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Life Cycle Cost Assessment of Photovoltaic Systems in the APEC Region

APEC Energy Working Group

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KEY ABBREVIATIONS

APEC	Asia-Pacific Economic Cooperation
C_I	Initial Investment Cost
C_{OMR}	Operation, Maintenance & Repair Cost
C_{rep}	Replacement Cost
C_{res}	Residual Value
EWG	Energy Working Group
LCCA	Life Cycle Cost Assessment/ Life Cycle Cost Analysis
LCOE	Levelized Cost of Energy
PV	Photovoltaic
ISO	International Organization for Standard
NS	Net Saving
SAPV	Stand-alone PV
SF	Solar Farm
SIR	Investment Ratio
NPV	Net Present Value
IRR	Internal Rate of Ratio
PB	Payback Period
ROI	Return of Investment
RPV	Rooftop PV
O&M	Operation & Maintenance
BOS	Balance of System

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FOREWORD

Environmental impact issues have never be put to rest in order to set things in ordeal with energy supply and demand. These issues have to be studied and be investigated into for the extraction of possible solutions, an Environmental Assessment (EA) method, namely the Life Cycle Assessment was developed in the early 90's and it is still used by a wide range of companies. LCA is the assessment of the environmental impact of a given product or service throughout its lifespan and it is one of the most well-known analysis methods which provide guidance on assuring consistency, balance, transparency and quality of to enhance the credibility and reliability of the results. LCA is a completely structured, comprehensive and internationally standardized method. It quantifies and qualifies all relevant emissions and resources consumed and the related environmental and health impacts and resource depletion issues.

Associated to LCA, another study of which covers the economic assessment upon implemented paradigm is the Life Cycle Cost Assessment (LCCA). LCCA is a process of evaluating the economic performance of a system over its entire life. Sometimes known as "whole cost accounting" or "total cost of ownership," LCCA balances initial monetary investment with the long-term expense of owning and operating the project. LCCA is based upon the assumptions that multiple design options can meet programmatic needs and achieve acceptable performance, and that these options have differing initial costs, operating costs, maintenance costs, and possibly different life cycles. In other words, LCCA will assist in providing the bigger picture of the project from economic point of view as well as environmental cost incurred throughout the project lifetime.

The EWG06 2017A Project, Economic and Life Cycle Analysis of Photovoltaic Systems in APEC Region towards Low-Carbon Society aims to prepare a documentation for APEC Member Economies especially APEC financial ministries can adopt or contextualize its applicability based on their respective circumstances according to such objectives:

I. Develop recommendation for report & guideline of economic and life cycle assessment of solar PV system for future development;
II. Creating a network of solar PV players and financial institutions in APEC economies for multilateral and regional cooperation;
III. Increase knowledge of participants and society on the environmental impact of solar PV systems through workshop and publication.

The project aligns with the APEC Member Economies undergoing policy and programme shifts to promote development of sustainable communities across the region. Furthermore, it follows the Energy Working Group's (EWG) Strategic Plan 2014-2018, which aims to promote energy efficiency and sustainable communities. The report and guidelines recommendation are intended to be develop using Life Cycle Analysis (LCA) and Life Cycle Cost Analysis (LCCA) tools to identify the most viable photovoltaic systems both in terms of environmental impact and economic.

The project is expected to be completed within timeframe of 11 months from January to November of 2018 with the following benefits:

- Enhancing cooperation among international energy agencies in utilizing LCA and LCCA report as reference tools in the PV industry.
- Policy recommendation to be based on LCA studies, analysis and issues.
- Strong communication highway as the report & guideline will be made accessible.
- Increase awareness among the PV industries & society on the environmental impact of the solar PV systems.

The Expert Meeting and Workshop are expected deliverables as a platform to discuss and brainstorm and agreed on a set of guidelines for the project as a whole whilst taking into account APEC regional expert's point of views in term of best practices and successful stories sharing from public and private sectors of APEC economies. This involvement shall promote capacity building among project beneficiaries and APEC economies experts which furthermore widen the scope of applied LCA & LCCA studies through real industrial player's case studies.

