieving the target of "US$1/W" PV technology needs the module price of US$0.50/W, BOS and installation price of US$0.40/W and power electronics is US$0.10/W (DOE, 2012). From the industrial point of view, these values are aspirant, but potentially acquirable. For acquiring this target the procedure and policies are analyzed (DOE, 2010). To achieve the target, it will be very helpful if the cell and module efficiency is increased and the required areas for the module are decreased. Surek reported that every 1% increase in PV module efficiency reduces the BOS cost by between US$0.07/W and US$0.10/W (Surek, 2010). At the same time, it is forecasted that the electricity prices will be increased about 5% annually and would be RM0.82/kWh by 2030 (Fantazzini, 2011; Schuman, 2012). Figure 4.1 shows the forecasted electricity price in Malaysia from 2012 to 2030.

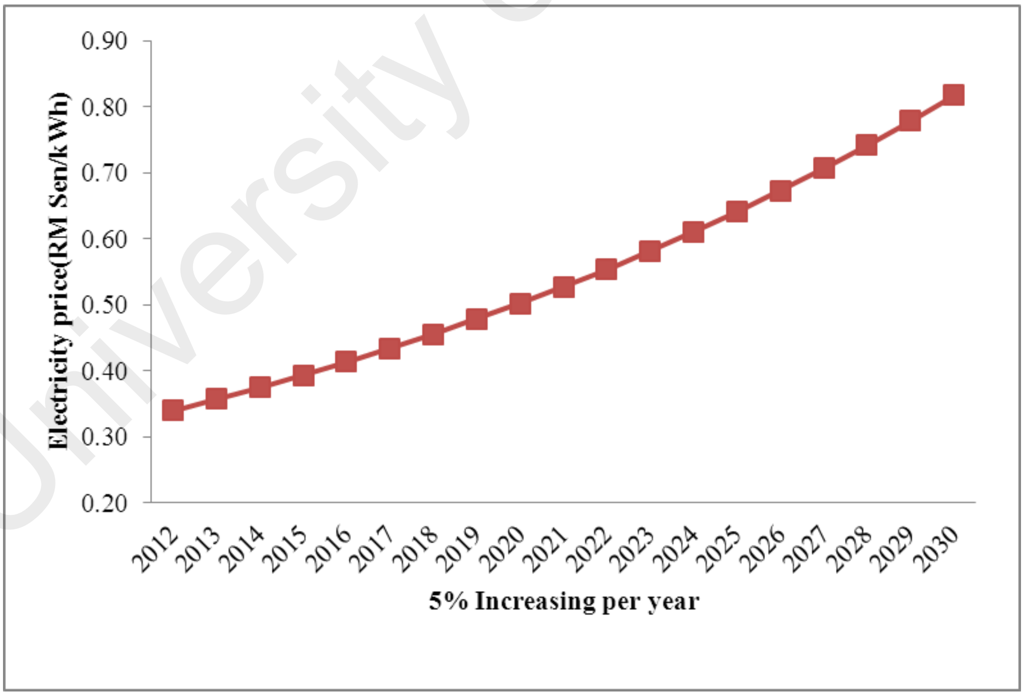

Figure 4.1: Forecast electricity price in Malaysia from 2012 to 2030.

(Fantazzini, 2011; Schuman, 2012)

4.2.2 NPV, IRR%, PBP and LCOE

This thesis emphasizes the use of large scale photovoltaic installation as a clean energy source to supply the energy demand in Malaysia. For economic analysis, the net present value (NPV), payback year (PBY) and the internal rate of return (IRR) are the most important parameters (Agustin, 2006; Lin, 2011; Saidur et al., 2010; Saidur et al., 2012). The project is profitable when the NPV is positive. The analysis is done based on produced electricity with selling price of RM0.40/kWh, RM0.45/kWh, RM0.50/kWh, RM0.55/kWh and SEDA FiT rate of RM0.551/kWh in 2015. In Johor Baharu average solar insolation is 1625 kWh/year. Annual cell efficiency digression rate is 0.5% and the inflation rate is 3%.

Decision making criteria (on the basis of NPV):

If the NPV is greater than 0, accept the project.

If the NPV is less than 0, reject the project

Decision making criteria (on the basis of IRR %):

The IRR% is bigger than discount rate, the project is profitable.

The IRR% is smaller than discount rate, the project is rejected.

Table 4.3: The nomenclatures and parameters needed for the financial analysis.

Item	Unit	Quantity
Plant capacity	MW	30
Module price	RM/W	1.80, 1.62, 1.44, 1.37, 1.30
Inverter price	RM/W	1.125
Module efficiency	%	17%
Module efficiency degradation/year	%	0.5
Inverter efficiency	%	98
BOS efficiency	%	96
Average Yearly Solar Insolation in Johor bahru	$kWh/m^2/year$	1625
Annual Cost of Operation and Maintenance	%	1%
Insurance cost	%	0.4%
Contract Period	year	21
Discounted Rate	%	6
FiT Rate (2014)	RM/kWh	0.612
Loan Interest Rate	%	1-5
Loan Tenure	year	15
Inflation	%	3
Inverter replacement	times	2
US$ 1= RM 3.60	Date (02.03.2015)	
EURO 1= RM 4.10	Date (02.03.2015)	

4.2.2.1 NPV, IRR% and PBP of 30 MW PV plant when Self-financing and different electricity selling prices

(a) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, and with 100% self-financing, then the NPVs are as follows:

When the module price is RM1.80/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM110.27 million, RM156.69 million, RM203.11 million, and RM249.53 million respectively. When the module price is RM1.62/W (US$0.45/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM135.94 million, RM182.36 million, RM228.78 million, and RM275.20 million respectively. When the module price is RM1.44/W (US$0.40/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM161.61 million, RM208.03 million, RM254.45 million, and RM300.87 million respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM171.87 million, RM218.30 million, RM264.72 million, and RM311.14 million respectively. When the module price is RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM182.14 million, RM228.56 million, RM275.00 million, and RM321.41 million respectively. Figure 4.2 shows that when the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50 /kWh and RM0.55/kWh, the NPV is positive. For these selling prices, the project will be profitable for all the above mention module prices.

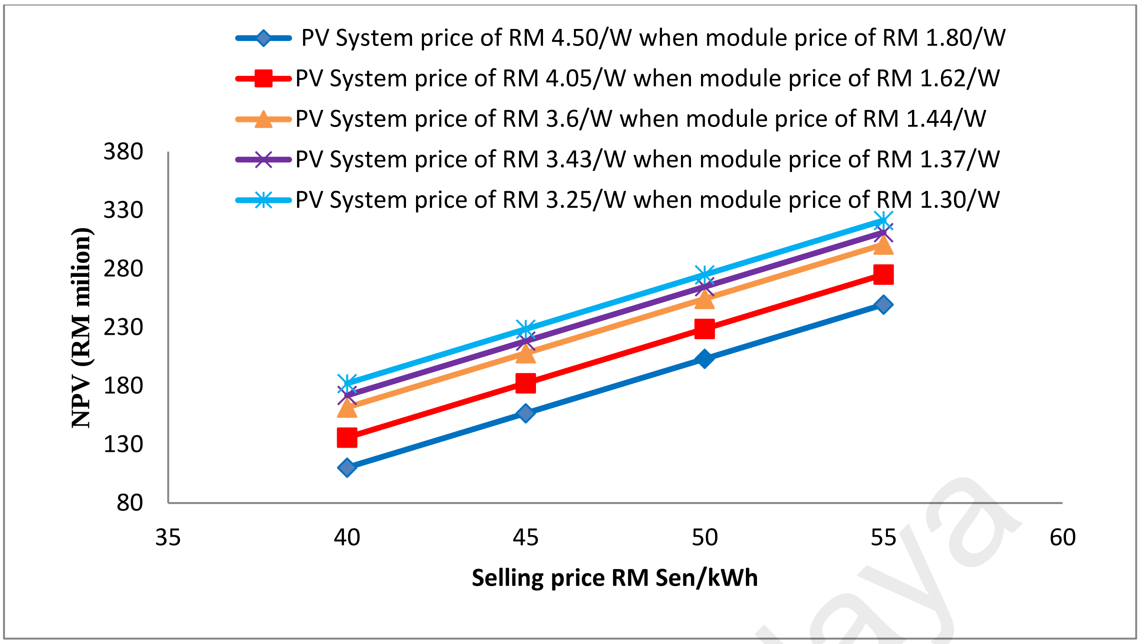

Figure 4.2: Relation between selling price and NPV (Self-financing)

(b) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, and with 100% self-financing, the IRRs are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 6.8%, 9.2%, 11.4%, and 13.5% respectively. When the module price is RM1.62/W (US$0.45/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 8.9%, 11.4%, 13.7%, and 15.9% respectively. When the module price is RM1.44/W (US$0.40/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 11.3%, 13.9%, 16.4%, and 18.8% respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 12.4%, 15.1%, 17.7%, and 20.2% respectively. When the module price is RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 13.6%, 16.3%, 19.0%, and 21.6% respectively. Figure 4.3 shows that all the selling prices are acceptable for all the module pieces. When the selling price is high, the IRR is also high, and vice-versa.

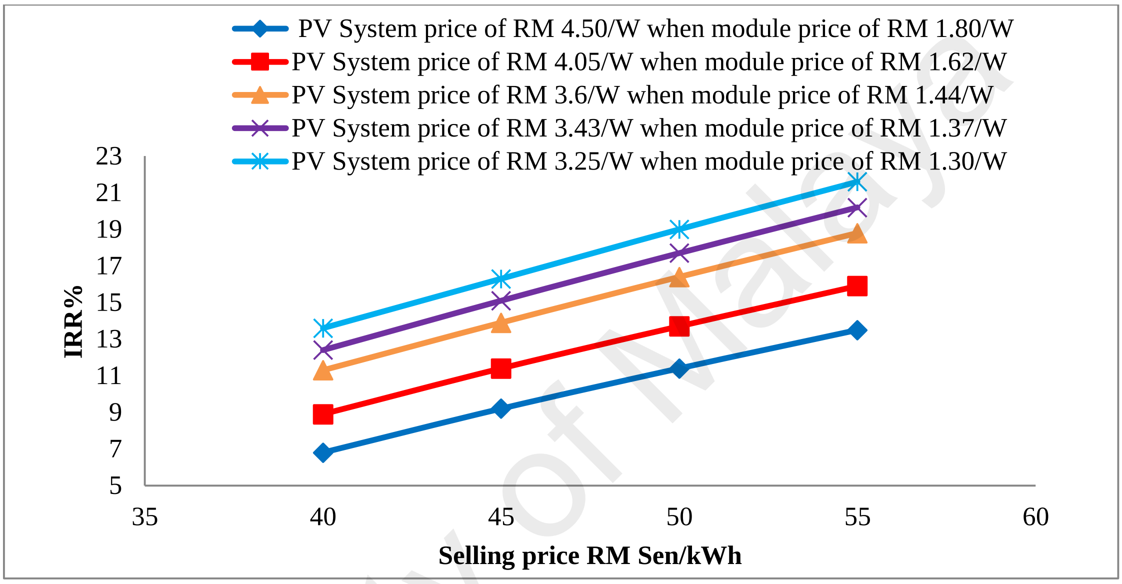

Figure 4.3: Selling price versus IRR% (Self-financing)

(c) When the module prices RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, and 100% self-financing, then the payback periods are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 11.4 years, 9.9 years, 8.7 years, and 6.3 years, respectively. When the module price is RM1.62/W (US$0.45/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 10.1 years, 8.8

years, 6.3 years, and 5.7 years, respectively. When the module price is RM1.44/W (US$0.40/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 8.8 years, 6.2 years, 5.5 years, and 5.0 years, respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 6.7 years, 5.9 years, 5.2 years, and 4.8 years, respectively. When the module price is RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 6.3 years, 5.6 years, 4.9 years and 4.5 years, respectively. Figure 4.4 shows that for all the selling prices, the payback periods are acceptable because they stay within economic lifetimes.

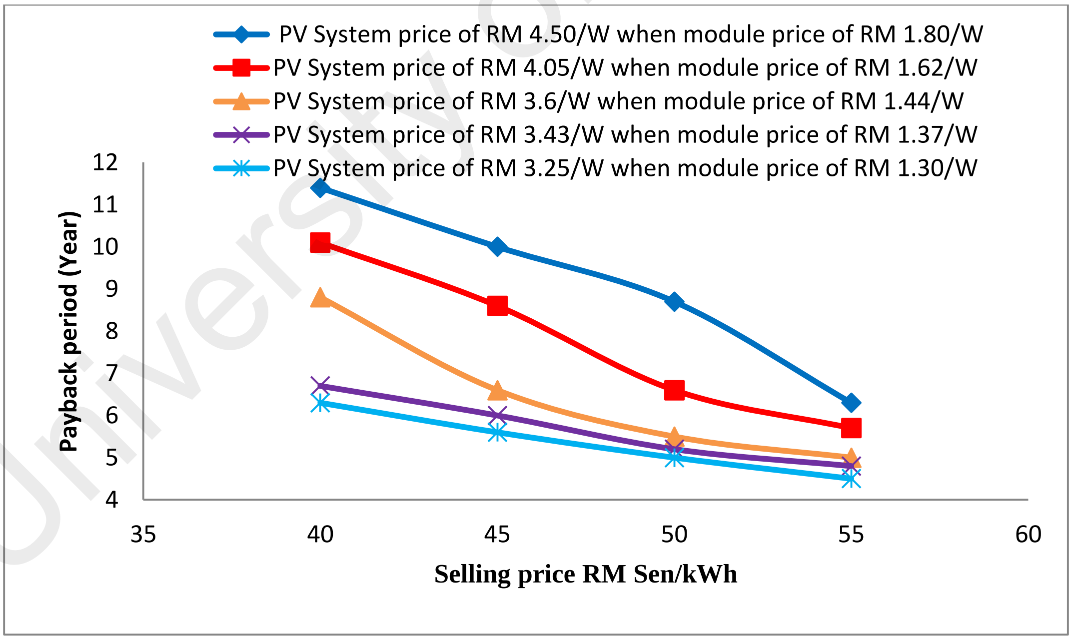

Figure 4.4: Selling price versus payback period (When self-financing)

4.2.2.2 NPV, IRR%, PBP and LCOE of 30 MW PV plant when 50% bank loan (with 1%, 2%, 3% 4% and 5% interest and loan tenure 15 years) and different electricity selling prices

(a) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 50% bank loan with 1% interest and Loan Tenure15 years, the NPVs are as follows:

When the module price is RM1.80/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM19.05 million, RM60.82 million, RM102.58 million, and RM144.34 million respectively. When the module price is RM1.62/W (US$0.45/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the NPVs are RM50.13 million, RM91.89 million, RM133.65 million, and RM175.41 million respectively. When the module price is RM1.44/W (US$0.40/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the NPVs are RM81.21 million, RM122.97 million, RM164.73 million, and RM206.49 million respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM93.64 million, RM135.4 million, RM177.16 million, and RM218.92 million respectively. When the module price is RM1.3/W (US$0.36/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM106.07 million, RM147.83 million, RM189.60 million, and RM231.35 million respectively. Figure 4.5 shows that these selling prices, the project will be profitable for all the above mention module prices.

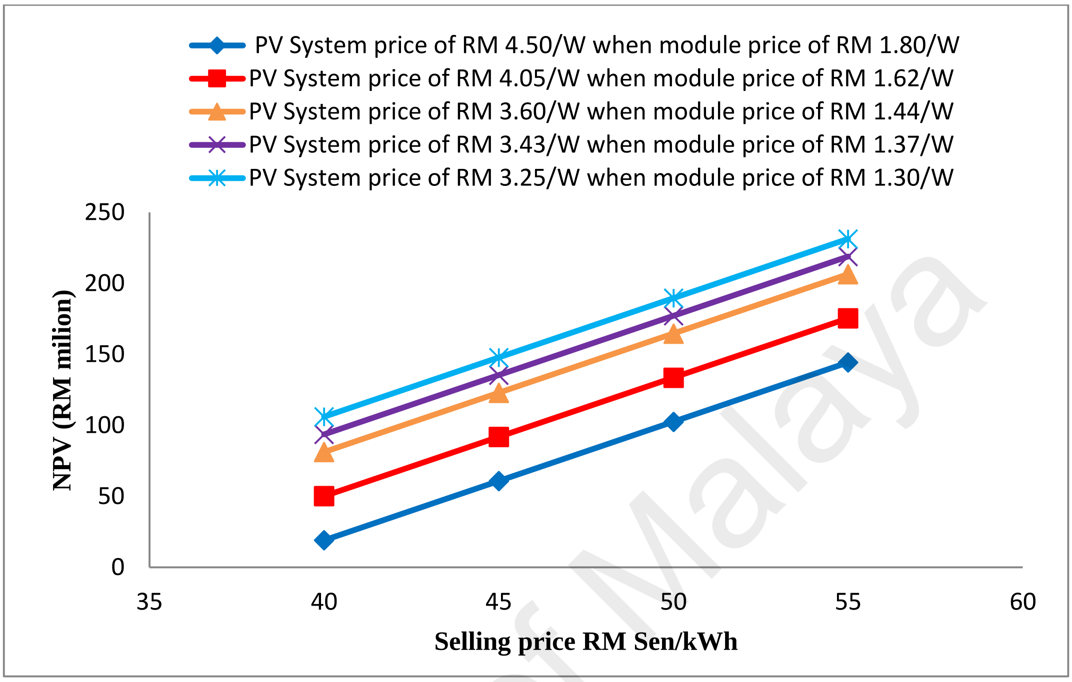

Figure 4.5: Selling price versus NPV (50% loan with 1% interest)

(b) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 50% bank loan with 1% interest and Loan Tenure15 years, the IRRs are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 2.3%, 4.8%, 7.2%, and 9.4% respectively. When the module price is RM1.62/W (US$0.45/W) and with the above mention condition, the IRRs are 4.5%, 7.2%, 9.6%, and 11.9% respectively. When the module price is RM1.44/W (US$0.40/W) and with the above mention condition, the IRRs are 7.1%, 9.9%, 12.4%, and 14.9% respectively.

When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 8.3%, 11.1%, 13.7%, and 16.3% respectively. When the module price is RM1.30/W (US$0.36/W) and with the above mention condition, the IRRs are 9.5%, 12.4%, 15.1%, and 17.8% respectively. Figure 4.6 shows that all the selling prices are acceptable for all the above mention module pieces. When the selling price is high, the IRR is also high, and vice-versa.

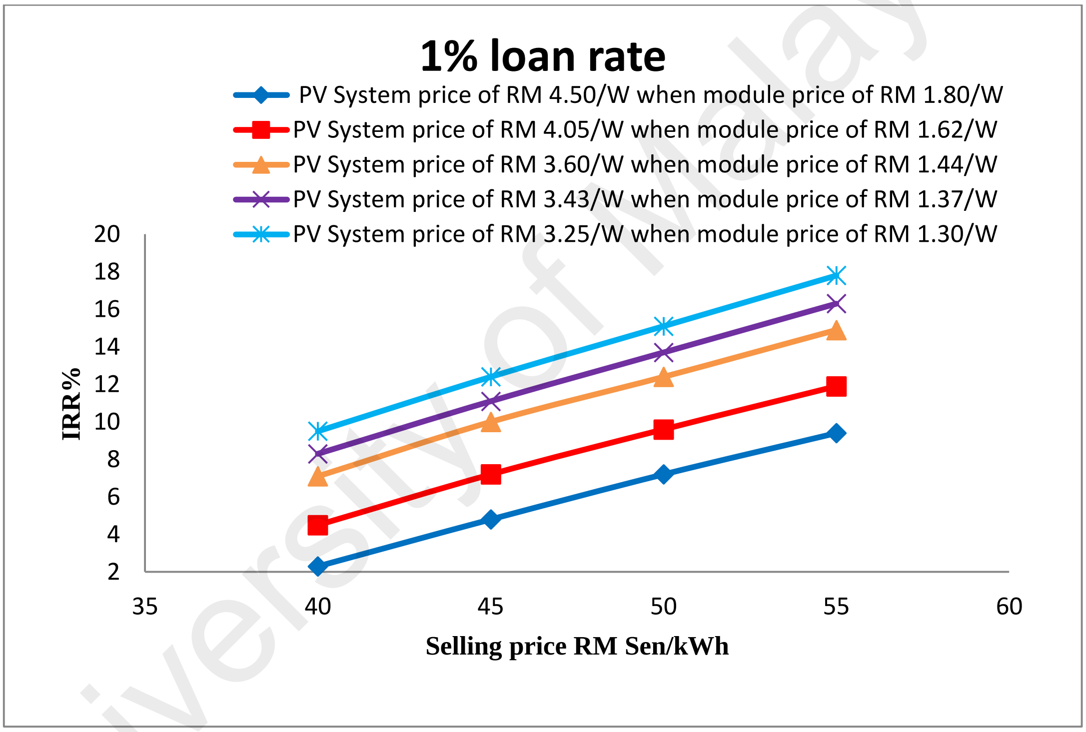

Figure 4.6: Selling price versus IRR% (50% loan with 1% interest)

(c) When the module prices RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 50% bank loan with 1% interest and Loan Tenure15 years, the payback periods are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 18.9 years, 16.2 years, 11.6 years, and 10.1 years, respectively. When the module price is RM1.62/W (US$0.45/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 16.5 years, 11.7 years, 10.0 years, and 8.7 years, respectively. When the module price is RM1.44/W (US$0.40/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 11.7 years, 9.8 years, 6.8 years, and 6.0 years, respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 10.8 years, 9.1 years, 6.4 years, and 5.6 years, respectively. When the module price is RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 10.0 years, 6.8 years, 6.0 years and 5.2 years, respectively. Figure 4.7 shows that for all the selling prices, the payback periods are acceptable because they stay within lifetimes (21 years).

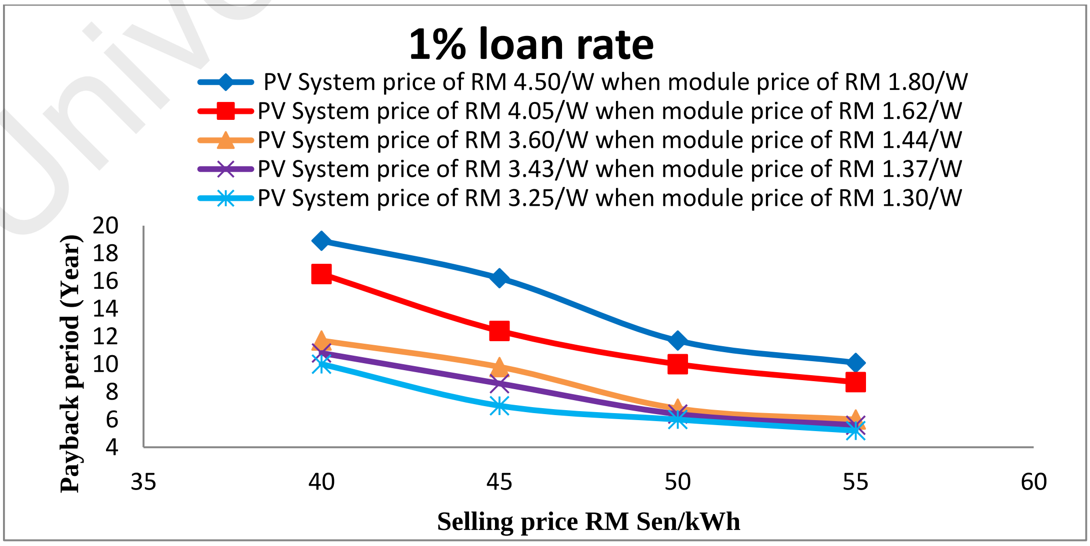

Figure 4.7: Selling price versus payback period (50% loan with 1% interest)

(d) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 50% bank loan with 2% interest and Loan Tenure15 years, the NPVs are as follows:

When the module price is RM1.80/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM0.37 million, RM37.37 million, RM75.11 million, and RM112.85 million respectively. When the module price is RM1.62/W (US$0.45/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the NPVs are RM29.44 million, RM67.19 million, RM104.93 million, and RM142.67 million respectively. When the module price is RM1.44/W (US$0.40/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the NPVs are RM59.26 million, RM97.00 million, RM134.74 million, and RM172.48 million respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM71.19 million, RM108.93 million, RM146.67 million, and RM184.41 million respectively. When the module price is RM1.3/W (US$0.36/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM83.11 million, RM120.85 million, RM158.93 million, and RM196.31 million respectively. Figure 4.8 shows that these selling prices, the project will be profitable for all the above mention module prices.

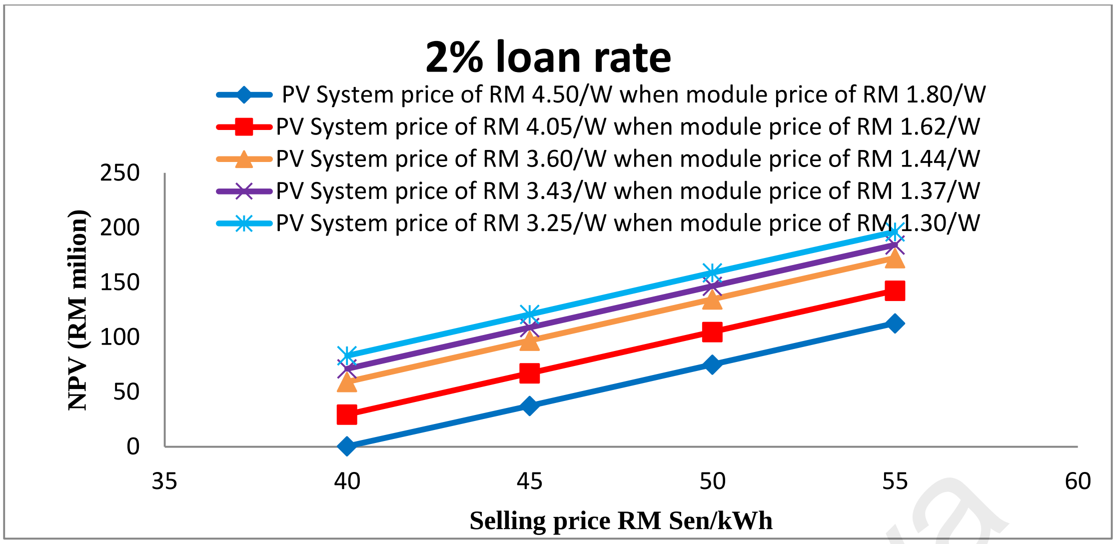

Figure 4.8: Selling price versus NPV (50% loan with 2% interest)

(e) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 50% bank loan with 2% interest and Loan Tenure15 years, the IRRs are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 2%, 4.6%, 6.9%, and 9.2% respectively. When the module price is RM1.62/W (US$0.45/W) and with the above mention condition, the IRRs are 4.2%, 6.9%, 9.3%, and 11.7% respectively. When the module price is RM1.44/W (US$0.40/W) and with the above mention condition, the IRRs are 6.8%, 9.6%, 12.2%, and 14.7% respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 8%, 10.8%, 13.5%, and 16.1% respectively. When the module price is RM1.30/W (US$0.36/W) and with the above mention condition, the IRRs are 9.2%, 12.1%, 14.9%, and 17.5% respectively. Figure 4.9 shows that when the selling price is RM0.40/kWh, the IRR is lower than the 2% loan rate. This price is unprofitable for the project, so it must exceed RM0.40/kWh for module price RM1.80/W. When the selling prices are RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRR are higher than the 2% loan rate. The selling prices of RM0.45/kWh, RM0.50/kWh and RM0.55 /kWh are thus acceptable for module price RM1.80/W, whereas all the selling prices are acceptable for module pieces are RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W). When the selling price is high, the IRR is also high, and vice-versa.