This report provides an update of the life cycle analysis (LCA) framework as well as the complete photovoltaic system case study assessment result and discussion of the subject.

EXECUTIVE SUMMARY

This report focuses on the Life Cycle Cost Assessments (LCCA) of Photovoltaic (PV) Systems; Solar Farm system, Solar Rooftop system and Solar for Rural electrification system. In particular, this report provides comprehensive descriptions of methods and models used when analysing the PV systems life cycle from cradle-to-grave.

The main objectives of this report are:

1. To develop an economic assessment of photovoltaic systems framework through Life Cycle Cost Analysis (LCCA) from cradle-to-grave.
2. To identify the economically viable photovoltaic systems (Solar Farm, BIPV and Stand-alone) based on its cost and return of investment period.
3. To infuse Life Cycle Cost Analysis as a tool for photovoltaic systems policy development.

In the first section, ‘APEC Region Photovoltaic Context’, best practices in PV systems within the APEC economies are documented. In addition, an overview of the performance of PV system in APEC member economies in South East Asia region.

In the second section, ‘Background’, a brief explanation on the background of the study that is carried out. It includes the approach of the study is conducted which align to the project objectives. Goal and scope definition explain to understand the overall economic impact of PV system that is studied. In addition, brief definition of each PV system studied.

In the third section, touch more on the case studies selected for each type of PV system. The case studies consist of five case studies from Malaysia, Thailand and Indonesia. Detail information of the case studies is included. In particular, Solar farm, Solar rooftop and Solar for rural electrification have been analysed in this study comparing real case study data to the experimental data in Microsoft Excel. The framework of the project is also is included in this section.

The extracted data of both indirect and direct energy consumption of the system are described in the fourth chapter, ‘Life Cycle Cost Assessment (LCCA)’. This section outlines the LCCA’s mechanism and the economic analysis that under this assessment. The mechanism consist of five steps which are:

1. Step 1: Establish framework design & Define analysis period.
2. Step 2: Determine activity timing.
3. Step 3: Estimate costs.
4. Step 4: Compute life cycle costs.
5. Step 5: Analyse results & Evaluate alternatives.

While, the economic analysis involved is consist of life cycle cost (LCC), levelized cost of energy (LCOE), net savings (NS), savings to investment ratio (SIR), net present value (NPV), internal rate of return (IRR) and payback period (PB). These calculations can be done using Microsoft Excel. The system boundary of LCCA is also mentioned in this section. The system boundary explains the phase involve throughout the PV system lifetime and highlight the cost involved.

Then, the gathered data is analysed are compiled and compare to layout the PV systems performance and viability over each design. The full report delivers a comprehensive set of practical guidelines for analytical PV system monitoring. Applied systematically, these guidelines will contribute to further increasing the performance of PV power plants.

1.0 APEC REGION PHOTOVOLTAIC CONTEXT

Asia-Pacific Economic Cooperation (APEC) is a regional economic forum organisation for 21 Pacific Rim member economies, which promotes a balanced, inclusive, sustainable, innovative and secure growth and by accelerating regional economic integration. In 2011, APEC had a population of about 2.77 billion people with an average annual rate of 0.9% from 1990 to 2011. On the other hand, the rest of the world grew at the rate of 1.5% per year from 2.99 billion to 4.09 billion during the same period [1].

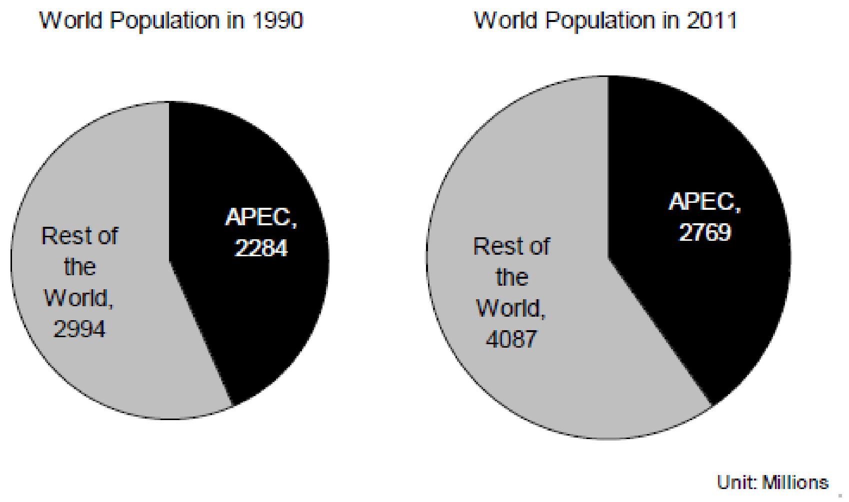


Figure 1. 1 APEC population in 1990 and 2011[1].

The population kept increasing to 2.8 billion recorded in 2014 but with a slower growth rate of 0.7% from 2013 [2]. Despite the slow population growth, APEC economies displayed significant increase of 3.8% (USD 54811 billion, in 2010 USD purchasing power parity [PPP]) in 2014 from the 2013 GDP levels of USD 52794 billion (2010 USD PPP) [2]. When compare the GDP from 2014 with the current GDP that have recorded (GDP [PPP] in 2017), it showed major increase of 26.8% (USD 69505.902 billion) from 2014 GDP levels. This increasing numbers of GDP year on year, indicated the economic growth and development of APEC members economies are moving in positive direction.

Solar energy is one of the common renewable energy (RE) resources in APEC member economies. The development of solar photovoltaic (PV) technology deployment however varies from economies to economies. In the past, solar PV technologies have been mainly deployed in remote off-grid areas as a viable option to provide energy services in isolated communities. More recently, with technological advancement and learning that result in declining system costs and improved performance, coupled with supportive investment policies and regulatory frameworks, grid-tied solar PV electricity generation in the APEC member economies has been increasing. Currently, China leads the pack with the highest amount of installed PV solar power. China contribute 23% of global installation. The is followed by The United States and Japan which ranked second (14%) and third (4%)

respectively [3]. These three economies are the most developed economies with the highest PV installed capacity not only in APEC member economies but also in the world.

Besides that, APEC member economies play very significant role in total global shipment of solar PV. According to market research in 2015, the total global shipment of solar PV amounted to 50.8 GW. The top four main contributors to the global shipment solar PV are all APEC member economies, in which China contributed about 48% (24.38 GW), followed by Chinese Taipei 20% (10.16 GW), Malaysia 12% (6.096 GW) and Japan 6% (3.048 GW) [4].

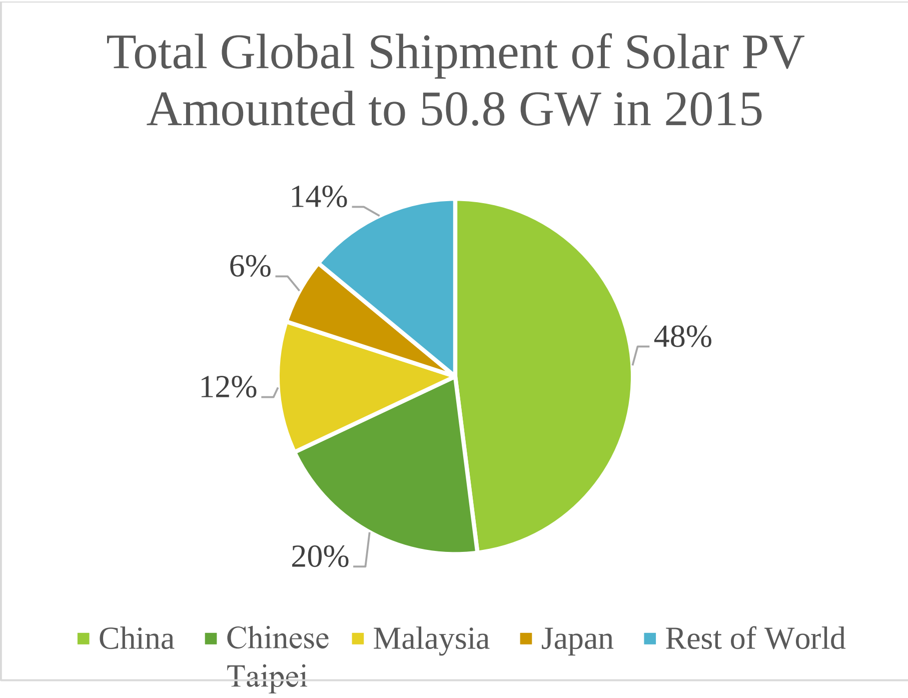


Figure 1. 2 Total global shipment of solar PV amounted to 50.8 GW in 2015.