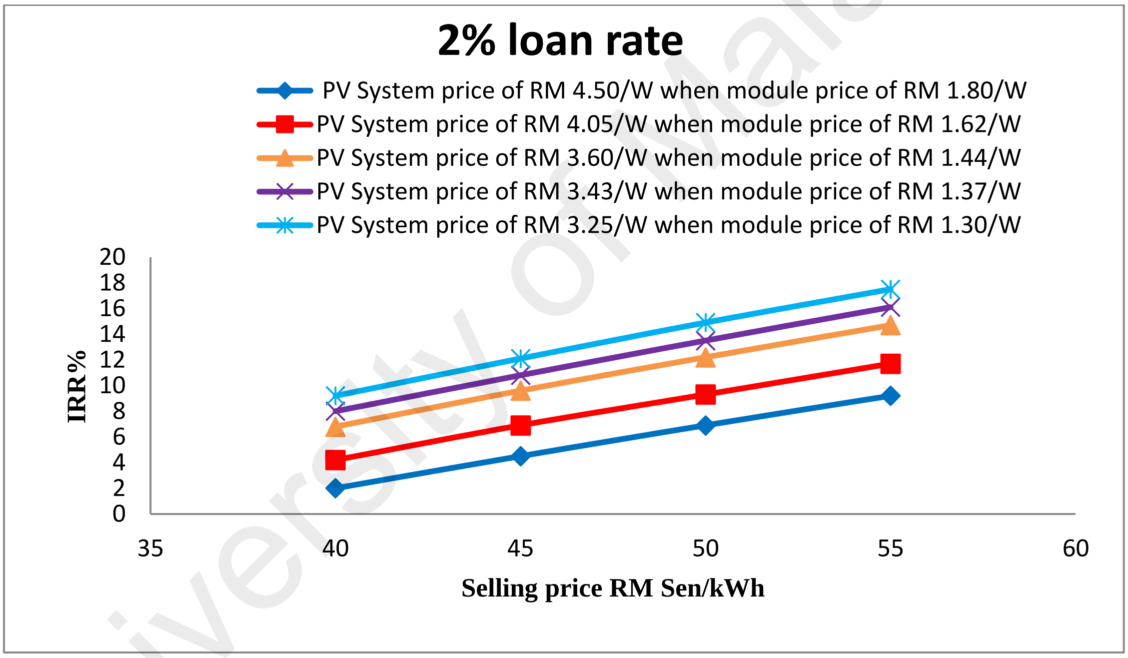

Figure 4.9: Selling price versus IRR% (When 50% loan with 2% interest)

(f) When the module prices RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 50% bank loan with 2% interest and Loan Tenure15 years, the payback periods are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 19.2 years, 16.5 years, 11.9 years, and 10.3 years, respectively. When the module price is RM1.62/W (US$0.45/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 16.8 years, 12.0 years, 10.1 years, and 8.8 years, respectively. When the module price is RM1.44/W (US$0.40/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 12.0 years, 10.0 years, 6.9 years, and 6.1 years, respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 11.1years, 9.3 years, 6.5 years, and 5.7 years, respectively. When the module price is RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 10.2 years, 7.0 years, 6.0 years and 5.3 years, respectively. Figure 4.10 shows that for all the selling prices, the payback periods are acceptable because they stay within lifetimes 21 years.

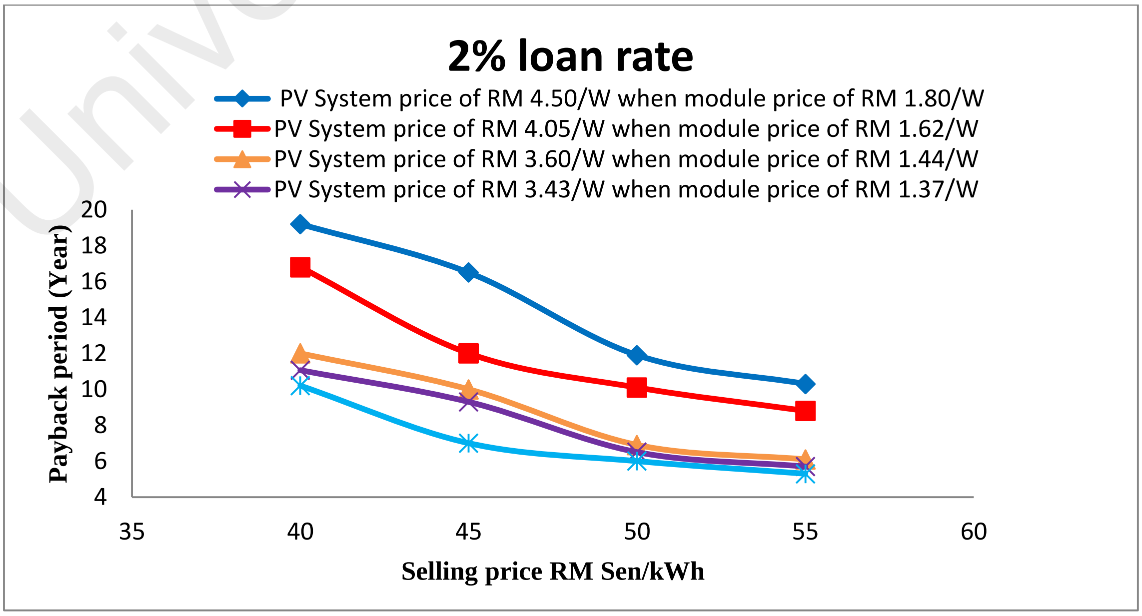

Figure 4.10: Selling price versus payback period (50% loan with 2% interest)

(g) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 50% bank loan with 3% interest and Loan Tenure15 years, the NPVs are as follows:

When the module price is RM1.80/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM-18.06 million, RM16.90 million, RM50.46 million, and RM84.72 million respectively. When the module price is RM1.62/W (US$0.45/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the NPVs are RM10.75 million, RM45.01 million, RM79.27 million, and RM113.53 million respectively. When the module price is RM1.44/W (US$0.40/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the NPVs are RM39.56 million, RM73.82 million, RM108.08 million, and RM142.34 million respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM51.09 million, RM86.35 million, RM119.61 million, and RM153.87 million respectively. When the module price is RM1.3/W (US$0.36/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM62.61 million, RM96.87 million, RM131.13 million, and RM165.39 million respectively. Figure 4.11 shows that if the selling price is RM0.40/kWh, the NPV is negative and unacceptable for the project. The selling price must exceed RM0.40/kWh for the module price RM1.80/W, when the selling prices are RM0.45/kWh, RM0.50

/kWh and RM 0.55/kWh, the NPVs are positive. For rest of the selling prices, the project will be profitable for all the above mention module prices.

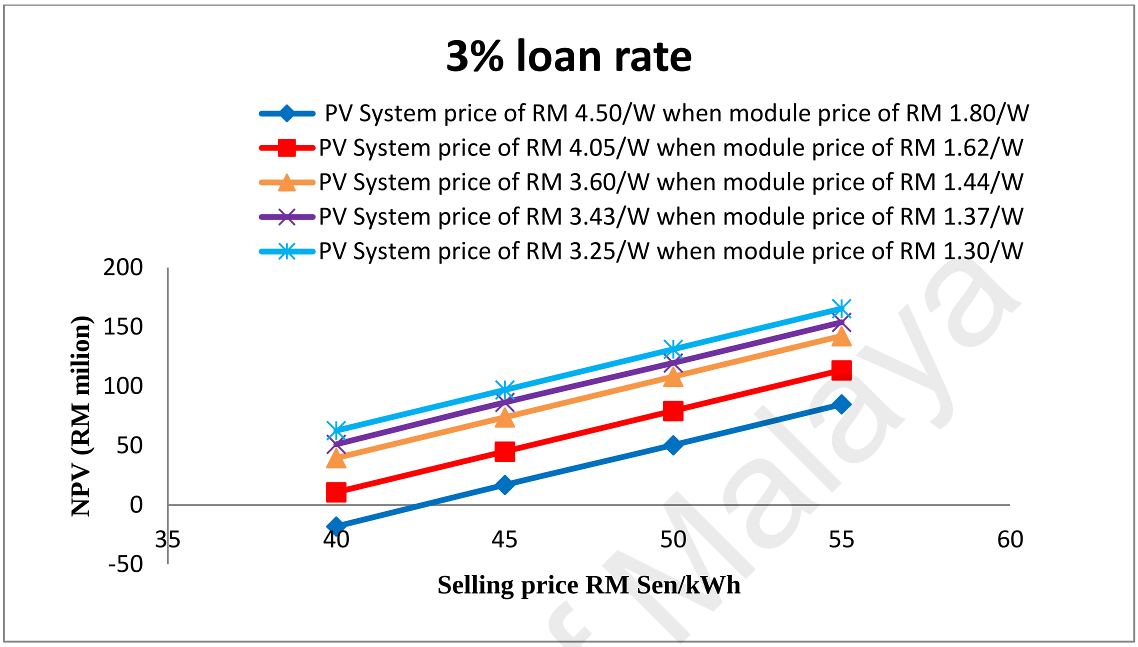

Figure 4.11: Relation between selling price and NPV (When 50% loan with 3% interest)

(h) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 50% bank loan with 3% interest and Loan Tenure15 years, the IRRs are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 1.6%, 4.2%, 6.6%, and 8.8% respectively. When the module price is RM1.62/W (US$0.45/W) and with the above mention condition, the IRRs are 3.9%, 6.5%, 9.0%, and 11.4% respectively. When the module price is RM1.44/W (US$0.40/W) and with the above mention condition, the IRRs are 6.5%, 9.3%, 11.9%, and 14.4% respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 7.7%, 10.5%, 13.2%, and 15.7% respectively. When the module price is RM1.30/W (US$0.36/W) and with the above mention condition, the IRRs are 8.9%, 11.8%, 14.6%, and 17.2% respectively. Figure 4.12 shows that when the selling price is RM0.40/kWh, the IRR is lower than the 3% loan interest. This price is unprofitable for the project, so it must exceed RM0.40/kWh for module price RM1.80/W. When the selling prices are RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRR is higher than the 3% loan interest. The selling prices of RM0.45/kWh, RM0.50/kWh and RM0.55 /kWh are thus acceptable for module price RM1.80/W, whereas all the selling prices are acceptable for module pieces are RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W). When the selling price is high, the IRR is also high, and vice-versa.

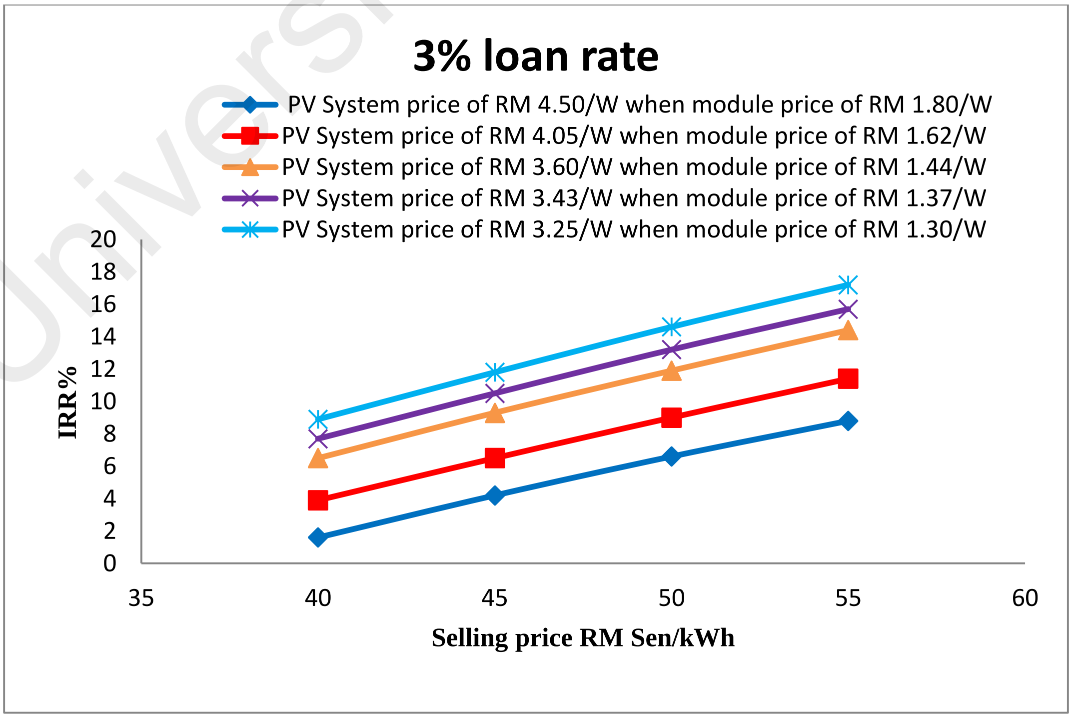

Figure 4.12: Selling price versus IRR% (50% loan with 3% interest)

(i) When the module prices RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 50% bank loan with 3% interest and Loan Tenure15 years, the payback periods are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 19.7 years, 16.9 years, 12.3 years, and 10.5 years, respectively. When the module price is RM1.62/W (US$0.45/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 17.2 years, 12.3 years, 10.4 years, and 9.0 years, respectively. When the module price is RM1.44/W (US$0.40/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 12.34 years, 10.2 years, 8.7 years, and 6.2 years, respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 11.4 years, 9.5 years, 6.6 years, and 5.8 years, respectively. When the module price is RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 10.5 years, 8.8 years, 6.2 years and 5.4 years, respectively. Figure 4.13 shows that for all the selling prices, the payback periods are acceptable because they stay within lifetimes 21 years.

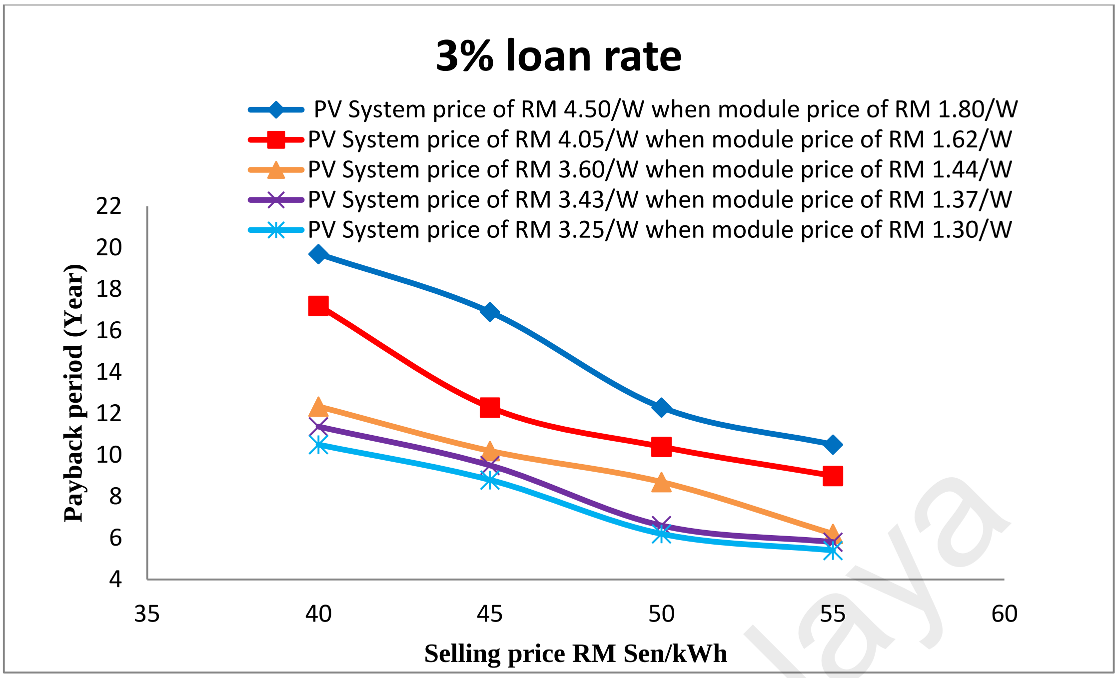

Figure 4.13: Selling price versus payback period (When 50% loan with 3% interest)

(j) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 50% bank loan with 4% interest and Loan Tenure15 years, the NPVs are as follows:

When the module price is RM1.80/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM-34.02 million, RM2.79million, RM28.45 million, and RM59.68 million respectively. When the module price is RM1.62/W (US$0.45/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the NPVs are RM6.03 million, RM25.21 million, RM56.40 million, and RM 87.68 million respectively. When the module price is RM1.44/W (US$0.40/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the NPVs are RM21.97 million, RM53.20 million, RM84.40 million, and RM115.70

million respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM33.16 million, RM64.40 million, RM95.63 million, and RM126.87 million respectively. When the module price is RM1.3/W (US$0.36/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM44.36 million, RM75.60 million, RM106.83 million, and RM138.06 million respectively. Figure 4.14 shows that if the selling price is RM0.40/kWh, the NPV is negative and unacceptable for the project. The selling price must exceed RM0.40/kWh the module price RM1.80/W, when the selling prices are RM0.45/kWh, RM0.50 /kWh and RM 0.55/kWh, the NPVs are positive. For these selling prices, the project will be profitable for all the above mention module prices.

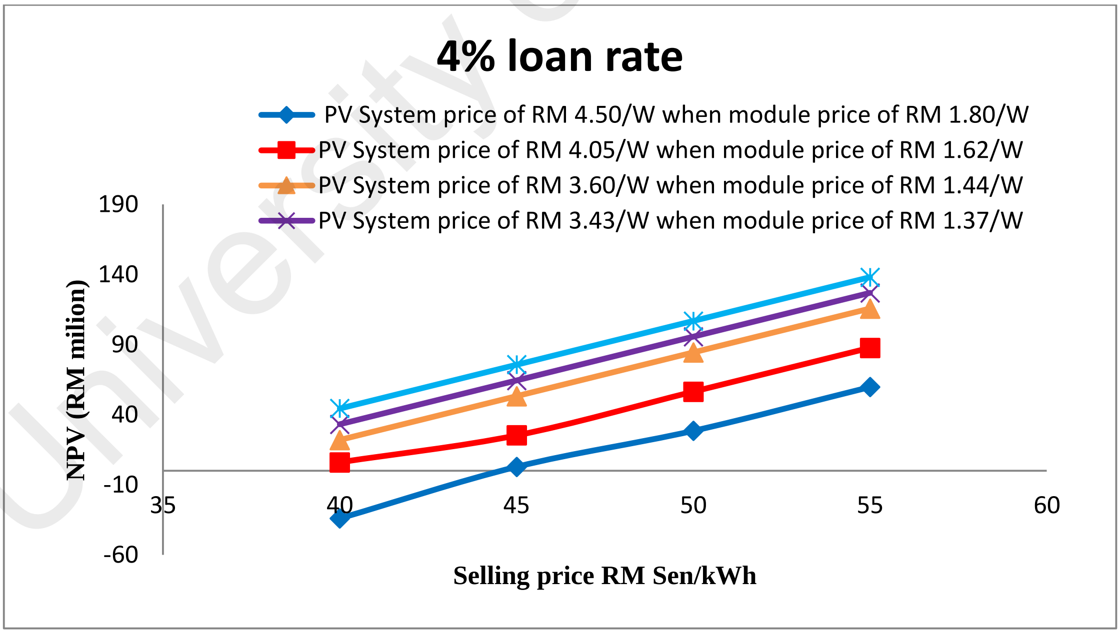

Figure 4.14: Relation between selling price and NPV (50% loan with 4% interest)

(k) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 50% bank loan with 4% interest and Loan Tenure15 years, the IRRs are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 1.2%, 3.8%, 6.2%, and 8.4% respectively. When the module price is RM1.62/W (US$0.45/W) and with the above mention condition, the IRRs are 3.5%, 6.1%, 8.6%, and 11.0% respectively. When the module price is RM1.44/W (US$0.40/W) and with the above mention condition, the IRRs are 6.1%, 8.9%, 11.5%, and 14.0% respectively.

When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 7.3%, 10.1%, 12.8%, and 15.4% respectively. When the module price is RM1.30/W (US$0.36/W) and with the above mention condition, the IRRs are 8.5%, 11.4%, 14.2%, and 16.9% respectively. Figure 4.15 shows that when the selling prices are RM0.40/kWh and RM0.45/kWh, the IRRs are lower than the 4% loan interest. These prices are unprofitable for the project, so these must exceed RM0.45/kWh for module price RM1.80/W and RM0.40/kWh for module price RM1.62/W. When the selling prices are RM0.50/kWh and RM0.55/kWh, the IRR is higher than the 4% loan interest. The selling prices of RM0.50/kWh and RM0.55 /kWh are thus acceptable for module price RM1.80/W, whereas all the selling prices are acceptable for module pieces are RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W). When the selling price is high, the IRR is also high, and vice-versa.

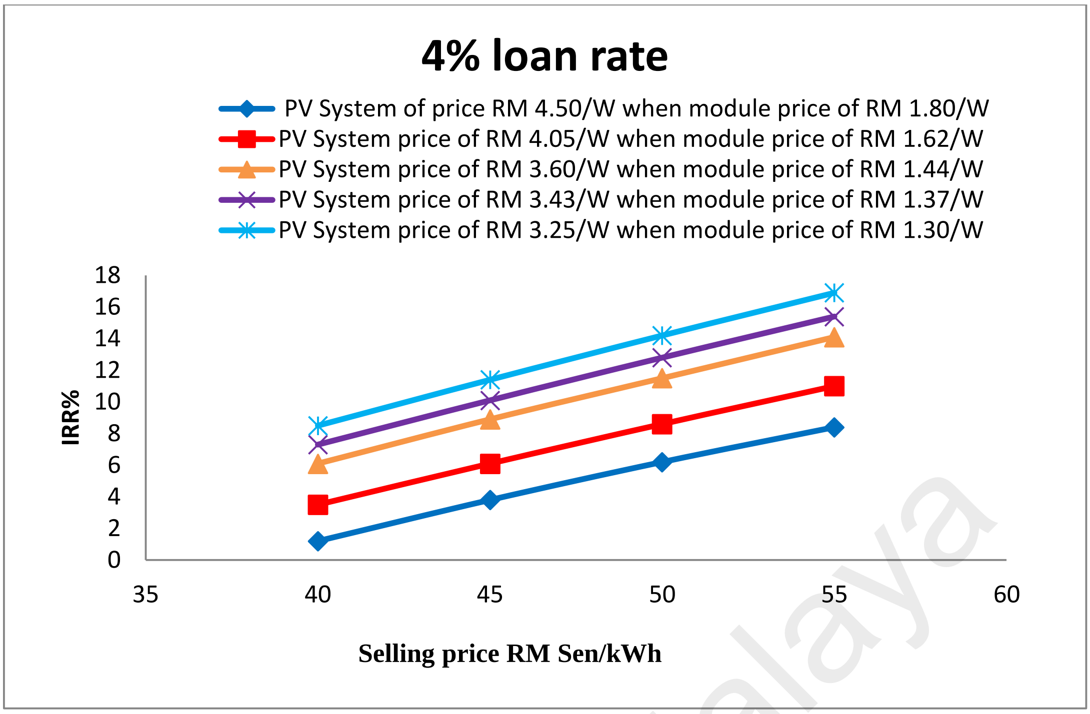

Figure 4.15: Selling price versus IRR% (50% loan with 4% interest)

(I) When the module prices RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 50% bank loan with 4% interest and Loan Tenure15 years, the payback periods are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 20.2 years, 17.3 years, 12.7 years, and 10.8 years, respectively. When the module price is RM1.62/W (US$0.45/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 17.6 years, 12.7 years, 10.7 years, and 9.2 years, respectively. When the module price is RM1.44/W (US$0.40/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 12.8 years, 10.5 years, 9.0

years, and 6.3 years, respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 11.7 years, 9.7 years, 6.7 years, and 5.9 years, respectively. When the module price is RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 10.8 years, 9.0 years, 6.3 years and 5.5 years, respectively. Figure 4.16 shows that for all the selling prices, the payback periods are acceptable because they stay within lifetimes 21 years.