1.1 APEC Member Economies in South East Asia Region

Meanwhile, in the APEC member economies in South East Asia part, which mostly are developing economies but the development on this technology are rapidly increase. The main contributor is due to the deployment in Malaysia and Thailand; the two first member economies (in South East Asia) that introduced the PV solar feed rate policies [5]. Capacity installed in Malaysia and Thailand alone represents about 95% of the total South East Asia PV solar capacity in 2014 [5]. A significant increase in solar PV installed between 2010 and 2014 can also be seen in Indonesia. Indonesia has introduced ceiling prices for solar power generation PV in 2013. Figure 1.3 shows the solar PV installed capacity in the Association of South East Asia Nations (ASEAN) member states [5].

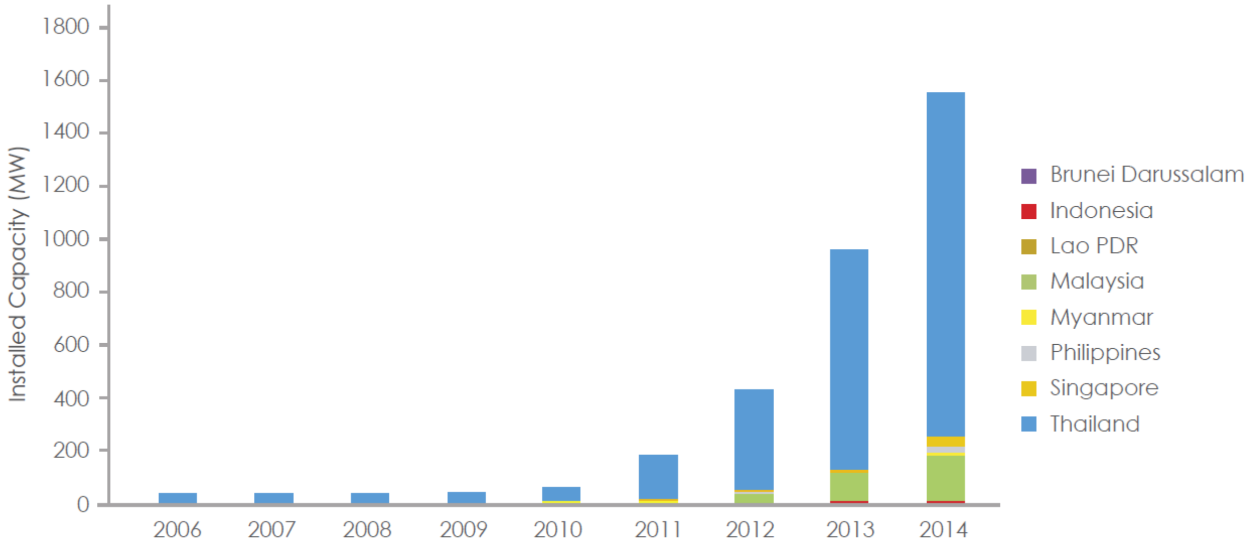


Figure 1. 3 Solar PV installed capacity in the ASEAN member states [5].

In addition, electricity tariff rates in the Philippines and Singapore are determined by market mechanisms and not subsidised. With the sharp decline of solar PV system costs since 2010, solar PV technology becomes an attractive option for both utility scale and rooftop installations in these Member States.

The same pattern can be observed in the solar PV deployment, an exponential increase can be seen from 2010 until present (Figure 1.4). Again, the increase mainly came from Malaysia and Thailand. The two Member States have combined generation share of more than 97% of the total solar PV electricity generation in the AMS in 2014.