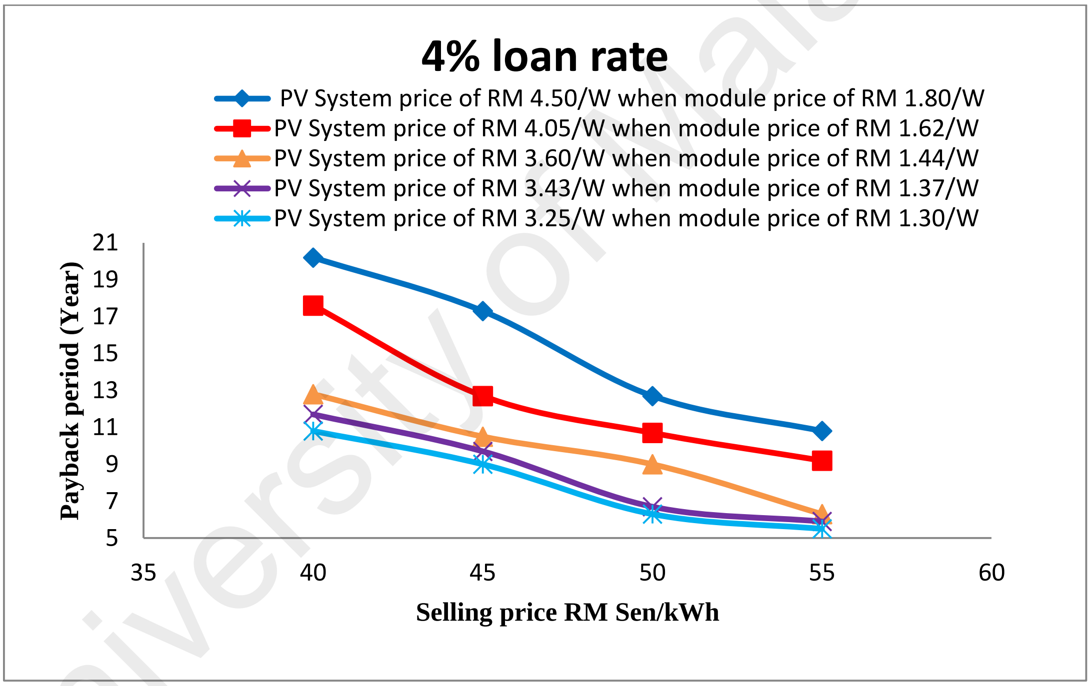

Figure 4.16: Selling price versus payback period (50% loan with 4% interest)

(m) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 50% bank loan with 5% interest and Loan Tenure15 years, the NPVs are as follows:

When the module price is RM1.80/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM-47.11 million, RM-18.51 million, RM10.08 million, and RM38.67 million respectively. When the module price is RM1.62/W (US$0.45/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the NPVs are RM-19.91 million, RM8.68 million, RM37.28 million, and RM65.87 million respectively. When the module price is RM1.44/W (US$0.40/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the NPVs are RM7.29 million, RM35.88 million, RM64.47 million, and RM93.06 million respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM18.17 million, RM46.76 million, RM75.35 million, and RM103.94 million respectively. When the module price is RM1.3/W (US$0.36/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM29.04 million, RM57.64 million, RM86.23 million, and RM114.82 million respectively. Figure 4.17 shows when the selling prices are RM0.40/kWh and RM0.45/kWh, the NPVs are negative and unacceptable for the project. These prices are unprofitable for the project, so these must exceed RM0.45/kWh for module price RM1.80/Wand RM0.40/kWh for module price RM1.62/W. The selling prices of RM0.50/kWh and RM0.55 /kWh are thus acceptable for module price RM1.80/W, whereas all the selling prices are acceptable for module pieces are RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W). When the selling price is high, the IRR is also high, and vice-versa.

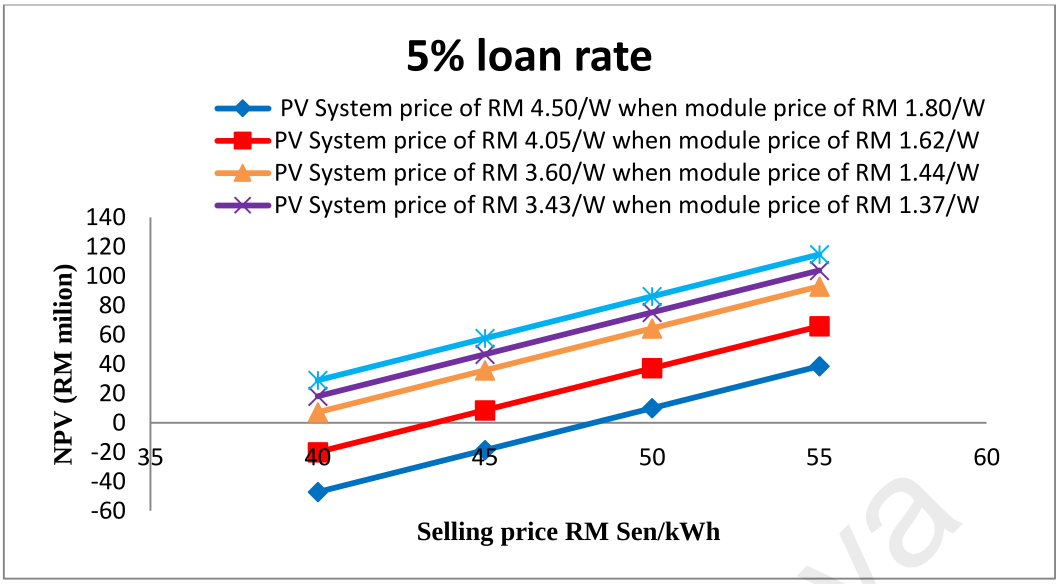

Figure 4.17: Relation between selling price and NPV (50% loan with 5% interest)

(n) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 50% bank loan with 5% interest and Loan Tenure15 years, the IRRs are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 0.8%, 3.4%, 5.8%, and 8.1% respectively. When the module price is RM1.62/W (US$0.45/W) and with the above mention condition, the IRRs are 3.1%, 5.8%, 8.3%, and 10.6% respectively. When the module price is RM1.44/W (US$0.40/W) and with the above mention condition, the IRRs are 5.7%, 8.5%, 11.1%, and 13.7% respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 6.9%, 9.8%, 12.5%, and 15.0% respectively. When the module price is RM1.30/W (US$0.36/W) and with the above mention condition, the IRRs are 8.2%, 11.1%, 13.9%, and 16.5% respectively. Figure 4.18 shows that when the selling prices are RM0.40/kWh and RM0.45/kWh, the IRRs are lower than the 5% loan interest. This price is unprofitable for the project, so it must exceed RM0.45/kWh for module price RM1.80/Wand RM0.40/kWh for module price RM1.62W. When the selling prices are RM0.50/kWh and RM0.55/kWh, the IRR are higher than the 5% loan interest. The selling prices of RM0.50/kWh and RM0.55 /kWh are thus acceptable for module price RM1.80/Wand The selling prices of RM 0.45/kWh RM0.50/kWh and RM0.55 /kWh are thus acceptable for module price RM1.62/W, whereas other all the selling prices are acceptable for module pieces are RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W). When the selling price is high, the IRR is also high, and vice-versa.

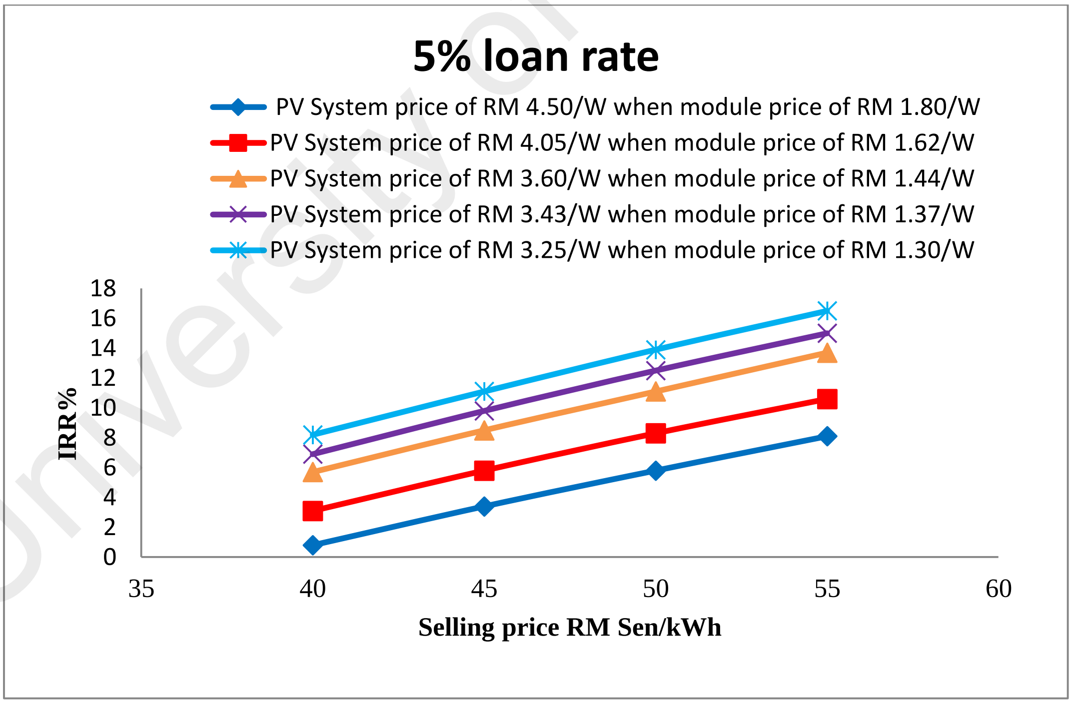

Figure 4.18: Selling price versus IRR% (50% loan with 5% interest)

(o) When the module prices RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 50% bank loan with 5% interest and Loan Tenure15 years, the payback periods are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 20.6 years, 17.7 years, 13.1 years, and 11.1 years, respectively. When the module price is RM1.62/W (US$0.45/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 18.1 years, 13.2 years, 11.0 years, and 9.5 years, respectively. When the module price is RM1.44/W (US$0.40/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 13.2 years, 10.8 years, 9.2 years, and 6.5 years, respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 12.1 years, 10.0 years, 6.9 years, and 6.0 years, respectively. When the module price is RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 11.1 years, 9.2 years, 6.4 years and 5.6 years, respectively. Figure 4.19 shows that all the selling prices are acceptable for all the above mention module pieces because they stay within lifetime 21 years.

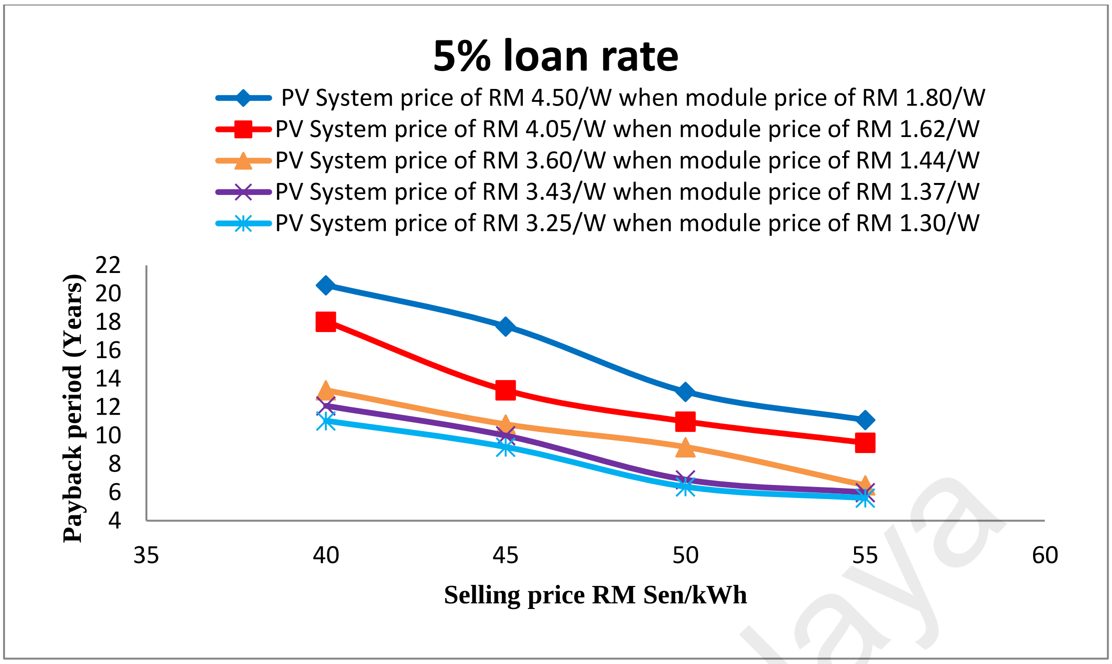

Figure 4.19: Selling price versus payback period (50% loan with 5% interest)

4.2.2.3 NPV, IRR%, PBP and LCOE of 30 MW PV plant when 100% bank loan with different interest and different selling prices

(a) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 100% bank loan with 1% interest and Loan Tenure15 years, the NPVs are as follows:

When the module price is RM1.80/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM-49.92 million, RM-8.16 million, RM33.60 million, and RM75.36 million respectively. When the module price is RM1.62/W (US$0.45/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the NPVs are RM-11.95 million, RM29.81 million, RM71.58 million, and RM113.34 million respectively. When the module price is RM1.44/W

(US$0.40/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the NPVs are RM26.03 million, RM67.79 million, RM109.55 million, and RM151.31 million respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM41.22 million, RM83.00 million, RM124.74 million, and RM166.30 million respectively. When the module price is RM1.30/W (US$0.36/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM56.41 million, RM98.17 million, RM139.93 million, and RM81.70 million respectively. Figure 4.20 shows that when the selling prices are RM0.40/kWh and RM0.45/kWh, the NPVs are negative and unacceptable for the project. The selling price must exceed RM0.45/kWh for the module price RM1.80/Wand RM0.40/kWh for module price RM1.62/W, when the selling prices are RM0.50 /kWh and RM 0.55/kWh, the NPVs are positive for module price RM1.80/W. For all the selling prices the project will be profitable, when the module prices are RM1.44/W, RM1.37/Wand RM1.30/W.

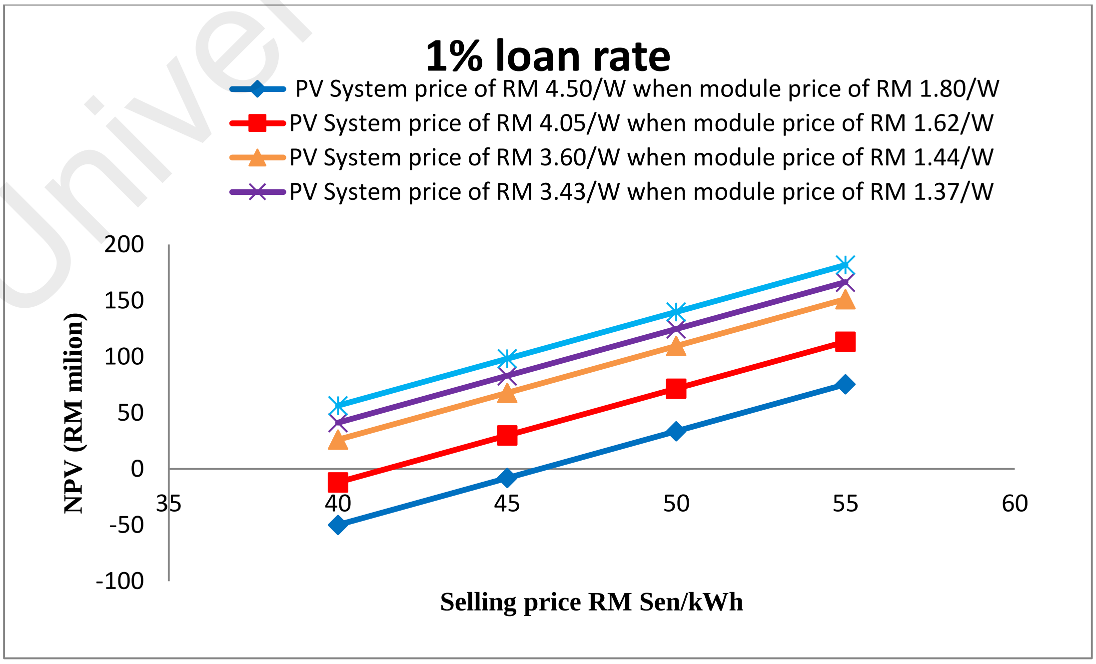

Figure 4.20: Selling price and NPV (100% loan with 1% interest)

(b) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 100% bank loan with 1% interest and Loan Tenure15 years, the IRRs are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are -2.2%, 0.5%, 3.0%, and 5.3% respectively. When the module price is RM1.62/W (US$0.45/W) and with the above mention condition, the IRRs are 0.2%, 2.9%, 5.5%, and 7.9% respectively. When the module price is RM1.44/W (US$0.40/W) and with the above mention condition, the IRRs are 2.9%, 5.8%, 8.4%, and 11.0% respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 4.1%, 7.0%, 9.8%, and 12.4% respectively. When the module price is RM1.30/W (US$0.36/W) and with the above mention condition, the IRRs are 5.4%, 8.4%, 11.2%, and 13.9% respectively. Figure 4.21 shows that when the selling prices are RM0.40/kWh and RM0.45/kWh, the IRR is lower than the 1% loan interest. This prices are unprofitable for the project, so it must exceed RM0.45/kWh for module price RM1.80/W. When the selling prices are RM0.50/kWh and RM0.55/kWh, the IRR is higher than the loan interest (1%). The selling prices of RM0.50/kWh and RM0.55 /kWh are thus acceptable for module price RM1.80/W, whereas all the selling prices are acceptable for module pieces are RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W). When the selling price is high, the IRR is also high, and vice-versa.

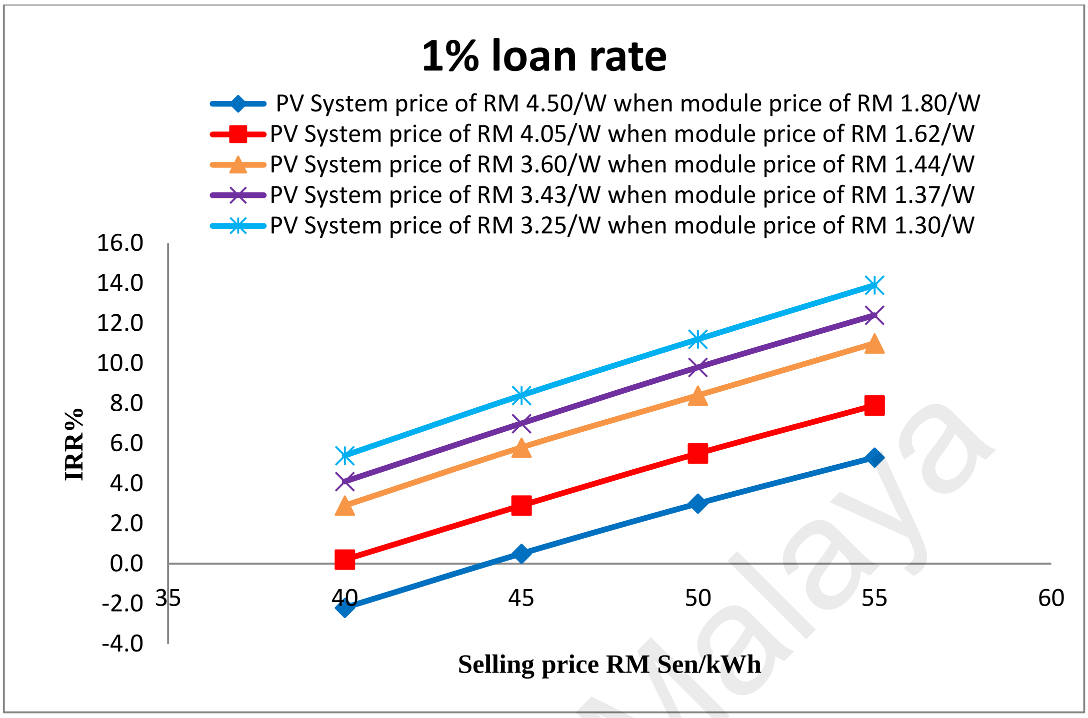

Figure 4.21: Selling price versus IRR% (100% loan with 1% interest)

(c) When the module prices RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 100% bank loan with 1% interest and Loan Tenure15 years, the payback periods are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh the payback periods are more than21 years, 21.0 years, 18.5 years, and 16.3 years, respectively. When the module price is RM1.62/W (US$0.45/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are more than21 years, 18.4 years, 16.2 years, and 11.6 years, respectively. When the module price is RM1.44/W (US$0.40/W) and the electricity selling prices are

RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 18.4 years, 13.8 years, 11.2 years, and 9.4 years, respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 17.3 years, 12.5 years, 10.2 years, and 7.0 years, respectively. When the module price is RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 16.2 years, 11.2 years, 9.3 years and 6.4 years, respectively. Figure 4.22 when the selling prices are RM0.40/kWh and RM0.45/kWh, the payback periods are higher than lifetime 21 years. This price is unprofitable for the project, so it must exceed RM0.45/kWh for module price RM1.80/W and RM0.45/kWh for module price RM1.62W. When the selling prices are RM0.50/kWh and RM0.55/kWh, the payback periods are within lifetime. The selling prices of RM0.50/kWh and RM0.55 /kWh are thus acceptable for module price RM1.80/W and The selling prices of RM RM0.50/kWh, RM0.45/kWh and RM0.55 /kWh are thus acceptable for module price RM1.62/W, whereas all the selling prices are acceptable for module pieces are RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W).

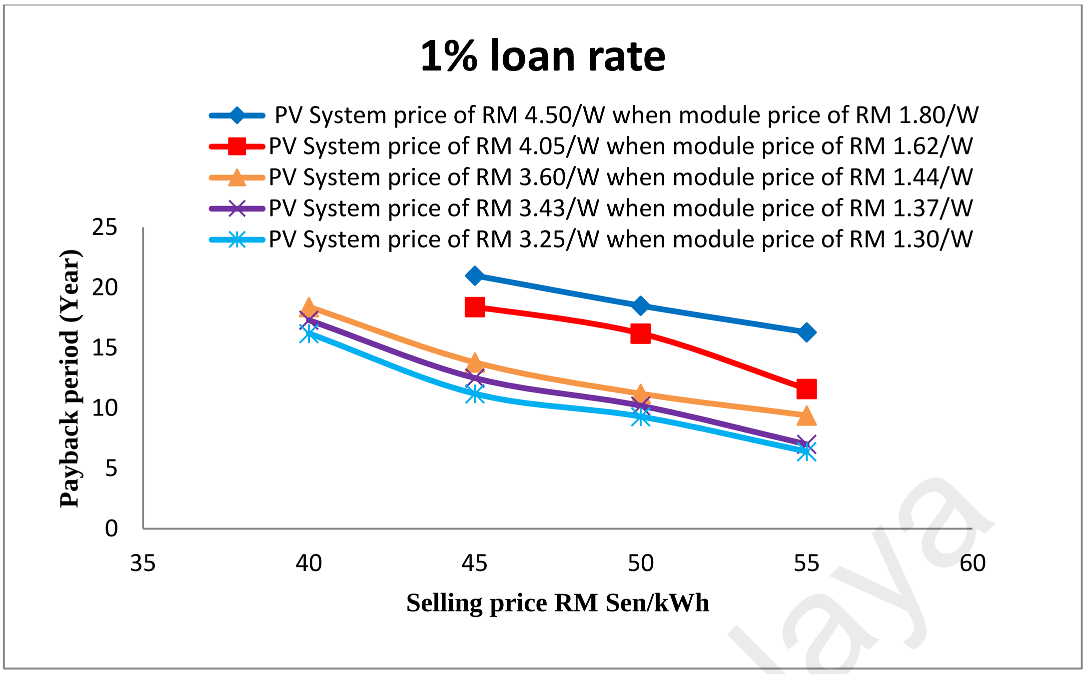

Figure 4.22: Selling price versus payback period (100% loan with 1% interest)

(d) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 100% bank loan with 2% interest and Loan Tenure15 years, the NPVs are as follows:

When the module price is RM1.80/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM-67.15 million, RM-29.41million, RM8.33 million, and RM46.07 million respectively. When the module price is RM1.62/W (US$0.45/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the NPVs are RM-30.66 million, RM7.08 million, RM44.82 million, and RM82.56 million respectively. When the module price is RM1.44/W (US$0.40/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the NPVs are RM5.83 million, RM43.57 million, RM81.31 million, and RM119.06 million respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM20.43 million, RM58.17 million, RM95.91 million, and RM133.65 million respectively. When the module price is RM1.3/W (US$0.36/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM35.03 million, RM72.77 million, RM110.51 million, and RM148.25 million respectively. Figure 4.23 shows when the selling prices are RM0.40/kWh and RM0.45/kWh, the NPVs are negative and unacceptable for the project. The selling price must exceed RM0.45/kWh the module price RM1.80/Wand RM0.40/kWh for module price RM1.62/W, when the selling prices are RM0.50/kWh and RM 0.55/kWh, the NPV is positive for module price RM1.80/W. For all the selling prices the project will be profitable, when the module prices are RM1.44/W, RM1.37/W and RM1.3/W.

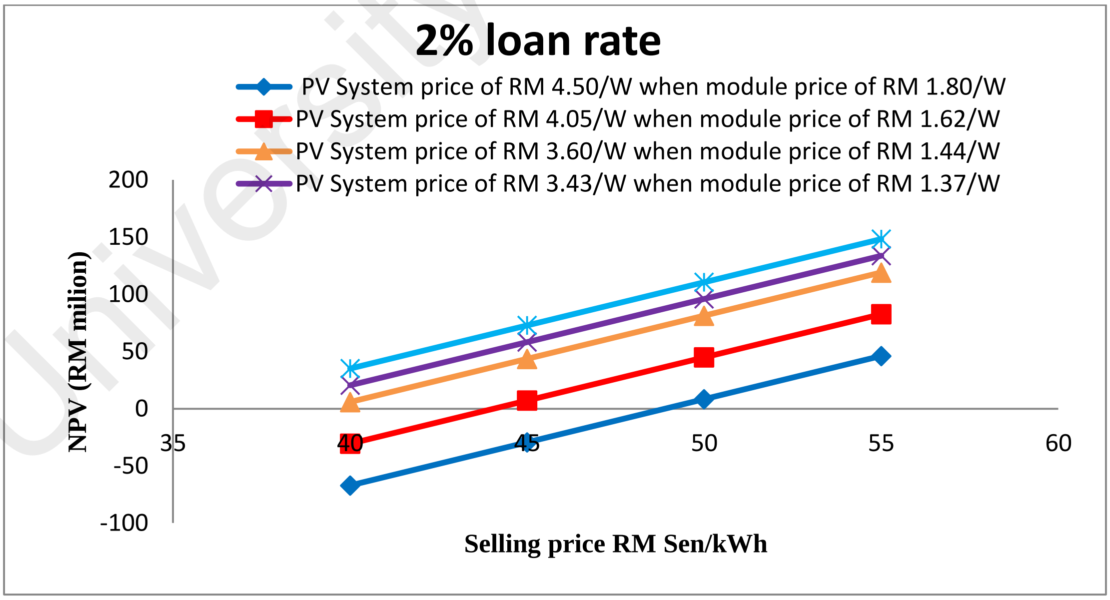

Figure 4.23: Selling price versus NPV (100% bank loan with 2% interest)

(e) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 100% bank loan with 2% interest and Loan Tenure15 years, the IRRs are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are -2.7%, 0.0%, 2.5%, and 4.8% respectively. When the module price is RM1.62/W (US$0.45/W) and with the above mention condition, the IRRs are -0.3%, 2.5%, 5.1%, and 7.5% respectively. When the module price is RM1.44/W (US$0.40/W) and with the above mention condition, the IRRs are 2.5%, 5.3%, 8.0%, and 10.5% respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 3.7%, 6.6%, 9.3%, and 12.0% respectively. When the module price is RM1.30/W (US$0.36/W) and with the above mention condition, the IRRs are 5.0%, 8.0%, 10.8%, and 13.5% respectively. Figure 4.24 shows that when the selling prices are RM0.40/kWh and RM0.45/kWh, the IRR are lower than the 2% loan interest. This price is unprofitable for the project, so it must exceed RM0.45/kWh for module price RM1.80/W. When the selling prices are RM0.50/kWh and RM0.55/kWh, the IRR is higher than the loan interest (2%). The selling prices of RM0.50/kWh and RM0.55 /kWh are thus acceptable for module price RM1.80/W, whereas all the selling prices are acceptable for module pieces are RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W). When the selling price is high, the IRR is also high, and vice-versa.

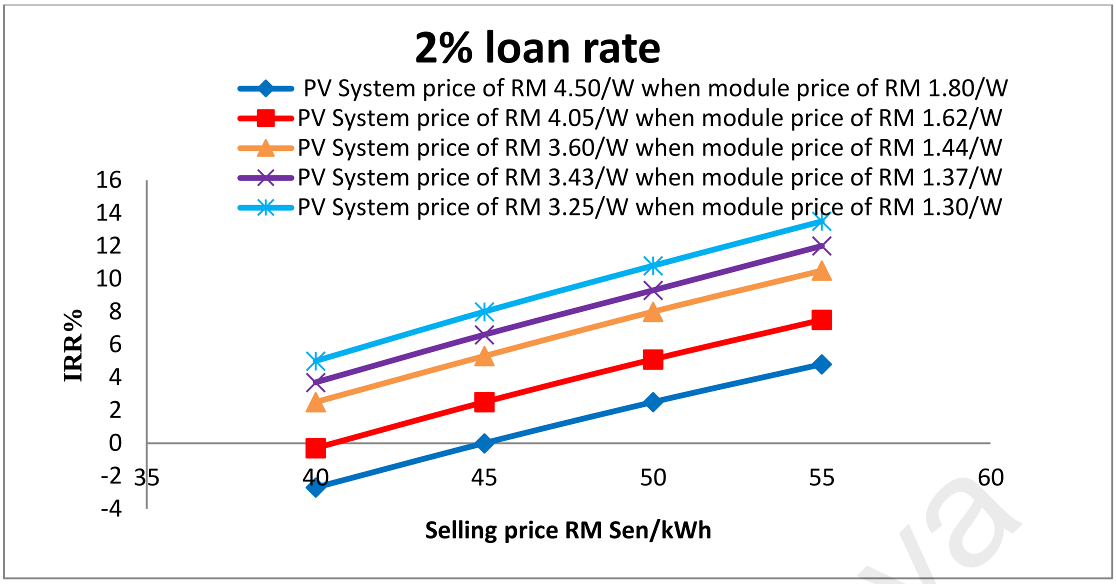

Figure 4.24: Selling price versus IRR% (100% loan with 2% interest)

(f) When the module prices RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 100% bank loan with 2% interest and Loan Tenure15 years, the payback periods are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh the payback periods are more than 21 years, more than 21 years, 18.8 years, and 16.7 years, respectively. When the module price is RM1.62/W (US$0.45/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are more than 21 years, 18.8 years, 16.6 years, and 12.1 years, respectively. When the module price is RM1.44/W (US$0.40/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 18.9 years, 16.3 years, 11.6 years, and 9.7 years, respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 17.7 years, 13.0 years, 10.6 years, and 8.9 years, respectively. When the module price is RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 16.6 years, 11.7 years, 9.6 years and 6.8 years, respectively. Figure 4.25 shows that when the selling prices are RM0.40/kWh and RM0.45/kWh, the payback periods are higher than lifetime. These prices are unprofitable for the project, so it must exceed RM0.45/kWh for module price RM1.80/Wand RM0.45/kWh for module price RM1.62W. When the selling prices are RM0.50/kWh and RM0.55/kWh, the payback periods are within lifetime. The selling prices of RM0.50/kWh and RM0.55 /kWh are thus acceptable for module price RM1.80/W and The selling prices of RM RM0.45/kWh, RM0.50/kWh and RM0.55 /kWh are thus acceptable for module price RM1.62/W, whereas all the selling prices are acceptable for module pieces are RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W).

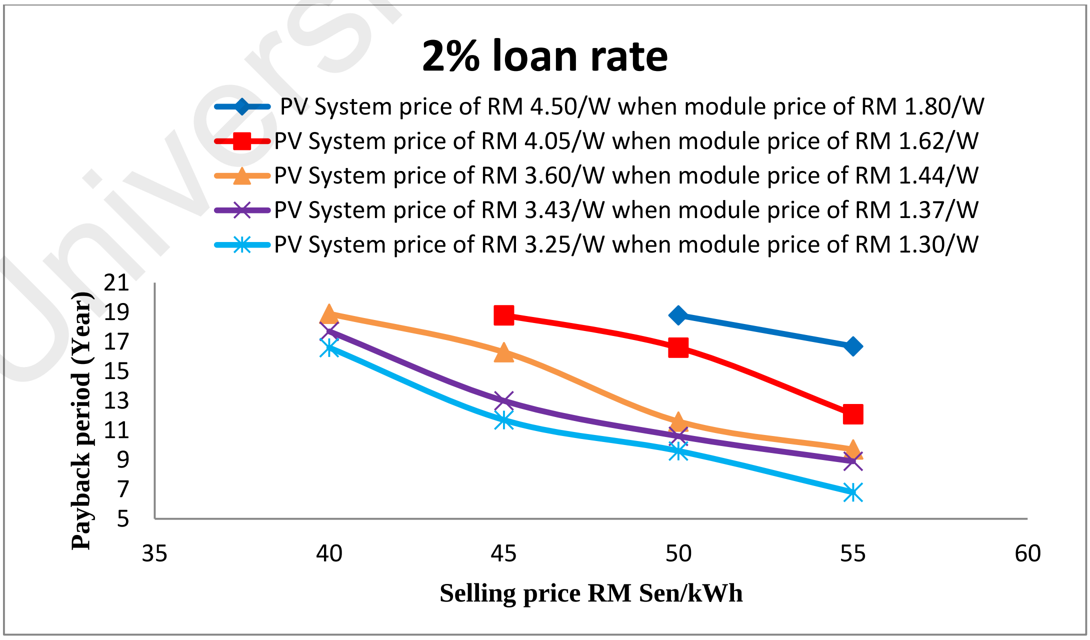

Figure 4.25: Selling price versus payback period (100% bank loan with 2% interest)

(g) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 100% bank loan with 3% interest and Loan Tenure15 years, the NPVs are as follows:

When the module price is RM1.80/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM-84.94 million, RM-50.68 million, RM-16.42 million, and RM17.84 million respectively. When the module price is RM1.62/W (US$0.45/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the NPVs are RM-49.44 million, RM-15.18 million, RM19.08 million, and RM53.34 million respectively. When the module price is RM1.44/W (US$0.40/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the NPVs are RM-13.94 million, RM20.32 million, RM54.58 million, and RM88.84 million respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM0.25 million, RM34.52 million, RM68.78 million, and RM103.03 million respectively. When the module price is RM1.3/W (US$0.36/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM14.45 million, RM48.71 million, RM82.98 million, and RM117.24 million respectively. Figure 4.26 shows that when the selling prices are RM0.40/kWh RM0.45/kWh and RM0.50/kWh, the NPVs are negative and unacceptable for the project. The selling price must exceed RM0.50/kWh for the module price RM1.80/Wand RM0.45/kWh for module price RM1.62/W, when the selling price is RM 0.55/kWh, the NPV is positive for module price RM1.80/W. For all the selling prices the project will be profitable, when the module prices are RM1.37/W and RM1.30/W.

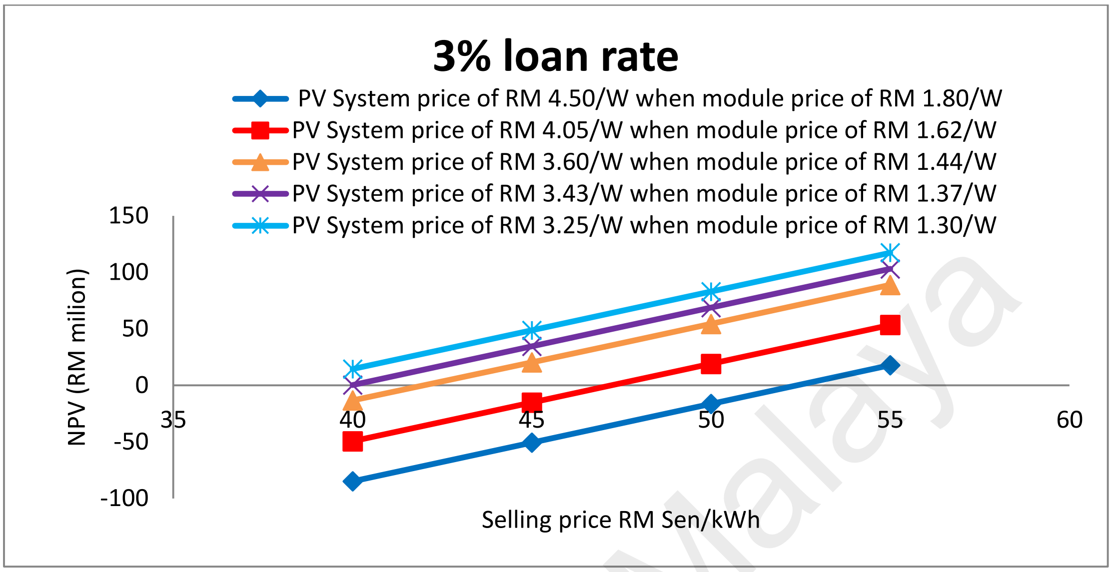

Figure 4.26: Selling price versus NPV (100% loan with 3% interest)

(h) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 100% bank loan with 3% interest and Loan Tenure15 years, the IRRs are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are -3.4%, -0.6%, 1.9%, and 4.2% respectively. When the module price is RM1.62/W (US$0.45/W) and with the above mention condition, the IRRs are -1.0%, 1.8%, 4.4%, and 6.8% respectively. When the module price is RM1.44/W (US$0.40/W) and with the above mention condition, the IRRs are 1.8%, 4.7%, 7.4%, and 9.9% respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are

RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 3.0%, 5.9%, 8.7%, and 11.3% respectively. When the module price is RM1.30/W (US$0.36/W) and with the above mention condition, the IRRs are 4.3%, 7.3%, 10.1%, and 12.9% respectively. Figure 4.27 shows that when the selling prices are RM0.40/kWh RM0.45/kWh and RM0.50/kWh, the IRR are lower than the 3% loan interest. These prices are unprofitable for the project, so it must exceed RM0.50/kWh for module price RM1.80/W. When the selling price is RM0.55/kWh, the IRR is higher than the loan interest (3%). The selling price of RM0.55/kWh is thus acceptable for module price RM1.80/W, whereas all the selling prices are acceptable for module pieces are RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W). When the selling price is high, the IRR is also high, and vice-versa.

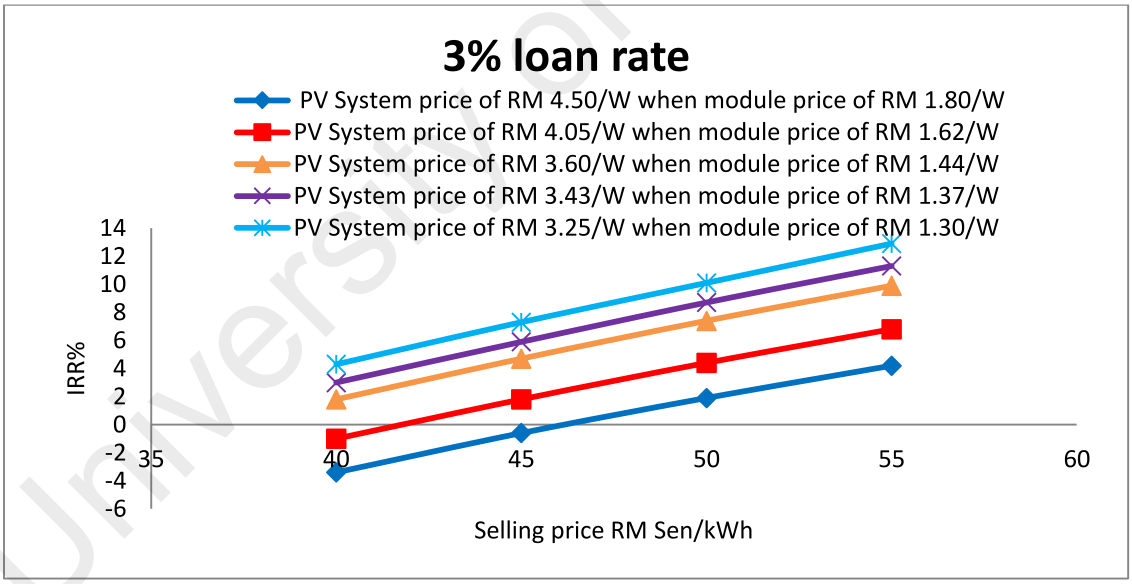

Figure 4.27: Selling price versus IRR% (100% loan with 3% interest)

(i) When the module prices RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 100% bank loan with 3% interest and Loan Tenure15 years, the payback periods are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh the payback periods are more than 21 years, more than 21 years, 19.5 years, and 17.3 years, respectively. When the module price is RM1.62/W (US$0.45/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are more than 21 years, 19.5 years, 17.1 years, and 12.9 years, respectively. When the module price is RM1.44/W (US$0.40/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 18.4 years, 13.9 years, 11.1 years, and 9.3 years, respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 17.2 years, 12.3 years, 10.0 years, and 6.8 years, respectively. When the module price is RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 10.5 years, 8.8 years, 6.2 years and 5.4 years, respectively. Figure 4.28 shows when the selling prices are RM0.40/kWh and RM0.45/kWh, the payback periods are higher than lifetime (21 years). These prices are unprofitable for the project, so it must exceed RM0.45/kWh for module price RM1.80/Wand RM0.45/kWh for module price RM1.62W. When the selling prices are RM0.50/kWh and RM0.55/kWh, the payback periods are within lifetime. The selling prices of RM0.50/kWh and RM0.55 /kWh are thus acceptable for module price RM1.80/W and The selling prices of RM RM0.45/kWh, RM0.50/kWh and RM0.55/kWh are thus acceptable for module price RM1.62/W, whereas all the selling prices are acceptable for module pieces are RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W).

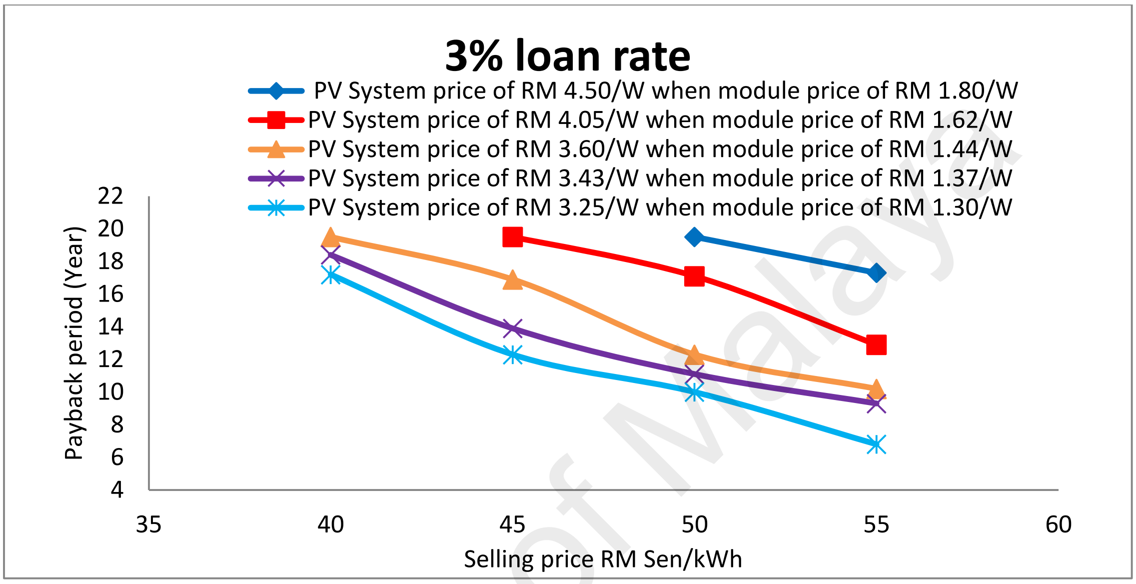

Figure 4.28: Selling price versus payback period (100% loan with 3% interest)

(j) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 100% bank loan with 4% interest and Loan Tenure15 years, the NPVs are as follows:

When the module price is RM1.80/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM-101.56 million, RM-70.33 million, RM-39.10 million, and RM-7.86 million respectively. When the module price is RM1.62/W (US$0.45/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and

RM0.55/kWh, the NPVs are RM-66.82 million, RM-35.58 million, RM-4.34 million, and RM26.88 million respectively. When the module price is RM1.44/W (US$0.40/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the NPVs are RM-32.07 million, RM0.83 million, RM30.40 million, and RM61.63 million respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM-18.17 million, RM13.06 million, RM44.30 million, and RM75.53 million respectively. When the module price is RM1.30/W (US$0.36/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM4.27 million, RM26.96 million, RM58.20 million, and RM89.43 million respectively. Figure 4.29 shows that when the module price is RM1.80/W, the NPV is negative for the entire selling prices. When the selling prices are RM0.40/kWh RM0.45/kWh and RM0.50/kWh, the NPV is negative and unacceptable for the project. The selling price must exceed RM0.50/kWh for the module price RM1.62/W, when the selling price is RM 0.55/kWh, the NPV is positive for module price RM1.62/W. For all the selling prices the project will be profitable, when the module price is RM1.30/W.

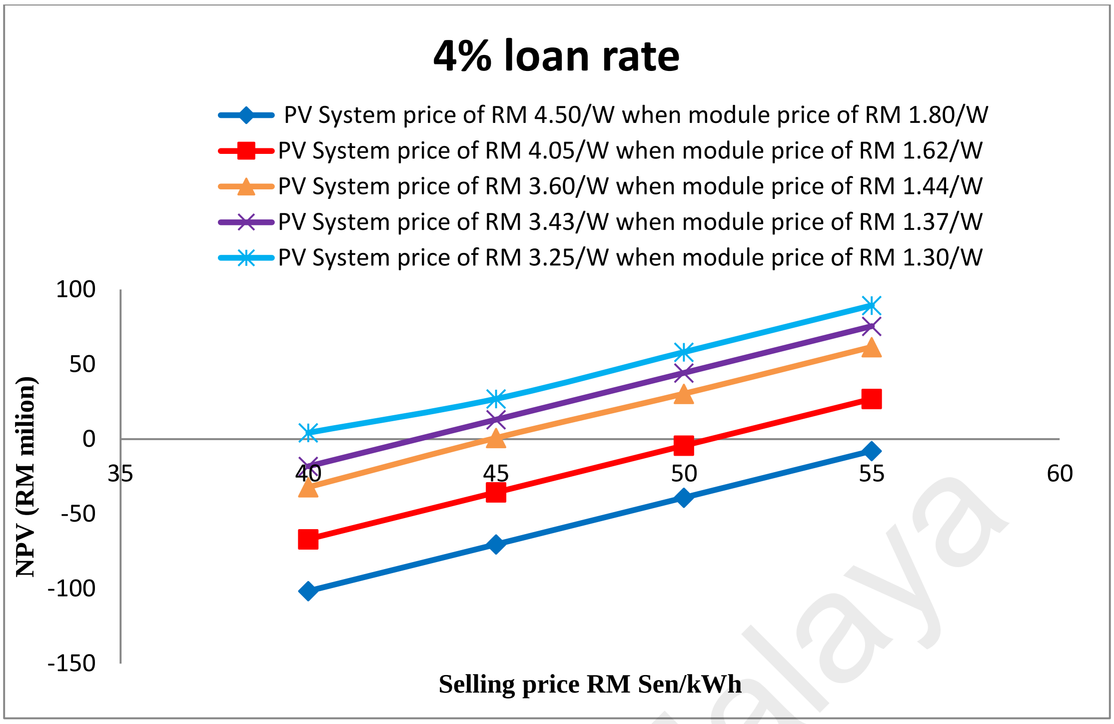

Figure 4.29: Selling price versus NPV (100% loan with 4% interest)

(k) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 100% bank loan with 4% interest and Loan Tenure15 years, the IRRs are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are -4.2%, -1.4%, 1.1%, and 3.4% respectively. When the module price is RM1.62/W (US$0.45/W) and with the above mention condition, the IRRs are -1.7%, 1.1%, 3.7%, and 6.1% respectively. When the module price is RM1.44/W (US$0.40/W) and with the above mention condition, the IRRs are 1.0%, 3.9%, 6.6%, and 9.2% respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 2.3%, 5.2%, 8.0%, and 10.6% respectively. When the module price is RM1.30/W (US$0.36/W) and with the above mention condition, the IRRs are 3.6%, 6.6%, 9.4%, and 12.1% respectively. Figure 4.30 shows that when the module price is RM1.80/W, the IRR is lower than the loan interest (4%) for the entire selling price. When module price RM1.62/Wand selling price is RM0.55/kWh, the IRR is higher than the loan interest (4%). The selling price of RM0.55 /kWh is thus acceptable for module price RM1.62/W, whereas RM0.45/kWh RM0.50/kWh RM0.55/kWh selling prices are acceptable for module pieces are RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W). When the selling price is high, the IRR is also high, and vice-versa.

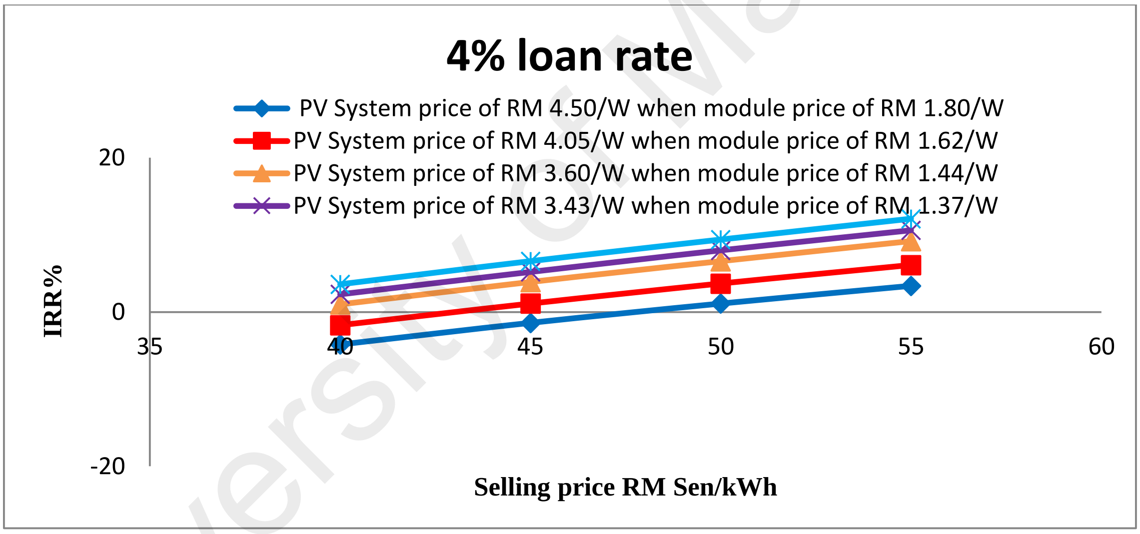

Figure 4.30: Selling price versus IRR% (100% loan with 4% interest)

(l) When the module prices RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 100% bank loan with 4% interest and Loan Tenure15 years, the payback periods are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh the payback periods are more than 21 years, more than 21 years, 20.3 years, and 18.0 years, respectively. When the module price is RM1.62/W (US$0.45/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are more than 21 years, 20.3 years, 17.8 years, and 13.9 years, respectively. When the module price is RM1.44/W (US$0.40/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 20.3 years, 17.6 years, 13.2 years, and 10.8 years, respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 19.1 years, 16.6 years, 11.8 years, and 9.8 years, respectively. When the module price is RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 17.9 years, 13.3 years, 10.6 years and 8.9 years, respectively. Figure 4.31 shows that when the selling prices are RM0.40/kWh and RM0.45/kWh, the payback periods are higher than lifetime (21years). These prices are unprofitable for the project, so it must exceed RM0.45/kWh for module price RM1.80/Wand RM0.45/kWh for module price RM1.62W. When the selling prices are RM0.50/kWh and RM0.55/kWh, the payback periods are within lifetime. The selling prices of RM0.50/kWh and RM0.55 /kWh are thus acceptable for module price RM1.80/W and The selling prices of RM RM0.45/kWh, RM0.50/kWh and RM0.55/kWh are thus acceptable for module price RM1.62/W, whereas all the selling prices are acceptable for module pieces are RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W).