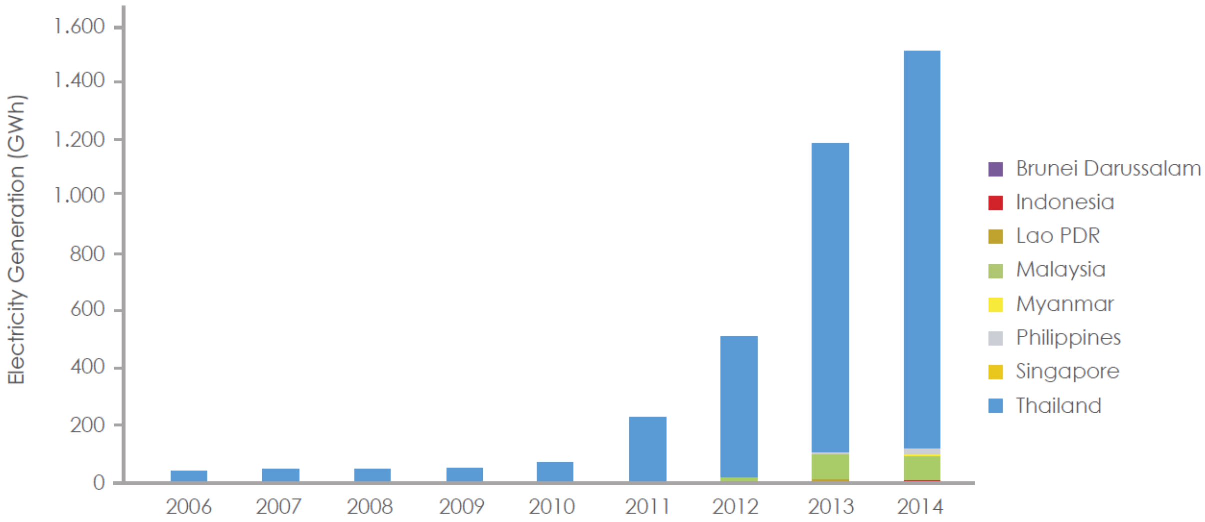


Figure 1. 4 Solar PV electricity generation in the ASEAN member states [5].

1.2 Solar PV Projects in South East Asia region

A total of 32 solar PV projects implemented in 4 participating AMS were analysed in this study. Almost two-thirds of these projects are from Malaysia while the remaining share are from Indonesia, Thailand and Viet Nam. Projects were classified into small (capacity below 100 kWp), medium (capacity above 100 kWp but below 1000 kWp) and large (capacity above 1000 kWp). In terms of capacity, more than one-half of the total samples are small while medium and large scale projects have almost the same number of samples. This is shown in Table 1.1.

Table 1. 1 Number of projects by ASEAN member states, by capacity size category

AMS	Number of Projects Analysed			
	Below 100 kWp	Above 100 kWp but below 1000 kWp	1000 kWp and above	Total
	small	*medium*	*large*	
Indonesia (ID)	-	-	2	**2**
Malaysia (MY)	12	6	3	**21**
Thailand (TH)	3	-	2	**5**
Viet Nam (VN)	2	1	1	**4**
TOTAL	**17**	**7**	**8**	**32**

2.0 BACKGROUND

2.1 Approach

This report concentrates mainly on the commercial use of photovoltaic solar energy technologies, such as solar farms, solar rooftop and solar stand-alone. This report is the result of a comprehensive study that uses a variety of primary and secondary data sources. This includes private communications with active professionals in related fields and industries, as well as documents and websites from various international, government, private, non-governmental, financial and academic organizations. Secondary sources include published reports, journal articles, reports in bulletin and renewable energy magazines, workshop proceedings and online news reports. All of the data is analysed by Microsoft Excel spreadsheet.

2.2 Objectives

This project is align to these objectives below:

4. To develop an economic assessment of photovoltaic systems framework through Life Cycle Cost Analysis (LCCA) from cradle-to-grave.
5. To identify the economically viable photovoltaic systems (Solar Farm, BIPV and Stand-alone) based on its cost and return of investment period.
6. To infuse Life Cycle Cost Analysis as a tool for photovoltaic systems policy development.