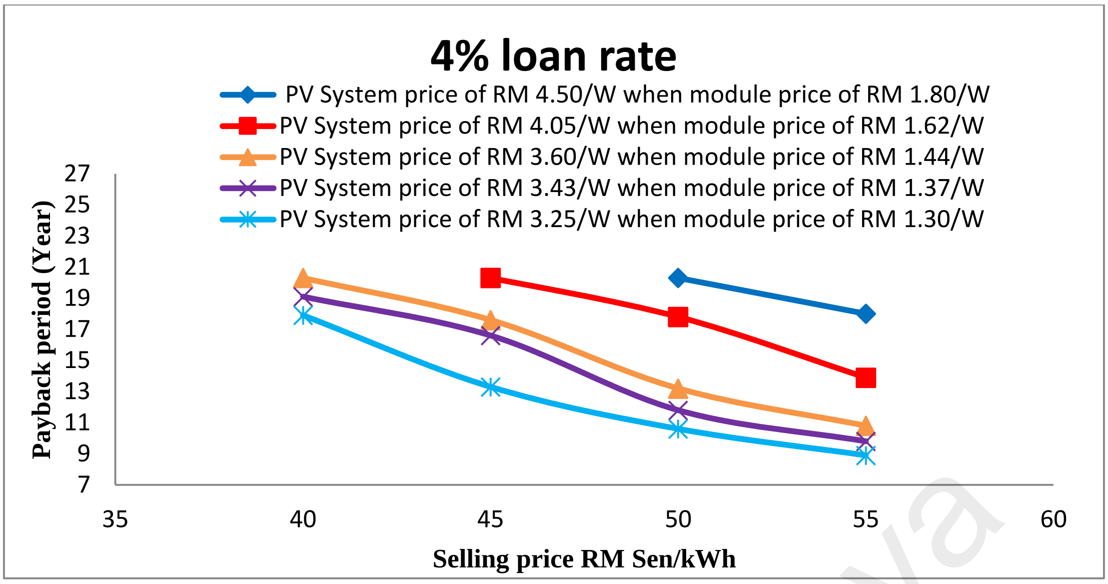

Figure 4.31: Selling price versus payback period (100% loan with 4% interest)

(m) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 100% bank loan with 5% interest and Loan Tenure15 years, the NPVs are as follows:

When the module price is RM1.80/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM-114.37 million, RM-85.77 million, RM-57.18 million, and RM-28.59 million respectively. When the module price is RM1.62/W (US$0.45/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the NPVs are RM-80.44 million, RM-51.85 million, RM-23.26 million, and RM5.33 million respectively. When the module price is RM1.44/W (US$0.40/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the NPVs are RM-46.52 million, RM-17.93 million, RM10.66 million, and RM39.26 million respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM-32.95 million, RM-4.36 million, RM24.23 million, and RM52.83 million respectively. When the module price is RM1.3/W (US$0.36/W), and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the corresponding NPVs are RM-19.38 million, RM9.21 million, RM37.80 million, and RM66.40 million respectively. Figure 4.32 shows that when the module price is RM1.80/W, the NPVs are negative for the entire selling prices. When the selling prices are RM0.40/kWh RM0.45/kWh and RM0.50/kWh for the module price RM1.62/W, the NPV is negative and unacceptable for the project. The selling price must exceed RM0.50/kWh for the module price RM1.62/W, when the selling price is RM 0.55/kWh, the NPV is positive for module price RM1.62/W. When the selling price is more than RM0.40/kWh, the project will be profitable for the module price RM1.30/W.

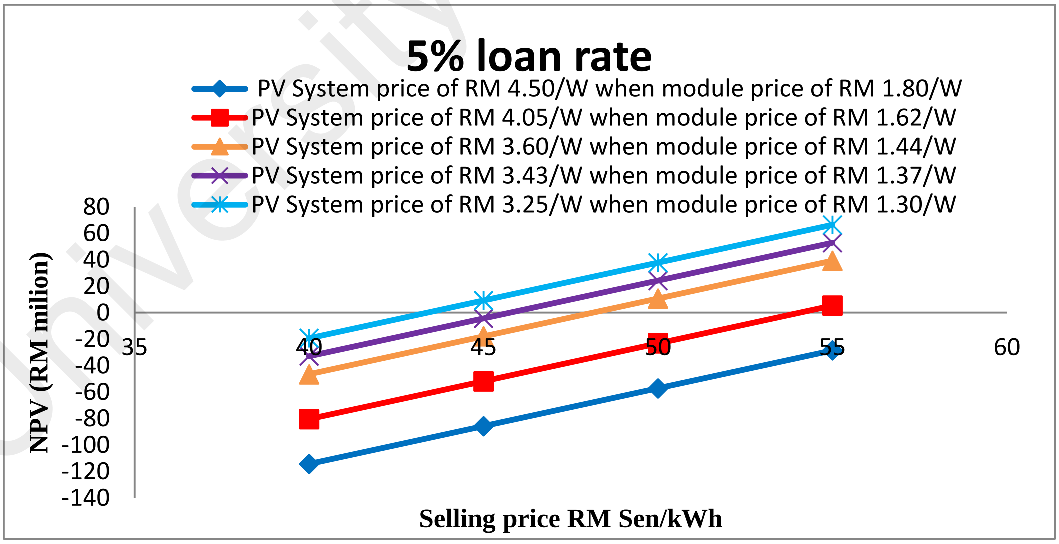

Figure 4.32: Selling price versus NPV (100% loan with 5% interest)

(n) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 100% bank loan with 5% interest and Loan Tenure15 years, the IRRs are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are -4.8%, -2.1%, 0.5%, and 2.8% respectively. When the module price is RM1.62/W (US$0.45/W) and with the above mention condition, the IRRs are -2.4%, 0.4%, 3.0%, and 5.4% respectively. When the module price is RM1.44/W (US$0.40/W) and with the above mention condition, the IRRs are 0.4%, 3.3%, 6.0%, and 8.6% respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the IRRs are 1.6%, 4.6%, 7.3%, and 10.0% respectively. When the module price is RM1.30/W (US$0.36/W) and with the above mention condition, the IRRs are 2.9%, 5.9%, 8.8%, and 11.5% respectively. Figure 4.33 shows that when the module price is RM1.80/W, the IRR is lower than the loan interest (4%) for the entire selling price. When module price RM1.62/Wand selling price is RM0.55/kWh, the IRR is higher than the loan interest (4%). The selling price of RM0.55 /kWh is thus acceptable for module price RM1.62/W, whereas RM0.50/kWh RM0.55/kWh selling prices are acceptable for module pieces are RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W). When the selling price is high, the IRR is also high, and vice-versa.

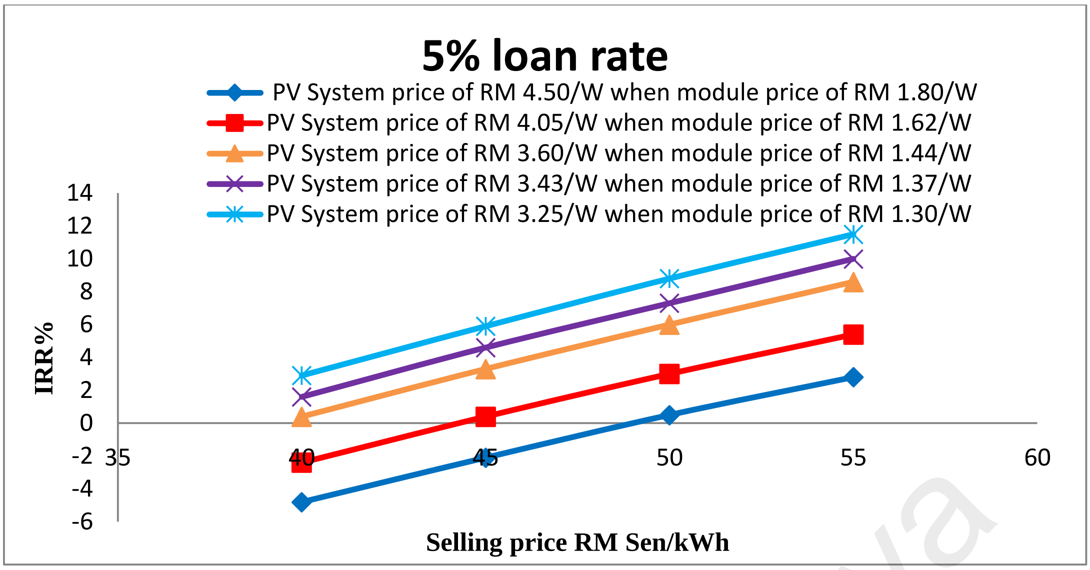

Figure 4.33: Selling price versus IRR% (100% loan with 5% interest)

(o) When the module prices RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, 100% bank loan with 5% interest and Loan Tenure15 years, the payback periods are as follows:

When the module price is RM1.8/W (US$0.50/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh the payback periods are more than 21 years, more than 21 years, 21.0 years, and 18.6 years, respectively. When the module price is RM1.62/W (US$0.45/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are more than 21 years, more than 21 years, 18.4 years, and 16.4 years, respectively. When the module price is RM1.44/W (US$0.40/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are more than 21 years, 18.2 years, 16.0 years, and 11.4 years, respectively. When the module price is RM1.37/W (US$0.38/W) and the electricity selling prices are

RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 19.7 years, 17.1 years, 12.6 years, and 10.3 years, respectively. When the module price is RM1.30/W (US$0.36/W) and the electricity selling prices are RM0.40/kWh, RM0.45/kWh, RM0.50/kWh and RM0.55/kWh, the payback periods are 18.5 years, 16.1 years, 11.2 years and 9.3 years, respectively. Figure 4.34 shows when the selling prices are RM0.40/kWh and RM0.45/kWh, the payback periods are higher than lifetime (21years). These prices are unprofitable for the project, so it must exceed RM0.45/kWh for module price RM1.80/W and RM1.62W. When the selling prices are RM0.50/kWh and RM0.55/kWh, the payback periods are within lifetime. The selling prices of RM0.55 /kWh is thus acceptable for module price RM1.80/Wand The selling prices of RM0.50/kWh and RM0.55/kWh are thus acceptable for module price RM1.62/W, whereas all the selling prices are acceptable for module pieces are RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W).

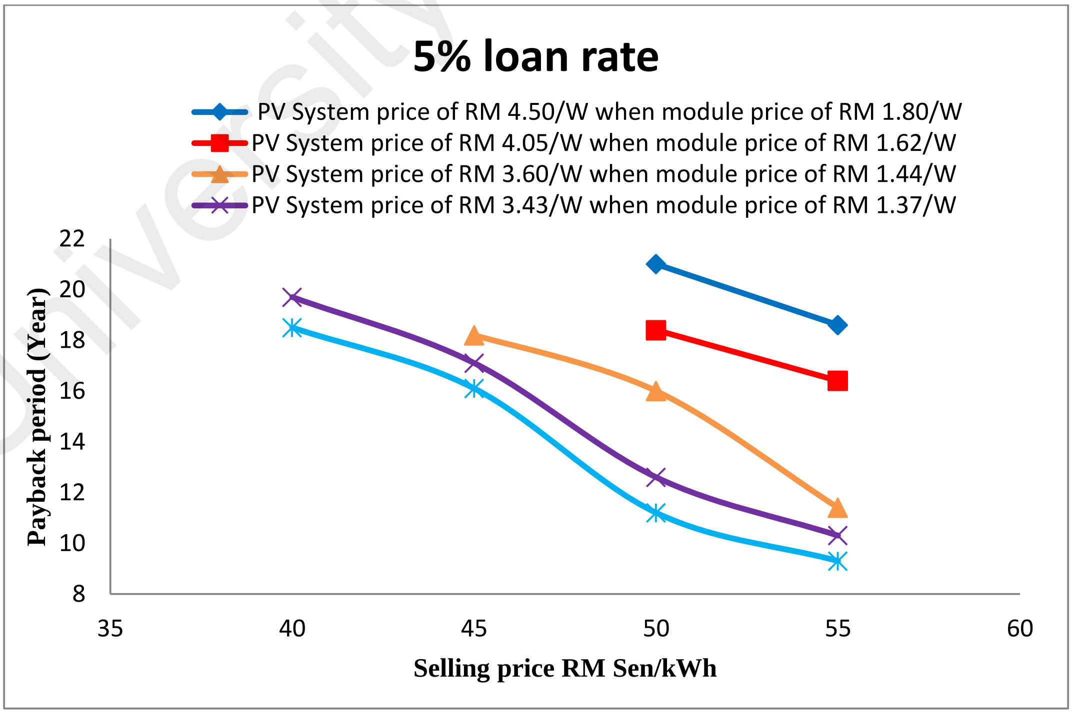

Figure 4.34: Selling price versus payback period (100% loan with 5% interest)

4.2.2.4 Different module prices, efficiency 17% and solar insolation's 1625 kWh/year, then the LCOEs are as follows:

When the module price is RM1.80/W (US$0.50/W), loan interest is 0%, 1%, 2%, 3%, 4%, and 5%, then, the LCOEs are RM0.42/ kWh, RM0.46/kWh, RM0.50/kWh, RM0.54/kWh, RM0.59/kWh and RM0.63/kWh respectively.

When the module price is RM1.62/W (US$0.45/W), loan rate is 0%, 1%, 2%, 3%, 4%, and 5%, then, the LCOEs are RM0.38/kWh, RM0.42/kWh, RM0.45/kWh, RM0.49/kWh, RM0.53/kWh and RM0.56/kWh respectively. When the module price is RM1.44/W (US$0.40/W), loan rate is 0%, 1%, 2%, 3%, 4%, and 5%, then, the LCOEs are RM0.34/kWh, RM0.37/ kWh, RM0.40/kWh, RM0.44/kWh, RM0.47/kWh, and RM0.50/kWh respectively. When the module price is RM1.37/W (US$0.38/W), loan rate is 0%, 1%, 2%, 3%, 4%, and 5%, then, the LCOEs are RM0.32/ kWh, RM0.35/kWh, RM0.38/kWh, RM0.41/kWh, RM0.45/kWh and RM0.48/kWh respectively. When the module price is RM1.30/W (US$0.36/W), loan rate is 0%, 1%, 2%, 3%, 4%, and 5%, then, the LCOEs are RM0.30/ kWh, RM0.33/kWh, RM0.36/kWh, RM0.39/kWh, RM0.42/kWh and RM0.45/kWh respectively.

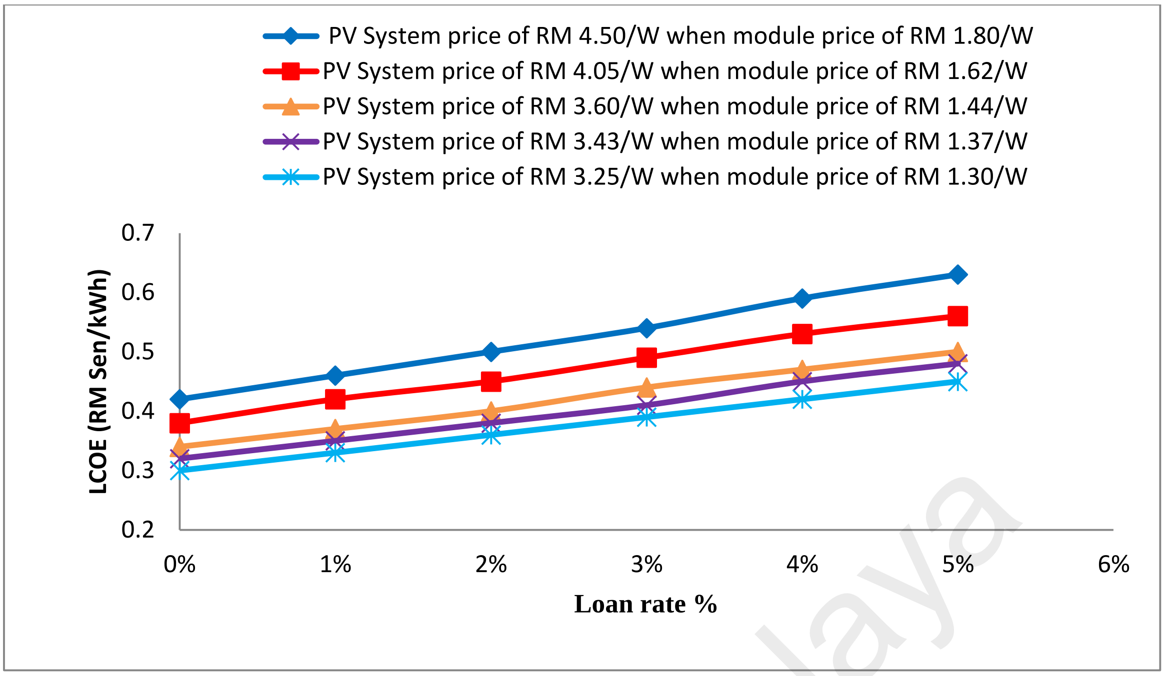

Figure 4.35: Loan interest versus LCOE

Table 4.4 shows the solar PV system LCOE in different countries. Where, Latin America has the lowest LCOE 0.11 to 0.31 USD/kWh. South Korean has the highest LCOE because of high capital cost and relatively low capacity factors.

Table 4.4: LCOE of PV system is in different countries.

(IRENA, 2013)

Country	**LCOE (USD/kWh)**	**Year**	**Remarks**
Latin America	0.11-0.31	2012	Normal
Germany	0.16-0.23	2012	Which is lower than most residential tariffs
China	0.15-0.35	2012	Normal
South Korean	0.15-0.56	2012	High capital cost and relatively low capacity factors.

4.2.2.5 NPV, IRR%, and PBP of 30 MW PV plant when self-financing and electricity selling by FIT rate

(a) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the FiT electricity is RM0.551/kWh in 2015 (by SEDA), the NPV, IRR% and PBP are as follows:

When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the FiT electricity is RM0.551/kWh in 2015, the NPVs are RM 144.34 million, RM 175.41 million, RM206.49 million, RM218.92 million, and RM 231.35 million respectively. When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the FiT electricity is RM0.551/kWh in 2015, the IRR are 9.4%, 11.9%, 14.9%, 16.3% and 17.8% respectively. When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W) and the FiT electricity is RM0.551/kWh in 2015, the payback periods are 10.1 years, 8.7 years, 6.0 years, 5.6 years, and 5.2 years respectively. The selling price is acceptable for all the module prices.

4.2.2.6 NPV, IRR%, and PBP of 30 MW PV plant when 50% self-financing and 50% bank loan and selling by FiT rate

(a) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W) and the FiT electricity is RM0.551/kWh in 2015(by SEDA), 50% bank loan with 1%, 2%,3%,4% and 5% interest, loan tenure 15 years, then the NPVs are shown in Figure 4.36.

When the module price is RM1.8/W (US$0.50/W), the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the NPVs are RM 75.36 million, RM46.07 million, RM17.84 million, RM-7.86 million, and RM -28.59 million respectively. When the module price is RM1.62/W (US$0.45/W), the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the NPVs are RM 113.34 million, RM82.56 million, RM53.34 million, RM26.88million, and RM 5.33 million respectively. When the module price is RM1.44/W (US$0.40/W), the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the NPVs are RM151.31 million, RM119.06 million, RM88.84 million, RM 61.63 million, and RM 39.26 million respectively. When the module price is RM1.37/W (US$0.38/W), the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the NPVs are RM 166.50 million, RM133.65 million, RM103.03 million, RM75.53 million, and RM 52.83 million respectively. When the module price is RM1.30/W (US$0.36/W), the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the NPVs are RM181.7 million, RM148.25million, RM117.24 million, RM 89.43 million, and RM 66.4 million respectively. For all the module prices, the selling prices RM0.55/kWh (FIT rate 2015) is acceptable because the NPVs are positive. When the module price is decreased, the NPV increased and when the loan interest increases the NPV decreases.

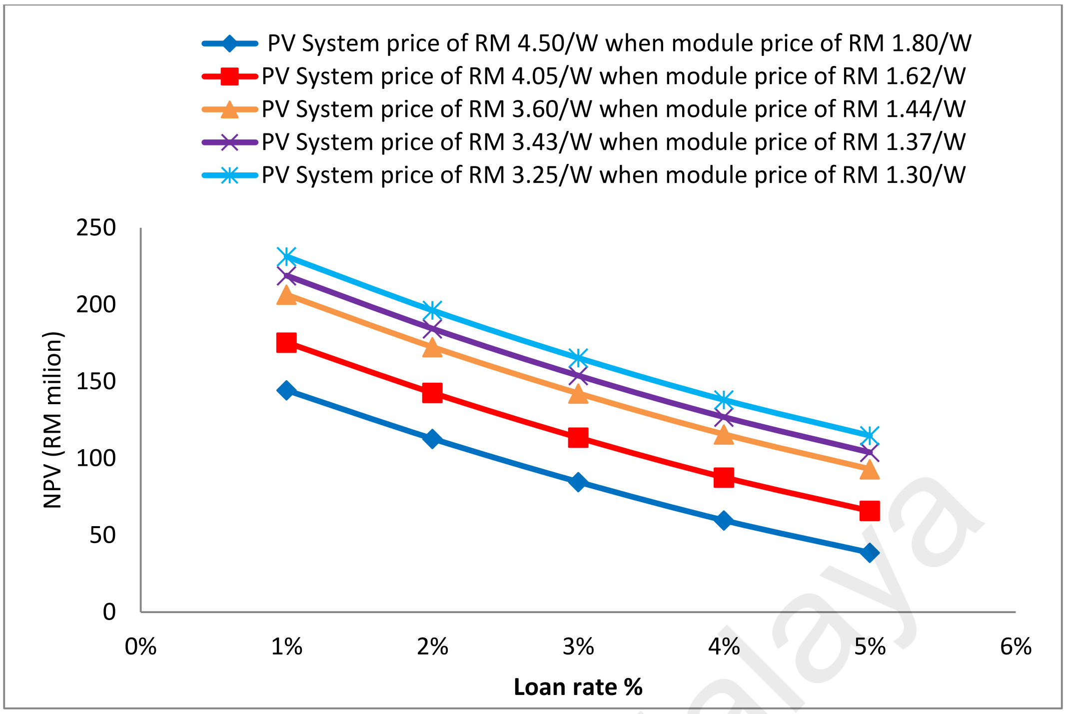

Figure 4.36: FiT rate versus NPV (50% loan)

(b) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W) and the FiT electricity is RM0.551/kWh in 2015 (by SEDA) and 50% bank loan with 1%, 2%,3%,4% and 5% interest, loan tenure 15 years,, the IRRs are shown in Figure 4.37.

When the module price is RM1.8/W (US$0.50/W) and the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the IRRs are 9.4%, 9.2%, 8.8%, 8.4%, and 8.1% respectively. When the module price is RM1.62/W (US$0.45/W) and with the above mention condition, the IRRs are 11.9%, 11.7%, 11.4%, 11.0% and 10.6% respectively. When the module price is RM1.44/W (US$0.40/W) and with the above mention condition, the IRRs are 14.9%, 14.7%, 14.4%, 14.0%, and 13.7% respectively.

When the module price is RM1.37/W (US$0.38/W) and with the above mention condition, the IRRs are 16.3%, 16.1%, 15.7%, 15.4%, and 15% respectively

When the module price is RM1.30/W (US$0.36/W) and with the above mention condition, the IRRs are 17.8%, 17.5%, 17.2%, 16.9% and 16.5% respectively. For all the module prices, the selling prices RM0.55/kWh (FIT rate 2015) is acceptable because the IRR% is higher than loan interest.

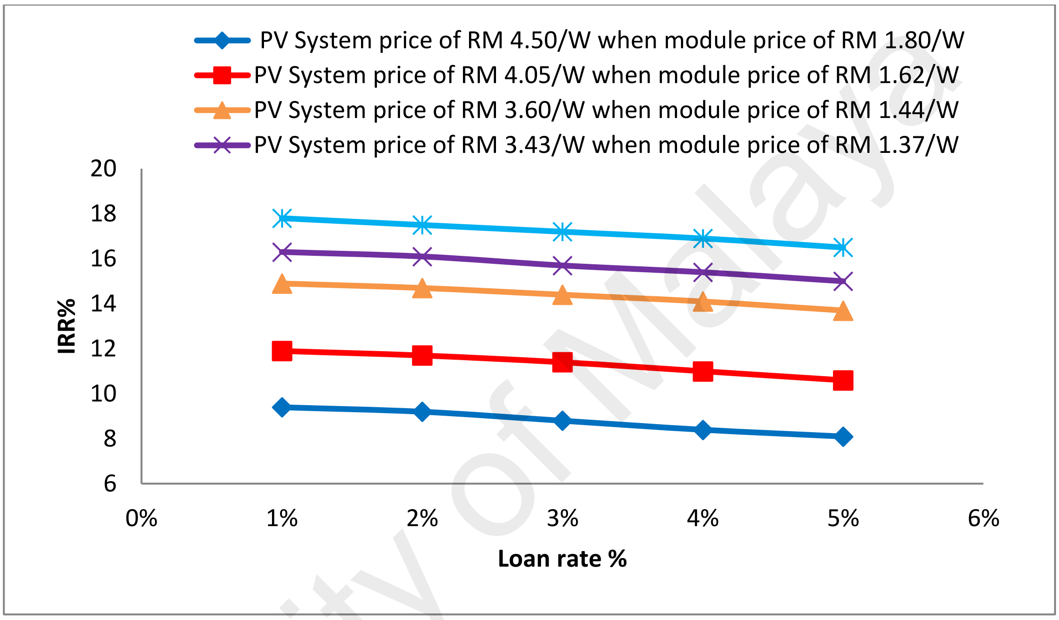

Figure 4.37: FiT rate versus IRR% (50% loan)

(c) When the module prices RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W)) and the FiT electricity is RM0.551/kWh in 2015(by SEDA) and digression is 10% per year, 50% bank loan with 1%, 2%,3%,4% and 5% interest, loan tenure 15 years, the payback periods are shown in Figure 4.38.

When the module price is RM1.8/W (US$0.50/W) and the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the payback periods are 10.1 years, 10.3 years, 10.5 years, 10.8 years and 11.1 years, respectively. When the module price is

RM1.62/W (US$0.45/W) and the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the payback periods are 8.7 years, 8.8 years, 9.0 years, 9.2 years and 9.5 years, respectively. When the module price is RM1.44/W (US$0.40/W) and the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the payback periods are 6.0 years, 6.1 years, 6.2 years, 6.3 years and 6.5 years, respectively. When the module price is RM1.37/W (US$0.38/W) and the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the payback periods are 5.6 years, 5.7 years, 5.8 years, 5.9 years and 6 years, respectively. When the module price is RM1.30/W (US$0.36/W) and the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the payback periods are 5.2 years, 5.3 years, 5.4 years, 5.5 years and 5.6 years, respectively. Figure 4.38 shows that for all the selling prices, the payback periods are acceptable because they stay within lifetimes 21 years. When the loan rate increases the payback period also increases and vice versa.

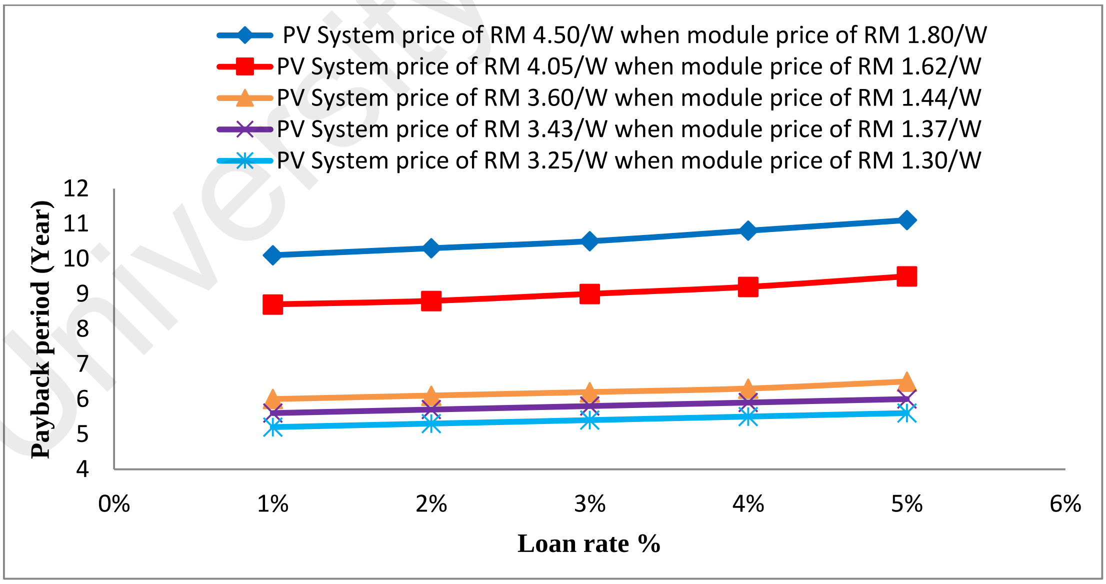

Figure 4.38: FiT rate versus payback period (50% loan)

4.2.2.7 NPV, IRR%, and PBP of 30 MW PV plant when 100% bank loan and electricity selling by FiT rate

(a) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the FiT electricity is RM0.551/kWh in 2015, 100% bank loan with 1%, 2%,3%,4% and 5% interest, loan tenure 15 years, then the NPV are shown in Figure 4.39.

When the module price is RM1.8/W (US$0.50/W), the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the NPVs are RM 75.36 million, RM46.07 million, RM17.84 million, RM-7.86 million, and RM -28.59 million respectively. When the module price is RM1.62/W (US$0.45/W), the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the NPVs are RM 113.34 million, RM82.56 million, RM53.34 million, RM26.88 million, and RM5.33 million respectively. When the module price is RM1.44/W (US$0.40/W), the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the NPVs are RM 151.31 million, RM119.06 million, RM88.84 million, RM6.63 million, and RM 39.26 million respectively. When the module price is RM1.37/W (US$0.38/W), the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the NPVs are RM 166.50 million, RM133.65 million, RM103.03 million, RM75.53 million, and RM 52.83 million respectively. When the module price is RM1.30/W (US$0.36/W), the FiT is RM0.551/kWh in 2015, loan rats are 1%, 2%, 3%, 4% and 5% then, the NPVs are RM181.75 million, RM148.25 million, RM117.24 million, RM89.43 million, and RM66.4 million respectively. The selling prices RM0.55/kWh (FIT rate 2015) is acceptable when module prices are RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W). When module price is

RM1.80/W (US$0.50/W) and loan interest 4% and 5%, the NPVs are negative, so these loan interest are not acceptable (the module price decreased, the NPV increased).

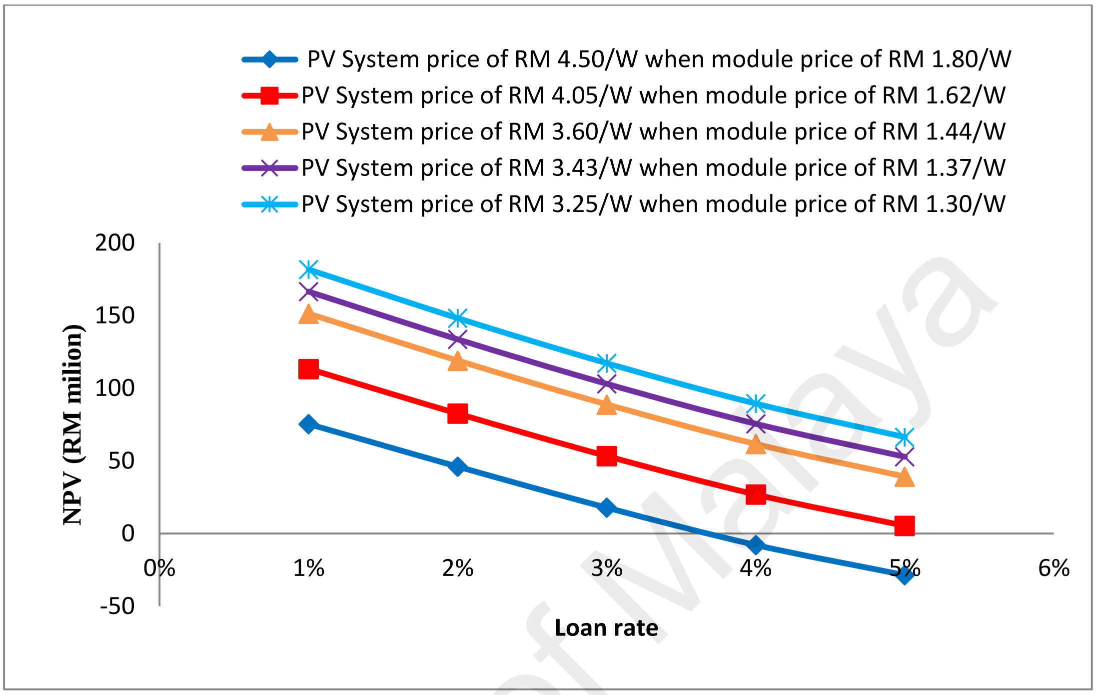

Figure 4.39: FiT rate versus NPV (100% loan)

(b) When the module prices are RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.44/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.30/W (US$0.36/W) and the FiT electricity is RM0.551/kWh in 2015 (by SEDA) and digression is 10% per year, 100% bank loan with 1%, 2%,3%,4% and 5% interest, loan tenure 15 years, are shown in Figure 4.39.

When the module price is RM1.8/W (US$0.50/W) the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the IRRs are 5.3%, 4.8%, 4.2%, 3.4% and 2.8% respectively. When the module price is RM1.62/W (US$0.45/W) and the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the IRRs are 7.9%, 7.5%, 6.8%, 6.1% and 5.4% respectively. When the module price is RM1.44/W (US$0.40/W) and the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5%

then, the IRRs are 11.0%, 10.5%, 9.9%, 9.2% and 8.6% respectively. When the module price is RM1.37/W (US$0.38/W) and the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the IRRs are 12.4%, 12.0%, 11.3%, 10.6%, and 10.0% respectively. When the module price is RM1.30/W (US$0.36/W) the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the IRRs are 13.9%, 13.5%, 12.9%, 12.1% and 11.5% respectively. The selling price RM0.55/kWh (FIT rate 2015) is acceptable, when module prices are RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W). When module price is RM1.80/W (US$0.50/W) and loan interest 4% and 5%, the IRR% is lower than loan interest, so these loan interests are not acceptable.

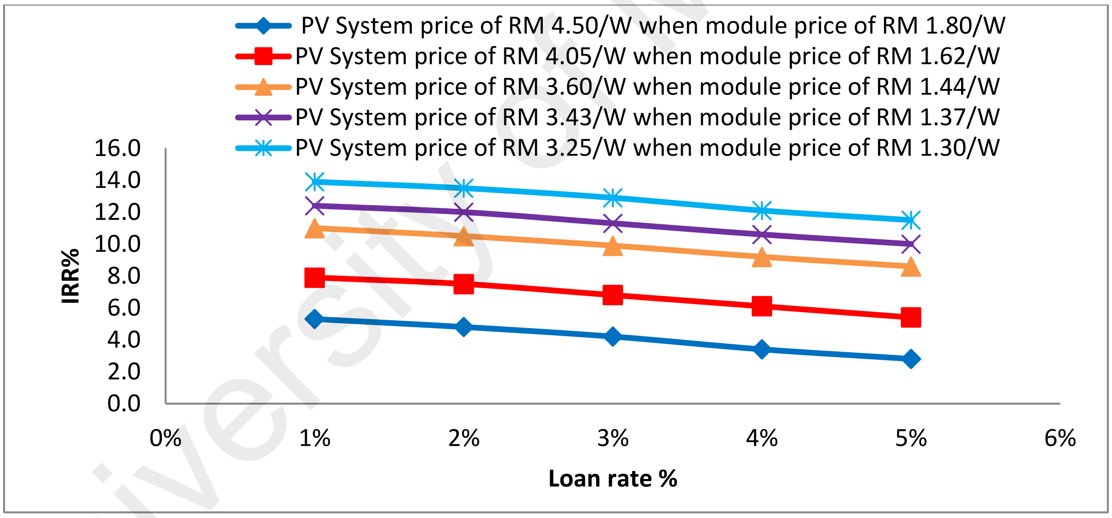

Figure 4.40: FiT rate versus IRR% (100% loan)

(c) When the module prices RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM1.11/W (US$0.40/W), RM1.37/W (US$0.38/W) and RM1.3/W (US$0.36/W) and the FiT electricity is RM0.551/kWh in 2015(by SEDA) and 100% bank loan with 1%, 2%,3%,4% and 5% interest, loan tenure 15 years, the payback periods are shown in Figure 4.41.

When the module price is RM1.8/W (US$0.50/W) and the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the payback periods are 16.3 years, 16.7 years, 17.3 years, 18.0 years and 18.6 years, respectively. When the module price is RM1.62/W (US$0.45/W) and the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the payback periods are 11.6 years, 12.1 years, 12.9 years, 13.9 years and 16.4 years, respectively. When the module price is RM1.44/W (US$0.40/W) and the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the payback periods are 9.4 years, 9.7 years, 10.2 years, 10.8 years and 11.4 years, respectively. When the module price is RM1.37/W (US$0.38/W) and the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the payback periods are 7.0 years, 8.9 years, 9.3 years, 9.8 and 10.3 years, respectively. When the module price is RM1.30/W (US$0.36/W) and the FiT is RM0.551/kWh in 2015, loan rate 1%, 2%, 3%, 4% and 5% then, the payback periods are 6.4 years, 6.8 years, 7.2 years, 8.9 years and 9.3 years, respectively. From the Figure, it is shown that the payback period is increased with increasing the loan rate. PV system cost and module price have great influence on the payback period compared to other parameters. It is also shown that for all the selling prices, the payback periods are acceptable because they stay within lifetime 21 years.

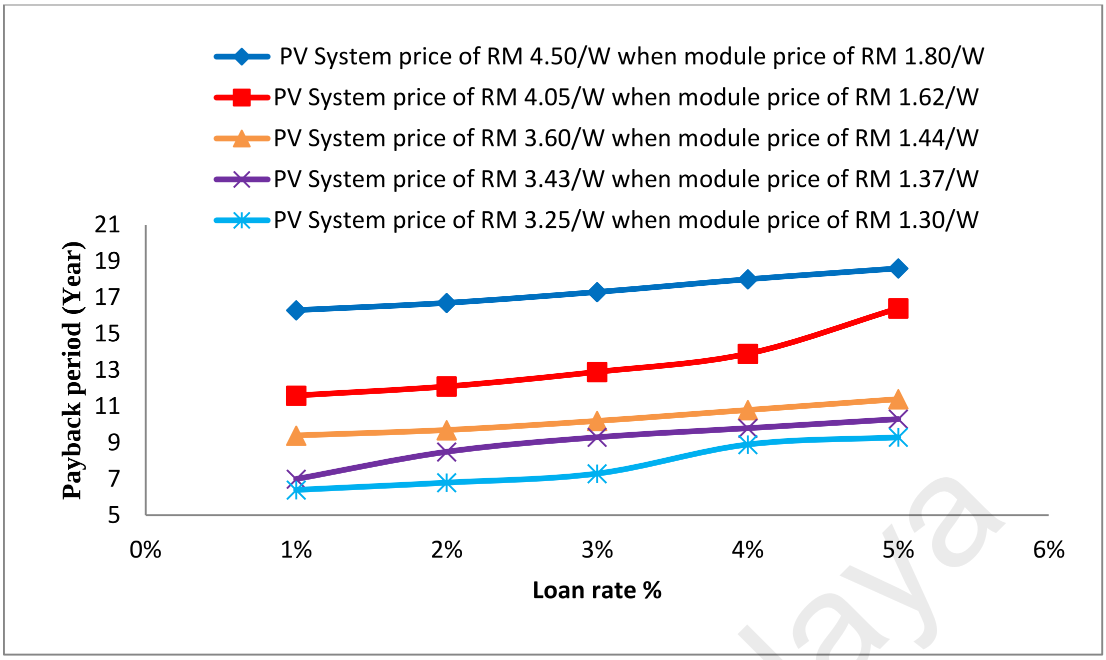

Figure 4.41: FiT rate versus payback period (100% loan)

4.2.2.8 Feed in Tariff (FiT) calculation on the basis of module prices and loan interest (%)

Feed in tariff is the most efficient and effective support schemes for promoting renewable energy generation especially for PV technology. In order to achieve the target of electricity generation 5.5% in 2015, the government of Malaysia has implemented the Feed in Tariff. Feed in Tariffs are long-term, guaranteed purchase agreements for green electricity at a price that can provide project developers a reasonable return of investment. The FIT rate was set on the basis of levelized cost of RE generation, plus a targeted return typically set by the policymakers or regulators. The government of Malaysia also provides soft loan with a 2% government subsidy of the interest rate and 60% guarantee on the amount of financing. The following factors influence the power generation costs and therefore should be taken into account when the tariff levels are determined (as shown in Table 4.5).

Table 4.5: Basis of determining FiT rates

(Haris, 2010)

Factors	**Solar PV**
WACC	7.5%
IRR%	3%-12%
Loan rate and tenure	6%-8%, 15 years
O&M, depreciation, insurance	1.4%
Annual cost increment	3%
Capacity factor	13%-16%
FiT duration	21 years
Capital expenditure	12-19/W
Simple payback period	<12 years
US$ 1.0= RM 3.60	Date (02.03.2015)
EURO 1.0= RM 4.10	Date (02.03.2015)

The FiT rate is calculated on the basis of module price and loan interest rate %. It is clear that when the module price is high then LCOE is also high, so FiT rate should be high. Module price is decreasing day by day, with the decreasing of module price the LCOE is also decreasing. So, FiT rate should be decreased. When module price RM1.80/W (US$0.50/W) loan interest 3%, then for 30 MW plant FiT rate is RM0.63/kWh. At the same time when module price RM1.44/W (US$0.40/W) loan interest 3%, then for 30 MW plant FiT rate is RM0.50/kWh. When loan interest is high than LCOE is also high, so FiT rate should be high. When module price RM1.44/W (US$0.40/W) with loan interest of 1%, then for 30 MW plant FiT rate is RM0.44/kWh, at the same time when the module price remain the same but the loan rate is 4%, FiT rate is RM0.53/kWh. Tables 4.6, 4.7, 4.8, 4.9, and 4.10 shows the different FiT rate with different module prices RM1.80/W (US$0.50/W), RM1.62/W (US$0.45/W), RM

1.44/W (US$0.40/W), RM 1.37/W (US$0.38/W) and RM 1.30/W (US$0.36/W) and different loan interest (0%, 1%, 2%, 3%, 4%, and 5%).

Table 4.6: Feed in Tariff (FiT) when PV system price RM4.50/W (module price RM1.80/W (US$0.50/W))

Installation capacity (MW)	0%	1%	2%	3%	4%	5%
10	0.558	0.602	0.658	0.702	0.747	0.792
30	0.500	0.540	0.590	0.630	0.670	0.710
50	0.475	0.513	0.561	0.599	0.637	0.675
70	0.458	0.495	0.541	0.578	0.614	0.651
100	0.442	0.478	0.522	0.557	0.593	0.628

Table 4.7: Feed in Tariff (FiT) when PV system price RM4.05/W (module price RM1.62/W (US$0.45/W))

Installation capacity (MW)	0%	1%	2%	3%	4%	5%
10	0.502	0.546	0.591	0.624	0.669	0.714
30	0.450	0.490	0.530	0.560	0.600	0.640
50	0.428	0.466	0.504	0.532	0.570	0.608
70	0.413	0.449	0.486	0.513	0.550	0.587
100	0.398	0.433	0.469	0.495	0.531	0.566

Table 4.8: Feed in Tariff (FiT) when PV system price RM3.60/W (module price RM1.44/W (US$0.40/W))

Installation capacity (MW)	0%	1%	2%	3%	4%	5%
10	0.446	0.491	0.524	0.558	0.591	0.624
30	0.400	0.440	0.470	0.500	0.530	0.560
50	0.380	0.418	0.447	0.475	0.504	0.532
70	0.367	0.403	0.431	0.458	0.486	0.513
100	0.354	0.389	0.416	0.442	0.469	0.495

Table 4.9: Feed in Tariff (FiT) when PV System price RM3.42/W (module price RM1.37/W (US$0.38/W))

Installation capacity (MW)	0%	1%	2%	3%	4%	5%
10	0.424	0.457	0.502	0.535	0.569	0.602
30	0.380	0.410	0.450	0.480	0.510	0.540
50	0.361	0.390	0.428	0.456	0.485	0.513
70	0.348	0.376	0.413	0.440	0.468	0.495
100	0.336	0.363	0.398	0.425	0.451	0.478

Table 4.10: Feed in Tariff (FiT) when PV system price RM 3.24/W (module price RM 1.30/W (US$ 0.36/W))

Installation capacity (MW)	0%	1%	2%	3%	4%	5%
10	0.401	0.435	0.468	0.502	0.535	0.569
30	0.360	0.390	0.420	0.450	0.480	0.510
50	0.342	0.371	0.399	0.428	0.456	0.485
70	0.330	0.358	0.385	0.413	0.440	0.468
100	0.318	0.345	0.372	0.398	0.425	0.451

4.2.3 Grid parity analysis

Grid parity is a very important milestone for further photovoltaic diffusion. Grid parity in general explains the time point when a kWh PV electricity cost becomes equal to a kWh electricity price from the grid (Mondol, 2013). This point is called breakeven point. Grid parity analysis emphasizes on the breakeven point of the LCOE of solar PV system and the TNB tariff. The breakeven point will occur within 2021-2022 for PV system price RM4.50/W (module price RM1.80/W (US$0.50/W) and when electricity price increases 2%. At the same time, the breakeven point will occur within 2019-2020 for PV system prices RM4.50/W (module price RM1.80/W (US$0.50/W) and electricity price increase 5%. When PV system price is RM4.05/Wand RM3.60/W, then the breakeven point will occur within 2017-2019. Nevertheless, grid parity can be achieved earlier by possessing very good solar condition, low PV system prices, and high TNB electricity tariff. The line graph (Figure 4.42) used in breakeven analysis estimates when the total sales revenue will equal, the point where loss will end and profit will begin to accumulate. Usually, the time (year) is plotted on horizontal ('X') axis and LCOE (RM/kWh) on vertical ('Y') axis. Table 4.11 shows the Grid parity achieved by countries and year.

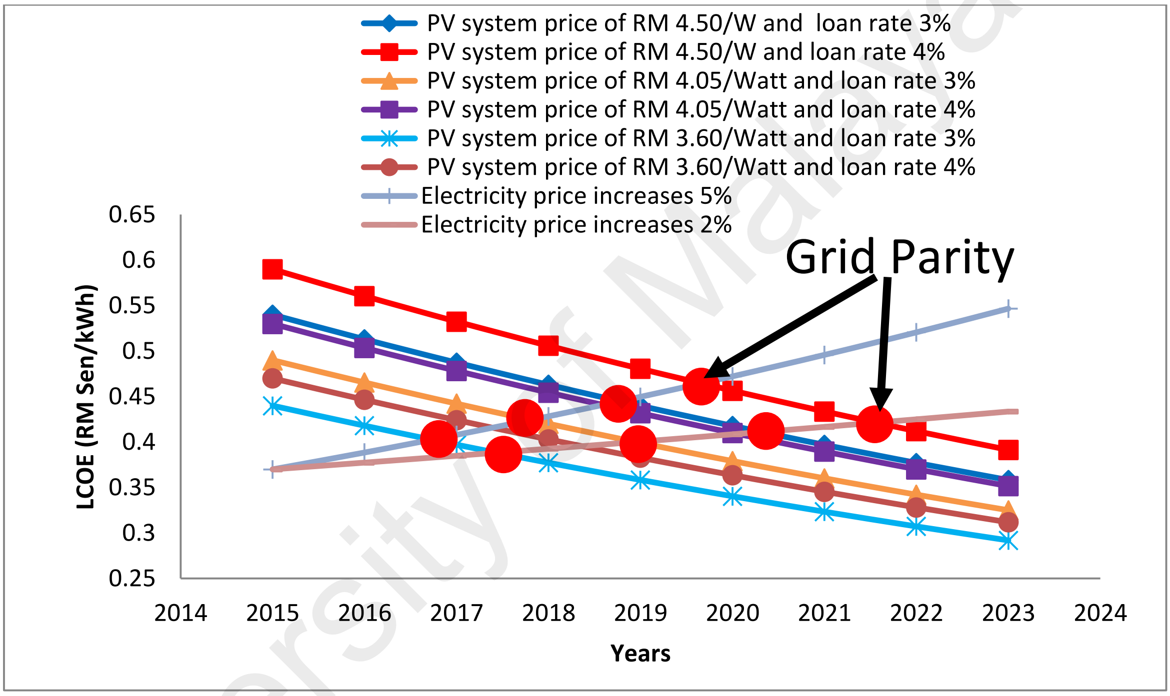

Figure 4.42: The grid parity analysis

PV system prices in 2015 is assumed for grid-parity analysis. PV system price includes module, inverter, land and all necessary balance of system components. PV system price RM4.50/W, RM4.05/W, and RM3.60/W, PV system price is decreasing 10% per year and electricity tariff will increase 2% and 5% per year. The grid parity occurs within 2021 to 2022 for PV system price RM4.50/W (module price RM1.80/W (US$0.50/W) and when electricity price increases 2%. At the same time, the grid parity will occur within 2019-2020 for PV system prices RM4.50/W (module price RM1.80/W

(US$0.50/W) and electricity price increase 5%. When PV system price is RM4.05/W and RM3.60/W, then the grid parity will occur within 2017-2019.

Table 4.11: Grid parity achieved by countries and year.

(Mondol, 2013)

Country	**Grid parity achieved year**
South Germany	2014
North Germany	2015
Southern Spain	2012-2013
Northern Spain	2014
Southern France	2016
other regions of France	2020
Italy	2011-2012

4.3 Environmental Impact

4.3.1 CO_2 emission scenario in Malaysia

Malaysia has recorded positive economic growth in recent years through structural change in industrialization, agriculture, tourism, and export activities. Economic growth has caused pollution in many sectors. For instance there is an increasing air pollution from industrial activities and motor vehicle emissions as well as water pollution from raw sewage. The continuous rise and accumulation of pollution could have many damaging effects (Chik, 2013). The CO_2 emissions (metric ton per capita) in Malaysia were reported at 6.57 in year of 2004 and increase to 7.7 in year 2010 and it is expected to be tripled by 2030. However, a report reveals from the International Energy Agency that Malaysia's CO_2 emission intensity is higher than world average which is 1.3 tonnes of CO_2 per RM3180 GDP (US$1000 GDP) compare to 0.73 tons of CO_2 per RM3180

GDP (US$1000 GDP) for the world average. Referring to the list of countries by carbon dioxide emissions per capita, Malaysia was at No. 51 in world rank with 7.7 metric tons of CO_2 per capita, and was the third largest contributor after Indonesia and Thailand (Ang, 2013; Sapuan, 2013) as shown in Figure 4.43. CO_2 emission intensity is measured in tonnes of CO_2 emitted from the use of energy to produce a unit of GDP RM3180 (US$1,000) (Sapuan, 2013).