2.3 Goal and Scope Definition

The goal & scope definitions are stated as to understand the overall life cycle impact of the solar technology systems from manufacturing towards its end-of-life (Cradle-to-grave). The life cycle study shall be a process-based method. Project case studies include three photovoltaic systems which are a Solar Farm with power production more than 1 MWp and are set up on land, a Solar Rooftop with power production within the range of 500 kWp to 1 MWp. Also, a Stand-alone Solar for Rural Electrification with power production less than 100 kWp to 500 kWp.

The system is set to be normalized over certain basis for comparison purposes which are a polycrystalline or monocrystalline system, all the systems are expected to be matured with 2 years of operation, a commercial site, within the APEC economies only. The analysis will be using and Excel spreadsheet for LCCA.

The scope of study is to assume 25 years of lifetime for all photovoltaic system in three case studies based on a 2 years matured system. Referencing on Energy Commission Malaysia, there will be a 21 years of licensing and renewal for the whole system. Other economies cases shall be taken into account in term of LCCA lookout. Obligatory properties include quantification of system's power production, energy and economic cycle.

3.0 FOREGROUND DATA COLLECTION

3.1 Case Study

The data collection will be done on site of three economies chosen from the list of members in APEC region economies as shown in the Table 3.1 APEC member economies. Hence, for this project Malaysia, Indonesia and Thailand are chosen for the project's case study.

Table 3. 1 APEC member economies

Abbreviations	Member Economies	Date of Joining
AUS	Australia	Nov 1989
BD	Brunei Darussalam	Nov 1989
CDA	Canada	Nov 1989
CHL	Chile	Nov 1994
PRC	People's Republic of China	Nov 1991
HKC	Hong Kong, China	Nov 1991
INA	Indonesia	Nov 1989
JPN	Japan	Nov 1989
ROK	Republic of Korea	Nov 1989
MAS	Malaysia	Nov 1989
MEX	Mexico	Nov 1993
NZ	New Zealand	Nov 1989
PNG	Papua New Guinea	Nov 1993
PE	Peru	Nov 1998
PH	The Republic of the Philippines	Nov 1989
RUS	The Russian Federation	Nov 1998
SGP	Singapore	Nov 1989
CT	Chinese Taipei	Nov 1991
THA	Thailand	Nov 1989
USA	United States	Nov 1989
VN	Viet Nam	Nov 1998

The case studies are expected to be within the APEC economies region to forecast great applicable report and guidelines. The case studies selection criteria has been agreed to be a matured system of more than 2 years of operation, a Polycrystalline or Monocrystalline photovoltaic modules system with an estimated lifetime of 25 years. It must be within the equatorial climate economy of similar solar irradiation period such as Malaysia, Thailand, and Indonesia. There are three categories for the case studies:

1. Solar farm, a system more than 1MW
2. Solar Rooftop, a system within the range of 500kW ~ 1MW
3. Stand-alone Solar, a system within 100kW ~ 500KW

The three categories for case studies will be initially evaluated from within Malaysia and also from other economies of similar climate that are proposed by the experts which are Indonesia and Thailand. This is due to evaluating other APEC economies point of view and shall widen the policy review as well as measures taken for photovoltaic systems. Other than that, the capacity factor for usual solar PV site is only 16~17% from whole expected system outcomes will be taken into account for each case studies.

3.1.1 Stand-alone PV system

Stand-alone PV system is a system that are not connected to the electricity grid. Stand-alone systems are typically small and supported by one array of balance of system. It is usually preferred to be installed in the rural area to satisfy the energy demand only without generating profit. At which point, if the demand is high, there are cases to which it become a stand-alone solar farm, with the availability of land space and initial investment. Stand-alone systems vary widely in size and application from wristwatches or calculators to remote buildings or spacecraft. If the load is to be supplied independently of solar insolation, the generated power is stored and buffered with a battery.