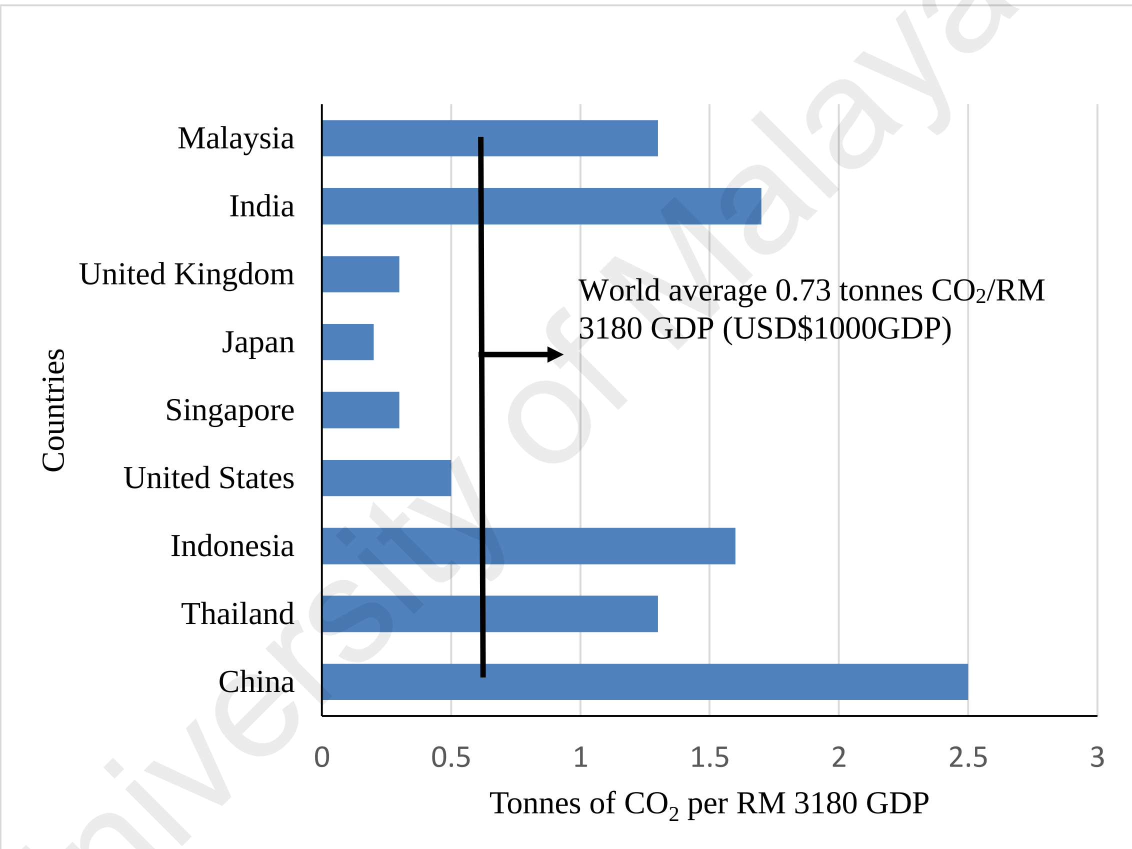

Figure 4.43: CO_2 emission intensity, 2010 (Tonnes CO_2/RM 3180 GDP).

(Chik, 2013)

Table 4.12: Carbon dioxide emissions in Malaysia from 2001 to 2013 (MCDE, 2014)

Year	Quantity (Metric tons)
2001	136.58
2002	149.63
2003	163.43
2004	164.39
2005	179.66
2006	188.86
2007	200.21
2008	200.49
2009	201.55
2010	222.55
2011	221.14
2012	230.28
2013	234.66

Gan et al. (Gan et al., 2008) has developed a comprehensive economy model to study the long-term forecasting of Malaysia's economic, energy and the environment until year 2030. Their projections indicated that Malaysia's gross domestic production (GDP) is expected to increase on average of 4.6 % from 2004 to 2030. Coal import will increase following a government policy of intensifying it's used of power generation. So Malaysia energy import dependency will increase and CO_2 emission are expected to be tripled up to 2030. Table 4.12 shows the Malaysia carbon dioxide emissions from 2001 to 2013. In Malaysia, electricity generation is also mostly fossil fuel based, in particular natural gas, coal and oil. In the electricity generation sector, the main target for gradual change in fuels usage are about gas 75% , coal 9% , hydro 10% and petroleum 6% in 2000 (KTAK, 2005) to gas 40%, hydro 30%, coal 29% and only petroleum 1% by 2020 (Masjuki, 2002). The using of fossil fuels in all the industries for electricity generation is one of the main causes for industrial air pollution. Malaysia should change the oil dependent energy consumption and gas dependent electricity generation system (Shaliza, 2011).

4.3.2 Mitigation steps to reduce CO_2 emission in Malaysia

Malaysia is aware about this problem. In 2009, UNFCCC conference in Copenhagen, The Prime Minister of Malaysia declared that Malaysia has promised to reduce up to 40% of emissions intensity by the year 2020 compared to 2005 levels (Bernama, 2009). According to the announcement, the government has acted accordingly by setting up a number of institutions that are responsible for managing and promoting the use of clean energy and mitigation steps are taken to decrease the total CO_2 emissions donated by transportation and electricity generation. A lot of positive policies and plan has been taken to reduce the of CO_2 emission from conventional fossil-fuel based power plants. As a future plan to reduce the CO_2 emission, the following things are considerable: Increasing the use of renewable energy, increasing plant efficiency, employing fuel balancing or fuel switching and employing CO_2 carbon capture and sequestration. The Ministry of energy, Green Technology and Water (KeTTHA) was given the role to promote the use of low-carbon energy for the entire industry. The Sustainable Energy Development Authority (SEDA) established in 2011 will identify the renewable energy (RE) that can be applied in the industry and be used efficiently. SEDA also has taken a lot of strategies to increase the use of renewable energy as an additional energy mix source in Five-fuel Diversification Strategy. From the different sources of renewable energy, photovoltaic solar energy and biomass seems to be promising alternative energy sources in Malaysia.

4.3.3 Environmental impacts from the PV manufacturing and operation of solar power plants

PV systems life cycle is comprised of three steps. The steps are as following,

(1) Manufacturing and construction phase

(2) Operational phase

(3) Decommissioning phase

Figure 4.44 shows that the PV systems life cycle. The first step of PV systems life cycle is the manufacturing and construction phase. In this step electricity needed is taken from the national grids which are generate from the traditional fossil fuel based power plants. So greenhouse gases would be emitted from this step. Table 4.14 shows total energy and electricity needs for production and installation of ground mounted and rooftop PV plants. Figure 4.45 shows the GHG emission rates of PV electricity generated by various PV systems, where about 35 to 50 g CO_2/kWh for different PV technology that is much smaller than the traditional fossil fuel based power generation system (Reinhard, 2006; Seng et al., 2008).

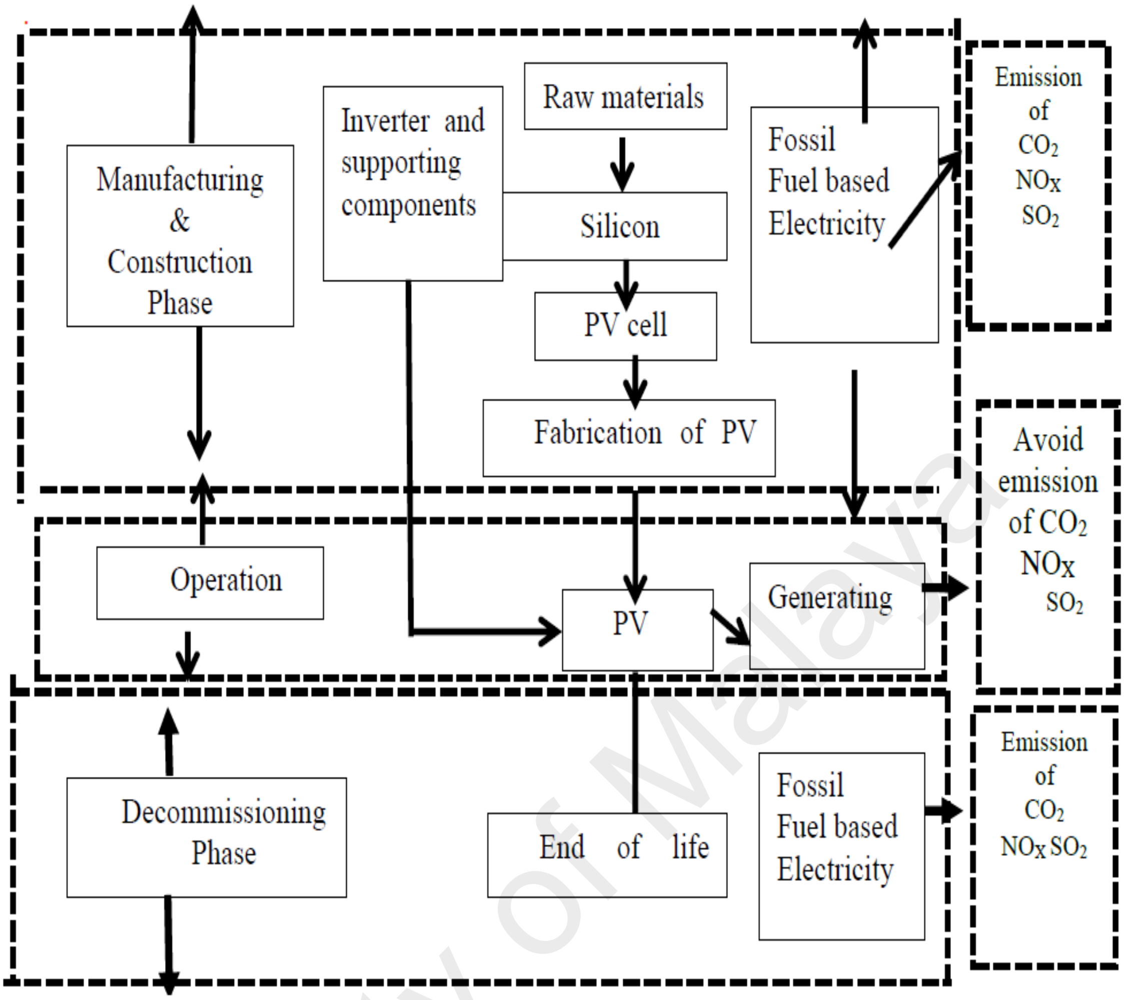

Figure 4.44: Energy flow for the three phases of PV system.

(Seng et al., 2008)

The second steps of PV systems life cycle is the operational phase. In this step clean electricity is generated by the solar PV system. So, huge amount of greenhouse gases emission can be reduced.

Table 4.13: Energy and electricity needs for production and installation of ground mounted and rooftop PV plants.

(Seng et al., 2008)

Types of PV modules	Ground mounted PV system		Roof top PV system	
	Energy needs (MJ/W)	Electricity needs (kWh/kWp)	Energy needs (MJ/W)	Electricity needs (kWh/kWp)
Monocrystalline silicon	61.06	5941.34	51.85	5043.5
Polycrystalline silicon	49.06	4774.02	36.37	3539.36
Amorphous silicon	48.27	4697.06	31.13	3029.47

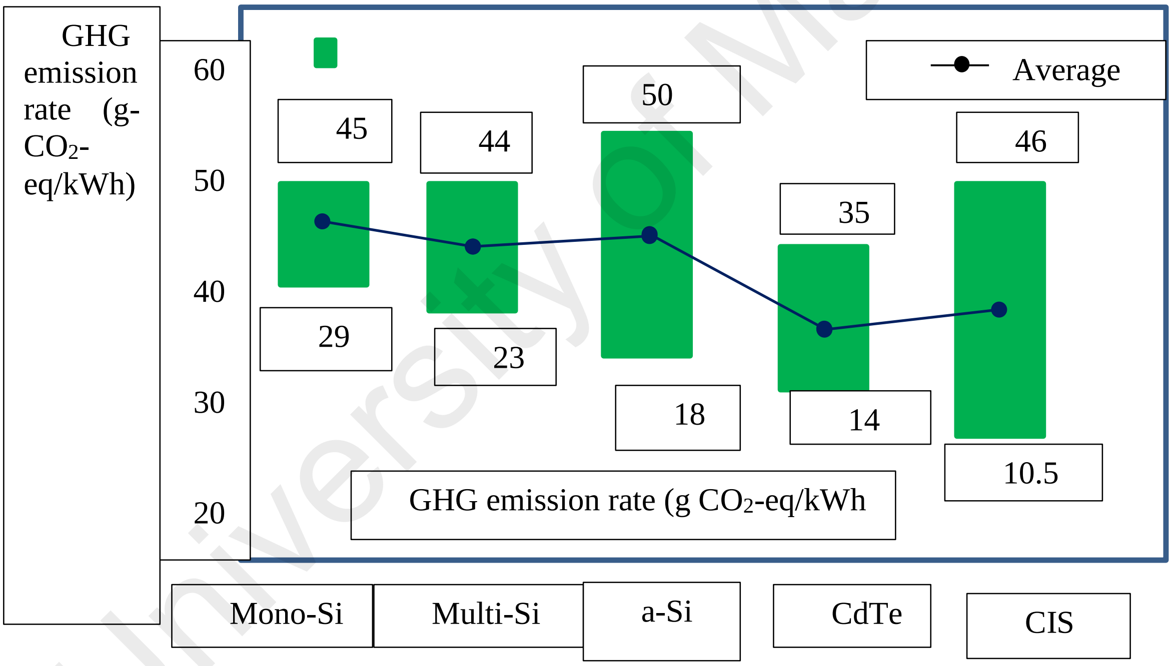

Figure 4.45: Review of GHG emission rates of PV electricity generated by various PV systems.

(Peng, 2013)

The third and last step of PV systems life cycle is decommissioning, in this step electricity is needed for recycling all the materials, for example: module frames and supporting structures. The electricity is taken from the national grids which are generating from the traditional fossil fuel based power plants. So greenhouse gases would be emitted from this step.

4.3.4 Emission reduction from 30 MW PV power plants

PV system is sustainable and can solve the environmental and social problems which are created by traditional fossil fuel system (EC, 1995, 1997). PV system is defined as zero emissions or emissions- free energy system. In fact, greenhouse gas emission is negligible from the PV system. During operation, the PV system release no CO_2, NO_x or SO_2 gases and not any by product for global warming. PV is sustainable and renewable energy system that is inherently safe than any-other traditional conventional electricity generating system. Photovoltaic system is clean, silent and abundant (EIPT, 2009).

Solar energy is obviously environmentally advantageous related to any other energy sources and does not deplete natural resources, CO_2 emission or generates liquid or solid waste products (Ahmed et al., 2013; Solangi et al., 2011; Tsoutsos et al., 2005). By using renewable energy systems, the CO_2 can be reduced significantly. The solar energy attracted more attentions compared to others renewable energy sources (Muneer et al., 2006). To overcome the negative impacts of fossil fuels on the environment, many countries have been forced to change the environmental friendly alternatives energy sources. Solar energy is the best renewable energy source and has the least negative impact on the environment (Solangi et al., 2011). As for the operational phase, PV systems generate clean electricity. Solar PV is replacement of traditional fossil fuel, so it can be calculated the energy (kWh) produced by solar PV system and how much emission can be avoided for this energy (kWh). Table 4.14 shows the amount of emission can be avoided by producing the electricity from 30 MW solar PV Technology in Malaysia where this project life time is calculated 21 years. From 30 MW PV plant 666431 tons, 8223 tons, 1991 tons and 296 tons of CO_2, SO_2, NOX and CO respectively can be avoided.

Table 4.14: Emission reduction from 30 MW PV power plants

Gases	Avoid for crude oil and petroleum	Avoid for Gas	Avoid for Coal	Total (Kg)
CO_2	244,166,632	216,833,897	205,430,749	666,431,279
SO_2	4,710,979	204,560	3,307,783	8,223,323
NO_x	718,137	368,208	905,288	1,991,633
CO	57,450	204,560	34,818	296,830

CHAPTER 5: CONCLUSION AND FUTURE WORK

5.1 Conclusions

Study has been carried out to assess the technical feasibility and economic viability of a 30 MW capacity solar photovoltaic power plant to support the growing energy demand of Malaysia. For this power generation a total of 120000 crystalline silicon modules are required. The total land area is 105 acres. Financial performance indicators: internal rate of return (IRR), net present value (NPV), payback periods (PBP) and levelized cost of electricity (LCOE) are analyzed for two economic conditions, i). Produced electricity is sold by RM0.40/kWh, RM0.45/kWh RM0.50/kWh and RM0.55/kWh, and ii) produced electricity is sold by FiT rate RM 0.551/kWh in 2015. The total cost arrange by different condition (100% self-financing, 50% self-financing + 50% bank loan with (1%, 2%,3%,4% and 5%) interest and 100% bank loan with (1%, 2%,3%,4% and 5%) interest.

- When the selling price RM0.40/kWh, RM0.45/kWh RM 0.50/kWh and RM 0.55 /kWh, 100% self-financing, the module price of RM 1.80/W (US$0.50/W), then the corresponding NPVs are RM110.27 million, RM156.69 million, RM203.11 million, and RM249.53 million respectively. The IRR% of 6.8%, 9.2%, 11.4%, and 13.5% respectively and the payback period 11.4 years, 9.9 years, 8.7 years, and 6.3 years, respectively.

- For the selling price of RM0.40/kWh, RM0.45/kWh RM 0.50/kWh and RM 0.55/kWh, 50% bank loan with 1%, and loan tenure 15 years), the module price of RM1.80/W (US$0.50/W), the corresponding NPVs are RM19.05 million, RM60.82 million, RM102.58 million, and RM144.34 million respectively. The IRR% is 2.3%, 4.8%, 7.2%, and 9.4% respectively. The payback periods are 18.9 years, 16.2 years, 11.6 years, and 10.1 years, respectively.

- If the selling price of RM0.40/kWh, RM0.45/kWh RM 0.50/kWh and RM 0.55/kWh, 100% bank loan with 1%, 2%, 3% 4% and 5% interest and loan tenure 15 years), the module price of RM1.80/W (US$0.50/W) and 1% interest, then the corresponding NPVs are RM-49.92 million, RM-8.16 million, RM33.60 million, and RM75.36 million respectively. The IRR% of -2.2%, 0.5%, 3.0%, and 5.3% respectively. The payback periods are more than21 years, 21.0 years, 18.5 years, and 16.3 years, respectively.

- The grid parity occurs within 2021 to 2022 for PV system price RM4.50/W (module price of RM1.80/W (US$0.50/W)) and when electricity price increases 2%. As the same time, the grid parity will occur within 2019-2020 for PV system prices RM4.50/W (module price of RM1.80/W (US$0.50/W)) and electricity price increase 5%. When PV system price is RM4.05/W and RM3.60/W, then the grid parity will occur within 2017-2019.

- In a 30MW PV plant, the emission of 666431 tons of CO_2, 8223 tons of SO_2, 1991 tons of NO_X, and 296.83 tons of CO can be prevented.

5.2 Future work

Future work should involve designing and experimental investigations. The following recommendation may be suggested such as

- Balance of system (BOS) prices should be calculated separately.
- Solar insolation data should be checked practically.
- Module efficiency and price should be justified.
- Exergy analysis of the PV systems
- Effect of different manufacturing and economic parameters for cost effectiveness

REFERENCES

Abbasi, T., & Abbasi, S.A. (2010). Production of clean energy by anaerobic digestion of phytomass—New prospects for a global warming amelioration technology. *Renewable and Sustainable Energy Reviews, 14*(6), 1653-1659.

Agustin, J.L.B., & Lopez, R.D. (2006). Economic and environmental analysis of grid-connected photovoltaic systems in Spain. *Renewable Energy, 31*, 1107–1128.

Ahmad, N.A., & Byrd, H. (2013). Empowering Distributed Solar PV Energy for Malaysian Rural Housing: Towards Energy Security and Equitability of Rural Communities. *Int. Journal of Renewable Energy Development, 2*(1), 59-68.

Ahmad, S., Kadir, M. Z. A. A., & Shafie, S. (2011). Current perspective of the renewable energy development in Malaysia. *Renewable and Sustainable Energy Reviews, 15*(2), 897–904.

Ahmed, F., Al Amin, A.Q., Hasanuzzaman, M., & Saidur, R. (2013). Alternative energy resources in Bangladesh and future prospect. *Renewable and Sustainable Energy Reviews, 25*(0), 698-707.

Alnaser, N.W., Flanagan, R., & Alnaser, W.E. (2008). Potential of making over to sustainable buildings in the Kingdom of Bahrain. *Energy Build, 40*, 1304–1323.

Amin, N., Lung, C.W., & Sopian, K. (2009). A practical field study of various solar cells on their performance in Malaysia. *Renewable Energy, 34*(8), 1939-1946.

Ang, C.T., Morad, N., Ismail, M.T., & Ismail, N. (2013). Projection of Carbon Dioxide Emissions by Energy Consumption and Transportation in Malaysia: A Time Series Approach. *Journal of Energy Technologies and Policy, 3*(1).

Bagnall, D.M., & Boreland, M. (2008). Photovoltaictechnologies. *EnergyPolicy, 36*, 4390–4396.

Basol, B.M., Aksu, S., Wang, J., Matus, T., & Johnson, T. (2008). Electroplating based CIGS technology for roll-to-roll manufacturing. *Proceedings of the 23rd European photovoltaic solar energy conference*, 2137–2141.

Bernama. (2009). Najib proffers conditional 40% carbon cuts at Copenhagen. . *http://www.themalaysianinsider.com/index.php/malaysia/46861-najib-proffers-conditional-40pc-carbon-cut*.

Neto, M.R.B., Carvalho, P.C.M., Carioca, J.O.B., & Ãstula, F.J.F. (2010). Biogas/photovoltaic hybrid power system for decentralized energy supply of rural areas. *Energy Policy, 38*(8), 4497-4506.

Carlson, D.E., & Wronskil, C.R. (1976). Amorphous silicon solar cell. Appl Phys Lett . *28*, 671.

CG. (2012). Best Practices in Photovoltaics *Clean & Green (San Francisco, CA). www.asyousow.org/health_safety/solar_report.shtml*.

Chaar, L.E., lamont, L.A., & Zein, N.E. (2011). Review of photovoltaic technologies. *Renewable and Sustainable Energy Reviews, 15*, 2165–2175.

Chandel, M., Agrawal, G.D., Mathur, S., & Mathur, A. (2014). Techno-economic analysis of solar photovoltaic power plant for garment zone of Jaipur city. *Case Studies in Thermal Engineering, 2*, 1-7.

Chen, C.S., Hsu, C.T., & Korimara, R. (2012). The Photovoltaic Generation System Impact on the Energy Demand of a Small Island and Its Financial Analysis. *Energy Procedia, 14*(0), 411-417

Chen W.N. (2012). Renewable Energy Status in Malaysia. *Sustainable Energy Development Authority Malaysia.*

Cheng J. H, Y.C.H., & Tu C.W. (2008). Trust and knowledge sharing in green supply chains. *Supply Chain Management: An International Journal, 13*, 283-295.

Chik, N.A., Rahim, K.A., Radam, A., & Shamsudin, M.N. (2013). Impact of Malaysian Industrial Energy Use on Carbon Dioxide Emissions. *Pertanika J. Social Science & Humanities, 21*(S), 13 - 28.

Chu, S.C., & OH, T.H. (2012). Solar energy outlook in Malaysia. *Renewable and Sustainable Energy Reviews, 16*, 564-574.

CIA. (2010). The World Fact Book, Malaysia; March 27, 2010. https://www.cia.gov/library/publications/the-world-factbook/geos/my.html.

CT. (2013). Solar PV Costs Will Fall By Half By 2020, But Prices Won't. *Clean Technica*.

Cucchiella, F., Adamo, I., Gastaldi, M., & Koh, S.C.L. (2012). Renewable energy options for buildings: Performance evaluations of integrated photovoltaic systems. *Energy and Buildings, 55*(0), 208-217.

Dahlan, N.Y., Jusoh, M. A., & Abdullah, W. N. A. (2014). Solar Grid Parity for Malaysia: Analysis Using Experience Curves. *2014 IEEE 8th International Power Engineering and Optimization Conference (PEOCO2014), Langkawi, The Jewel of Kedah,Malaysia. 24-25 March 2014*, 461-466.

Dincer, F., & Meral, M.E. (2010). Critical factors that affecting efficiency of solar cells. *Smart Grid and Renewable Energy, 1*, 47–50.

DOE. (2012). Photovoltaics: Technologies, Cost, and Performance. *Sun Shot Vision Study-2012 (U.S. Department of energy)*.

DOE, U.S. (2010). US$1/W Photovoltaic Systems Workshop Summary, US DOE, Washington, D.C.

DOE, U.S. (2012). Sunshot Vision Study, US DOE, Washington, D.C.

Dubey, S., Jadhav, N.Y., & Zakirova, B. (2013). Socio-Economic and Environmental Impacts of Silicon Based Photovoltaic (PV) Technologies. *Energy Procedia, 33*, 322 – 334.

Duffie, J.A., & Beckman, W.A. (2013). Solar Engineering of Thermal Processes. *John Wiley & Sons*.

EC. (1995). Externalities of Energy' Externe Project, dgxii, joule, Report No EUR 16520 EN.

EC. (1997). Energy for the future: Renewable Sources of Energy. White Paper, European Commission, DG XVII.

EC. (2012). National energy balance, Malaysia. *Energy commision, Malaysia*.

EC. (2013). PV Status Report (J R C scientific and policy report).*European commission Joint Research Centre*.

EIPT. (2009). Environmental impacts of photovoltaic technologies. *IEA PVPS Task 12, Subtask 20,LCA, Report IEA-PVPS T12-01*.

Eldada, L.A.F., Sang, B., Taylor, M., Lim, A., & Taylor, J. (2008). Development of hybrid copper indium selenide photovoltaic devices by the FASST printing process. *Proceedings of the 23rd European photovoltaic solar energy conference*, 2142–2146.

EPA. Non-Hydroelectric Renewable Energy. *(http://www.epa.gov/cleanenergy/energy-and-you/affect/non-hydro.html).*

EPIA. (2011a). Solar Generation. *European Photovoltaic Industry Association and Greenpeace, www.epia.org., 6*.

EPIA. (2011b). Solar Generation 6: Solar Photovoltaic Energy Empowering the World, *European Photovoltaic Industry Association*.

EPIA. (2012a). Market Report 2011. *European Photovoltaic Industry Association*.

EPIA. (2012b). Market Report 2011, Brussels. *European Photovoltaic Industry Association*.

EPIA. (2012c). Sustainability of Photovoltaic Systems: The Water Footprint [fact sheet] *European Photovoltaic Industry Association (Brussels, Belgium, EPIA Sustainability Working Group).*

EPIA. (2013a). Global market outlook for Photovoltaics 2013-2017. *European Photovoltaic Industry Association*.

EPIA. (2013b). Global Market Outlook for Photovoltaics 2013-2017. *European Photovoltaic Industry Association*.

EPIA. (2013c). Solar Photovoltaic Electricity Empowering the World (http://www.epia.org/publications/epiapublications/solargeneration-6.html). *European Photovoltaic Industry Association*.

EPRI. (2003). Potential Health and Environmental Impacts Associated with the Manufacture and Use of Photovoltaic Cells *Electric Power Research Institute*.

Erge, T.H.L.C. (2003). PV in buildings for Malaysia: prototype solar house in Photovoltaic Energy Conversion. *Proceedings of 3rd World Conference*.

Fantazzini, D., Höök, M., & Angelantoni, A. (2011). Global Oil Risks in The Early 21st Century *Energy Policy, 39*(12), 7865-7873.

Fawcett, S.E., Magnan, G.M., & Carter, M.W. (2008). Benefits, barriers, and bridges to effective supply chain management, Supply Chain Management. *An International Journal of Hydrogen Energy, 13*, 35–48.

Feldman, D., Barbose, G., Margolis, R.,Wiser, R., Darghouth, N., & Goodrich, A. (2012). Photovoltaic (PV) Pricing Trends: Historical, Recent, and Near-Term Projections. *SunShot, U.S. Department of Energy*. *http://www.osti.gov/bridge*.

Fong, W.K., Matsumoto, H., Lun, Y.F., & Kimura, R. (2007). System Dynamic Model for the Prediction of Urban Energy Consumption Trends. *6th International Conference on Indoor Air Quality, Ventilation & Energy Conservation in Buildings (IAQVEC 2007), Sendai, Sendai, Japan.*

Franklin, E.V., Blakers, A., & Weber, K. (2007). Sliver solar cells: high-efficiency low cost PV technology. *Advances in OptoElectronics 2007*.

Frisson, L., Bruton, T., & Declercq, K. (2000). Recent improvements in industrial PV module recycling. *16th European Photovoltaic Solar Energy Conference; Glasgow, UK.*

Fthenakis, V., & Kim, H.C. (2009). Land use and electricity generation: a life-cycle analysis. *Renewable and Sustainable Energy Reviews, 13*, 1465–1474.

Fthenakis, V., & Kim, H.C. (2010). Life-cycle uses of water in U.S. electricity generation. *Renewable and Sustainable Energy Reviews, 14*, 2039–2048.

Fthenakis, V.M., Kim, H.C., & Alsema, E. (2008). Emissions from photovoltaic life cycles. *Environmental Science and Technology, 42*, 2168–2174.

Gan, P.Y., & Li, Z.D. (2008). An econometric study on long-term energy outlook and the implications of renewable energy utilization in Malaysia. *Energy Policy*, *36*, 890-899.

GCE. (2013). Global Carbon Emissions, CO2 Now. Current CO2. *CO2 now.org*.

Graebig, M., Bringezu, S., & Fenner, R. (2010). Comparative analysis of environment impacts of maizebiogas and photovoltaics on a land use basis. *Solar Energy*, *84*, 1255–1263.

GREA. (2010). Solar Parks: Opportunities for Biodiversity. *German Renewable Energy Agency (accessed February 22, 2012). 45*.

Green, M.A., Chang, N., Clugston, D., Egan, R., Evans, R., Hogg, D., Jarnason, S. K.M., Lasswell, P., Sullivan, J.O., Schubert, U., Turner, A.,Wenham, S.R., & Young, T. (2004). Crystalline silicon on glass (CSG) thin-film solar cell modules. *Solar Energy, 77*, 857-863.

Green, M.A., Emery, K., Hishikawa,Y., Warta, W., & Dunlop, E.D. (2013). Solar cell efficiency tables (version 41). *Progress in Photovoltaics, 21*, 1.

GTS. (2013). Solar PV Module Costs to Fall to 36 Cents per Wby 2017 Retrieved 28 June 2013. *greentech solar*.

Gupta, S. (1989). Scope for solar energy utilization in the Indian textile industry. *Solar Energy, 42*, 311-318.

Haris, A.H. (2008a). MBIPV Project: catalyzing local PV market. *Finance & Investment Forum on PV Technology, : http://www.mbipv. net.my/dload/FIF-HH.pdf.*

Haris, A.H. (2008b). MBIPV Project: Catalyzing Local PV Market, Finance & Investment Forum on PV Technology, KualaLumpur, Malaysia.

Hasanuzzaman, M., Rahim, N.A., Hosenuzzaman, M., Saidur, R., Mahbubul, I.M., & Rashid, M.M. (2012). Energy savings in the combustion based process heating in industrial sector. *Renewable and Sustainable Energy Reviews, 16*(7), 4527-4536.

Hasanuzzaman, M., Rahim, N.A., Saidur, R., & Kazi, S.N. (2011). Energy savings and emissions reductions for rewinding and replacement of industrial motor. *Energy, 36*(1), 233-240.

Hashimoto, I. (2003). Present Status of Research and Development of PV Technology in Japan. *Proceedings of the 3rd IEEE World Conference on Photovoltaic Energy Conference*, 2522-2526.

Haw, L.C., Sopian,K., Sulaiman,K., Hafidz,M., & Yahya,M. (2009). Assessment of public perception on photovoltaic application in Malaysia urban residential areas usingTrudgill's frame work for analysis. *European Journal of Social Sciences, 8*(4), 589–603.

Hee, J.Y., Kumar, L.V., Danner, A.J., Yang, H. & Bhatia, C.S. (2012). The effect of dust on transmission and self-cleaning property of solar panels. *Energy Procedia, 15*, 421–427.

Hosenuzzaman, M., Rahim, N.A., Selvaraj, J., Hasanuzzaman, M., Malek, A.B.M.A. & Nahar, A. (2015). Global prospects, progress, policies, and environmental impact of solar photovoltaic power generation. *Renewable and Sustainable Energy Reviews, 41*, 284–297.

Huang, C.Y., Sung, C.H., & Yen, K.L. (2013). Experimental Study of Photovoltaic/Thermal (PV/T) Hybrid System *International Journal of Smart Grid and Clean Energy, 2*(2), 148-151.

IEA. (2010). Technology Roadmap (Solar photovoltaic energy). *International Energy Agency.*

IGES. (2004). Urban Energy Use and Greenhouse Gas Emission in Asian Mega Cities: Policies for a Sustainable Future. Kanagawa. *Institute of Global Environmental Strategies.*

Infantes, A.F., Contreras, J., & Agustin, J.L.B. (2006). Design of grid connected PV systems considering electrical, economical and environmental aspects:a practical case. *Renewable Energy. 31*, 2042–2062.

IPCC. (2007). Climate Change 2007: The Physical Science Basis. GenevaI. *ntergovernmental Panel on Climate Change*.

IRENA. (2012). Renewable energy technologies: cost analysis series (Solar Photovoltaics). *International Renewable Energy Agency, 1*(4/5).

IRENA. (2013). Renewable Power Generation Costs in 2012: An Overview. *International Renewable Energy Agency*.

Jaffar, A.J. (2009). Outlook of coal deand/supply &policy in malaysia,Cleaner coal:Moving towards Zero emmisions. *APEC.*

Jin, H., Qin, L., Hao, C.,Wang, L., & Jiao, F. (2011). The Study and Exploration of a New Generation of Photovoltaic Energy Storage System. *Energy Procedia 12*, 986-993.

Johari, A., Samseh, S.H., Ramli, M., & Hashim, H. (2012). Potential use of solar photovoltaic in peninsular Malaysia. *International Journal of Renewable Energy Resources, 2*, 1-5.

Jungbluth, N. (2005). Life cycle assessment of crystalline photovoltaics in the Swiss ecoinvent database. *Progress in Photovoltaics Application and Research, 13*(5), 429-446.

Kaldellis, J.K., & Kapsali, M. (2011). Simulating the dust effect on the energy performance of photovoltaic generators based on experimental measurements. *Energy & Environmental Science, 36*, 5154–5161.

Kamali, S.K.M. (2009). Feasibility analysis of a PV grid-connected System at University of Malaya Engineering Tower. *International Renewable Energy Congress*.

Kammen, D., Nelson, J., Mileva A., & Johnston, J. (2011). An Assessment of the Environmental Impacts of Concentrator Photovoltaics and Modeling of Concentrator Photovoltaic Deployment Using the SWITCH Model. *Berkeley, CA: Renewable and Appropriate Energy Laboratory, Energy and Resources Group, University of California at Berkeley*.

Kersten, F. (2011). PV Learning Curves: Past and Future Drivers of Cost Reduction, Proceedings of the 26th European Photovoltaic Solar Energy Conference, 5 – 9 September, Hamburg. *26th European Photovoltaic Solar Energy Conference, 5 – 9 September, Hamburg.*

KS. (2011). "Modules." Kyocera Solar. <*www.kyocerasolar.com/learn/modules.html*>.

KTAK. (2005). Energy Policy of Malaysia. *Ministry of Energy, Water and Communication.*

Kumar, R., & Rosen, M.A. (2011). A critical review of photovoltaic-thermal solar collectors for air heating. *Applied Energy, 88*, 3603–3614.

Lenardic, D. Large-scale photovoltaic power plants ranking 1–50 (http://www.pvresources.com/pvpowerplants/top50.aspx). *PVresources.com.*

Lesourd, J.B. (2001). Solar photovoltaic systems: the economics of a renewable energy resource. *Environmental Modelling & Software 16*, 147-156.

Lin, C.H., Hsieh, W.L., Chen, C.S., Hsu, C.T., Ku, T.T., & Tsai, C.T. (2011). Financial analysis of a large-scale photovoltaic system and its impact on distribution feeders. . *IEEE Trans. on Industry Applications, 47*, 1884-1891.

LSP. (2013). Solar PV Power Plants: Major Causes of Performance Degradation. *livingonsolarpower.wordpress.com/2013/06/10/solar-pv-power-plants-major-causes-of-performance-degradation/.*

Lynn, P.A. (2010). Electricity from Sunlight: An Introduction to Photovoltaics. 1st Chicester. *Wiley-Blackwell (an Imprint of John Wiley & Sons Ltd).*

M., P. (2006). The R&D potential of CIS thin-film solar modules. *Proceedings of the 21st European photovoltaic solar energy conference*, 1789–1795.

Mahlia, T.M.I., & Yanti P.A.A. (2010). Cost efficiency analysis and emissipn reduction by implementation of energy efficiency standards for electric motors. *Journal of cleaner production, 18,* 365-374.

Maranda, W.M. (2004). 1KWP photovoltaic system at the technical university of loddz. *OPTO electronics 12*(1), 75 -77.

Marian, B.A. (2005). performance parameters for grid connected PV system. *IEEE. Photovoltaic's specialist conference -Florida,*

Markvart, T.W. (2001). Solar electricity, *2*.

Martinot, E., & Sawin, J. (2009). Renewables Global Status Report 2009.(http://www.renewableenergyworld.com/rea/news/article/2009/09/renewables-global-status-report-2009-update? *Renewable Energy World.*

Masjuki, H.H., Mahlia, T.M.I., Choudhury, I.A., & Saidur, R. (2002). Potential CO2 reduction by fuel substitution to generate electricity in Malaysia. *Energy Conversion and Management, 43*, 763–770.

MBIPV. (2006). International Reviews of Regulatory Schemes for PV. *Malaysia Building Integrated Photovoltaic (MBIPV).*

MBIPV. (2007). Milestone Report for the Launching of National SURIA 1000 Programme. *Malaysia Building Integrated Photovoltaic (MBIPV).*

MBIPV. (2009). PV Industry Handbook 2009. PTM. *Malaysia Building Integrated Photovoltaic Project.MBIPV http://www.mbipv.net.my/dload.*

MCDE. (2014). Malaysia Carbon Dioxide Emissions. *https://ycharts.com/indicators/malaysia_carbon_dioxide_emissions*.

MEGTW. (2010). Ministry of Energy, Green Technology and Water Official. March 27, 2010. http://www.kettha.gov.my/default.asp.

Meij, R.W. (2007). The emissions of heavy metals and persistent organic pollutants from modern coal-fired power stations. *Atmospheric Environment, 41,* 9262–9272.

Mekhilef, S., Safari, A., Mustaffa, W.E.S., Saidur, R., Omara, R., & Younis, M.A.A. (2012). Solar energy in Malaysia: Current state and prospects. *Renewable and Sustainable Energy Reviews, 16,* 386– 396.

Mekhilef, S., Saidur, R., & Safari, A. (2011). A review on solar energy use in industries. *Renewable and Sustainable Energy Reviews, 15*, 1777–1790.

Mendonca, M., Jacobs, D., & Sovacool, B. (2010). The Feed-in Tariff Handbook. *Powering the Green Economy*.

MIDA. Malaysian Industrial Development Authority. March 27, 2010. http://www.mida.gov.my/en v2/.

Midtgard, O.M., Sætre, T.O., Yordanov, G., Imenes, A.G., & Nge, C.L. (2010). A qualitative examination of performance and energy yield of photovoltaic modules in southern Norway. *Renewable Energy, 35,* 1266–1274.

ML. (2014). MalaysiaLand-Land for Sale, Commercial, Industrial, Factory, Residential, Agriculture land in Malaysia, Kuala Lumpur, Selangor, Sabah, Sarawak. *malaysialand.com*.

Mohamed, A.O.H. (2012). Effect of Dust Accumulation on Performance of Photovoltaic Solar Modules in Sahara Environment. *Journal of Basic and Applied Scientific Research, 2*(11), 11030-11036.

Mondol, J.D., & Hillenbrand, S.K. (2013). Grid parity analysis of solar photovoltaic systems in Europe. *International Journal of Ambient Energy.*

MP. 10 th Malaysia Plan, Chapter 6: Building an Environment that Enhances Quality of Life. *10 th Malaysia Plan,*, 245-311.

MPIA. (2010). Malaysian PV industry association, March 27, 2010. http://www.mpia.org.my/ *Malaysian PV industry association*.

Mueller, A., Wambach, K., & Alsema, E. (2005). Life cycle analysis of a solar module recycling process. *20th European Photovoltaic Solar Energy Conference, Barcelona, Spain.*

Muneer, T., Asif, M., & Munawwar, S. (2005). Sustainable production of solar electricity with particular reference to the Indian economy. *Renewable and Sustainable Energy Reviews, 9,* 444–473.

Muneer, T., Maubleu, S., & Asif, M. (2006). Prospects of solar water heating for textile industry in Pakistan. *Renewable and Sustainable Energy Reviews, 10*(1), 1-23.

Nguyen, K.Q. (2007). Alternatives to grid extension for rural electrification: Decentralized renewable energy technologies in Vietnam. *Energy Policy, 35*(4), 2579-2589.

Shaliza, M.S., Zainura, Z. N., Haslena, H., Zaini, U., & Juhaizah, T. (2011). Projection of CO2 Emissions in Malaysia. *Environmental Progress and Sustainable Energy. Wiley Online Library, 30*(4), 658–665.

Notton, G., Cristofari, C., Mattei, M., & Poggi, P. (2005). Modelling of a double-glass photovoltaic module using finite differences. *Appled Thermal Eng., 25*, 2854–2877.

Oliver, M., & Jackson, T. (1999). The market for solar photovoltaics. *Energy Policy, 27*, 371–385.

Parida, B., Iniyan, S., & Goic, R. (2011). A review of solar photovoltaic technologies. *Renewable and Sustainable Energy Reviews, 15*(3), 1625-1636.

Pearce, J. (2002). open access "Photovoltaics – A Path to Sustainable Futures" (http://mtu.academia.edu/JoshuaPearce/Papers/1540219/Photovoltaics

PELE, A.F. (2012). PV industry looks to a bright future. *www.eetimes.com/document.asp?doc_id=1279960*.

Peng, J., Lu, L., & Yang, H. (2013). Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems *Renewable and Sustainable Energy Reviews, 19*, 255–274.

Koch, V.P., Hezel, R., & Goetzberger, A. (2009). Mile stones of Solar Conversion and Photovoltaics.in:High-Efficient Low-Cost Photovoltaics. *Springer Berlin,Heidelberg*, 1–5.

PVET. (2014). PV spot price-pv contract price update on 12/03/2014. *pv.energytrend.com/pricequotes.htm*.

PVI. (2014). Solar PV Module Weekly Spot Price. *PVinsights.com*.

Raugei, M., Isasa, M., & Palmer, P.F. (2012). Potential Cd Emissions from end-of-life CdTe. *International Journal of Life Cycle Assess. , 17*, 192–198.

Raugei. M.B., & Ulgiati, S. (2007). Lifecycleassessmentandenergypay-back time of advanced photovoltaic modules:CdTe and CIS compared to poly-Si. *Energy, 32*, 1310–1318.

Ray, k.I. (2010). photovoltaic cell efficience at elevated temperatures.

Reinhard, H. (2006). Demand side value of PV. PV Upscale-Urban Scale Photovoltaic Systems, Vienna. *Report of the IEE project*.

REN21. (2009). Renewables Global Status Report: (http://www.ren21.net/REN21Activities/GlobalStatusReport.aspx) 9.

REN21. (2011). Renewables 2011. *Global Status Report*, 22.

Repins, I.C.M., Egaas, B., DeHart, C., Scharf, J., & Perkins, C.L, (2008). 19.9% efficient ZnO/CdS/CuInGaSe2 solar cell with 81.2% fill actor. Prog Photovoltaics Res Appl. *16*, 235–239.

RI. (2013). Global Solar PV installed Capacity crosses 100GW Mark. renewindians.com (11 February 2013).

Rosenzweig, V.V., & Volarević, H. (2010). creation of optimal performance of an investment project. *Croatian Operational Research Review (CRORR), 1*.

Saidur, R., Hasanuzzaman, M., Mahlia, T.M.I., Rahim, N.A., & Mohammed, H.A. (2011). Chillers energy consumption, energy savings and emission analysis in an institutional buildings. *Energy, 36*(8), 5233-5238.

Saidur, R., Rahim, N.A., & Hasanuzzaman, M. (2010). A review on compressed-air energy use and energy savings. *Renewable and Sustainable Energy Reviews, 14*(4), 1135-1153.

Saidur, R., Sambandam, M., Hasanuzzaman, M., Devaraj, D., Rajakarunakaran, S., & Islam, M. (2012). An energy flow analysis in a paper-based industry. *Clean Technologies and Environmental Policy*, *14*(5), 905-916.

Sánchez, R.C.R., Milone, D.H., & Buitrago, R.H. (2010). Efficiency study of different photovoltaic plant connection schemes under dynamic shading. *International Journal of Hydrogen Energy, 35*(11), 5838–5843.

Sander, K., Schilling, S., Wambach, K., Schlenker, S., Müller, A., & Springer, J. (2007). Study on the development of a return and recovery system for photovoltaic products. *Institute for Environmental Strategies; Okopol Germany.*

Sapuan, N.M., Roly, M.R., & Rahim, K.B.A. (2013). Analyzing Carbon Dioxide Emission from Energy Resources. *World Applied Science journal, 23*, 17-21.

SC. (2011). Crystalline Silicon Technology, *SCHOTT Solar http://www.us.schott.com/photovoltaic/english.*

Schuman, M. (2012). How High Will Global Oil Prices Rise? *in Time: Business, Time Inc. US.*

SE. (2013). how solar cells work. *Solar Energy, http://energybible.com/solar_energy/solar_cells.html. http://india.gov.in/allimpfrms/alldocs/15657.pdf. http://www.pvresources.com/introduction/historicaloverview.aspx.*

SEDA. (2014). Amended Schedule for Solar PV effective from 15th March 2014. *ww.seda.gov.my*.

Seng, A.K. (2010). *Handbook for Solar Photovoltaic(PV) Systems*

Seng, L.Y., Lalchand, G., & Lin, G.M.S. (2008). Economical, environmental and technical analysis of building integrated photovoltaic systems in Malaysia. *Energy Policy, 36*, 2130–2142.

Chen, X.C.S. (2009). 30 KW solar power generation system application and operation. *Power Electronics, 10*, 42-44.

Shenck, N.S. (201). Alternative energy systems. *U.S. Naval Academy Lecture Readings*.

Shijun, Y., & Hongxing, Y. The Potential Electricity Generating Capacity of BIP In Hong Kong. *IEEE Xploree*, 1345 –1348.

SHLSC. (2014). solar panel prices, solar panel Malaysia, Singapore, Thailand, Chile, Colombia, Mexico, South Africa, Canada. *ALIbaba.com (Shandong Hilight-Solar Co., Ltd.)*.

SHM. (2008). Solar homes for Malaysia. *The Star Online; Tuesday July 8, 2008.http://thestar.com.my/lifestyle/story.asp?file=/2008/7/8/lifefocus/21669019 &sec=lifefocus.*

SHS. (2014). 300MW solar panel prices,solar panel Malaysia, Singapore, Thailand, Chile, Colombia, Mexico, South Africa, Canada. *Alibaba.com*.

Singh, P., & Ravindra, N.M. (2012). Temperature dependence of solar cell performancean analysis. *Solar Energy Materials and Solar Cells,, 101*, 36–45.

SIRIM. (2010). SIRIM Berhad. March 27, 2010. http://www.sirim.my/about us.asp.

Smestad, G.P., Krebs, F.C., Lampert, C.M., Granqvist, C.G., Chopra, K.L., Mathew, X., & Takakura, H. (2008). Reporting solar cell efficiencies in Solar Energy Materials and Solar Cells. . *Solar Energy Materials and Solar Cells, 92*(4), 371-373.

SO. (2006). Press: Govt launches solar energy panel programme for homes. *The Star Online; November 27, 2006 , http://www.mbipv.net.my/news1/2006/*

Solangi, K.H., Islam, M.R., Saidur, R., Rahim, N.A., & Fayaz, H. (2011). A review on global solar energy policy. *Renewable and Sustainable Energy Reviews, 15*(4), 2149-2163.

Solar, A. *http://www.antec-solar.de.*

Solar, F. *http://www.firstsolar.com/.*

SP. (2014a). Blue Carbon poly pv sunpower solar panel 300W. *Alibaba.com*.

SP. (2014b). Hot Sale sunpower 300W poly pv flexible solar panel manufacturer with TUV CE IEC certificate from China in low price. *Alibaba.com*.

SP. (2014c). Import sunpower mono solar panel 200w 250w 300w. *Alibaba.com*.

Sukk, F.M., Abu-Bakar, S.H., Munir,A.B., Yasin, S.H.M., Iniguez, R.R., McMeekin, S.G., Stewart , B.G., Sarmah, N., Mallick, T.K., Rahim, R.A., Karim, M.E., Ahmad, S., & Tahar, R.M. (2014). Feed-in tariff for solar photovoltaic: The rise of Japan. *Renewable Energy, 68*, 636-643.

Sukki, F.M., Iniguez, R.R., Bakar, S.H.A., McMeekin, S.G., & Stewart, B.G. (2011). An evaluation of the installation of solar photovoltaic in residential houses in Malaysia: Past,present,and future. *Energy Policy*, *39*, 7975–7987.

Sulaiman, S.A., Hussain, H.H., & Razali, N. (2011). Effects of dust on the performance of PV panels. *World Academy of Science Engineering and Technology, 58*, 588–593.

Surek, T. (2010). The Race to Grid Parity: Crystalline Silicon vs. Thin Films, Surek PV Consulting.

Svensson, G. (2007). Aspects of sustainable supply chain management (SSCM): conceptual framework and empirical example, Supply Chain Management. *An International Journal of Hydrogen Energy*, *12*, 262–266.

TESEA. (2012). Towards A 100% Electrified Southeast Asia, http://theenergycollective.com/benisuryadi/60017/towards-asean-100-electrified.

Tiwari, G.N.D. (2010). Fundamentals of Photovoltaic Modules and Their Applications. *Indian Institute of Technology (IIT), RSC publishing,*, 99-100.

Tour, A.D.L., Glachan, M., & Ménière, Y. (2013). What cost for photovoltaic modules in 2020?, Lessons from experience curve models. *Interdisciplinary Institute for Innovation, CERNA, MINES ParisTech*.

Tsoutsos, T., Frantzeskaki, N., & Gekas, V. (2005). Environmental impacts from the solar energy technologies. *Energy Policy, 33*(3), 289-296.

Turney, D., & Fthenakis, V. (2011). Environmental impacts from the installation and operation of large-scale solar power plants. *Renewable and Sustainable Energy Reviews*, *15*, 3261-3270.

Tyagi, V.V., Rahim, N.A.A., Rahim, N.A., Selvaraj, J.A.L. (2013). Progress in solar PV technology: Research and achievement. *Renewable and Sustainable Energy Reviews, 20*, 443–461.

US-EPA. (2009). The National Study of chemical residues in lake fish tissue. Washington, DC. *U.S. Environmental Protection Agency*.

Yamaguchi, M. (2001). Present status and prospects of photovoltaic technologies in Japan, Toyota Technological Institute, 2-12-1 Hisakata, Tempaku, Nagoya 468-8511, Japan. *Renewable and Sustainable Energy Review*, *5*, 113-135.

Yang, H. (1999). Development and prospect of solar energy photovoltaic in China. . *Power Supply Technologies and Applications, 2*(3), 43-45.

Zhang, J., Fu, M., Geng, Y., & Tao, J. (2011). Energy saving and emission reduction: A project of coal-resource integration in Shanxi Province, China. *Energy Policy, 39*(6), 3029-3032.

APPENDIX A

Related Publications

Journal:

1. **M. Hosenuzzaman**, N.A. Rahim, J. Selvaraj, M. Hasanuzzaman, A.B.M.A. Malek, A. Nahar, Global prospects, progress, policies and environmental impact of solar photovoltaic power generation, Renewable & Sustainable Energy Reviews, 41, (2015) PP 284-297 (**Q1, IF:5.51**.).

2. **M. Hosenuzzaman**, N.A. Rahim, J. Selvaraj, M. Hasanuzzaman, An analysis of economic flexibility and environmental impact of 30 MW solar photovoltaic plants in Malaysia, Energy (Under Review) **(Q1, IF:4.159)**

3. **M. Hosenuzzaman**, N.A. Rahim, J. Selvaraj, M. Hasanuzzaman, Environmental Impact Assessment of 30MW PV Power Plants in Malaysia (Under preparation for submission)

Conference:

4. **M. Hosenuzzaman**, N.A. Rahim, J. Selvaraj, M. Hasanuzzaman, Factors affecting the PV based power generation, 3rd IET International Conference on Clean Energy and Technology 2014 (CEAT-2014), 24-26 November 2014,Session-1-C-2 ,RS-13, Renewable and sustainable sources (17.00 PM), Kuching, Sarawak, Malaysia.

5. **M. Hosenuzzaman,** N.A. Rahim, Jeyraj Selvaraj, M. Hasanuzzaman , Abdul Malek, A.B.M, Photovoltaic technology and its policies in Malaysia, *Proceeding of The 2nd Power And Energy Conversion Symposium (PECS 2014), Sustainable Renewable Energy Development for the Future*, 12 May 2014, Universiti Teknikal Malaysia. Melaka. PP 105-109.