The balance of system for a stand-alone PV system is as shown in Figure 3.1 below. The whole system is usually connected to one string (one string usually holds 20 PV modules) due to its small generation. The generated DC current walkthrough the charge controller, which plays the important role in preventing battery from being overcharged and also it dissipating excess power from load resistance. Then, there is fuse and isolation switch that protect PV from accidental shorting our wires and automate switch off when it is not required. The fuse and isolation switch are optional to the complete system but implementing it can save energy and improve battery life.

Battery bank are typical for a stand-alone system since it store excess energy generated and allow flexible time of usage during nighttime. Then, the electricity is directed to the DC load demand before going to the inverter and convert into AC current for the AC load.

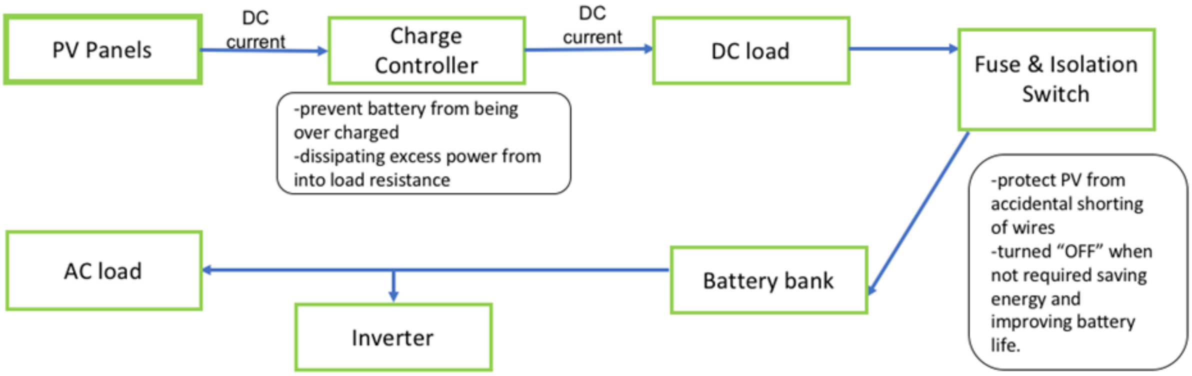


Figure 3. 1 Solar-alone PV system components and BOS

a) Case Study 1: Malaysia

The stand-alone PV system is located in a plantation rural area without electricity grid in Lenggeng, Seremban, Malaysia as illustrated as a map in Figure 3.2 below. The system is personally owned by the family since 2015. PV system is installed over a slanted-roof with a common BOS, completely utilized by the single vacation house for less than 24 hours a day. It's said that the electricity supply satisfy the demand and even have excess stored in the battery bank.

Figure 3. 2 Lenggeng, Seremban, Malaysia

The system is completely for personal use due to the unavailability of the electricity grid on the area and thus called as the smart house as shown in Figure 3.3. Other than that, problem also occurs throughout the operation, on which the energy stored in the battery is loss due to degradation and malfunctioning of the battery itself. Battery storage barely last for few months with every 3 month of maintenance and service. This highlight on the real case is that the quality of electrical component used in the balance of system is lacking.

Figure 3. 3 Smart House at Lenggeng, Malaysia

The following parameters were collected according to the Case Study.

1) Location : Lenggeng, Seremban (2.43’N, 101.57’E)
2) Effective area : 19.44 m^2
3) Irradiation : 1573.15 kWh/m2/year
4) Number of PV panel : 12 unit
5) Type of PV panel : Monocrystalline PV
6) Module-rate efficiency : 15%
7) System’s performance : 0.75
8) System timeframe : 2015 – 2040
9) Expected lifetime of BOS
    a) PV module warranties : 25 years with every 3 month of maintenance.
    b) Degradation ratio for PV : 0.59% per year
    c) Inverters : 1 unit (25 years with one replacement)
    d) Battery : 12 unit (3 years)
    e) Electric installation : 30 years

f) Mounting Structure : 30 years

10) Average grid electricity mix {MY} : 46.3% Gas + 41.0% Coal + 10.7% Hydro

Based on the ground energy production since 2016 of system installation, energy generated per year (kWh/year) stretches for 25 years of expected lifetime are as exemplified in Figure 3.4.

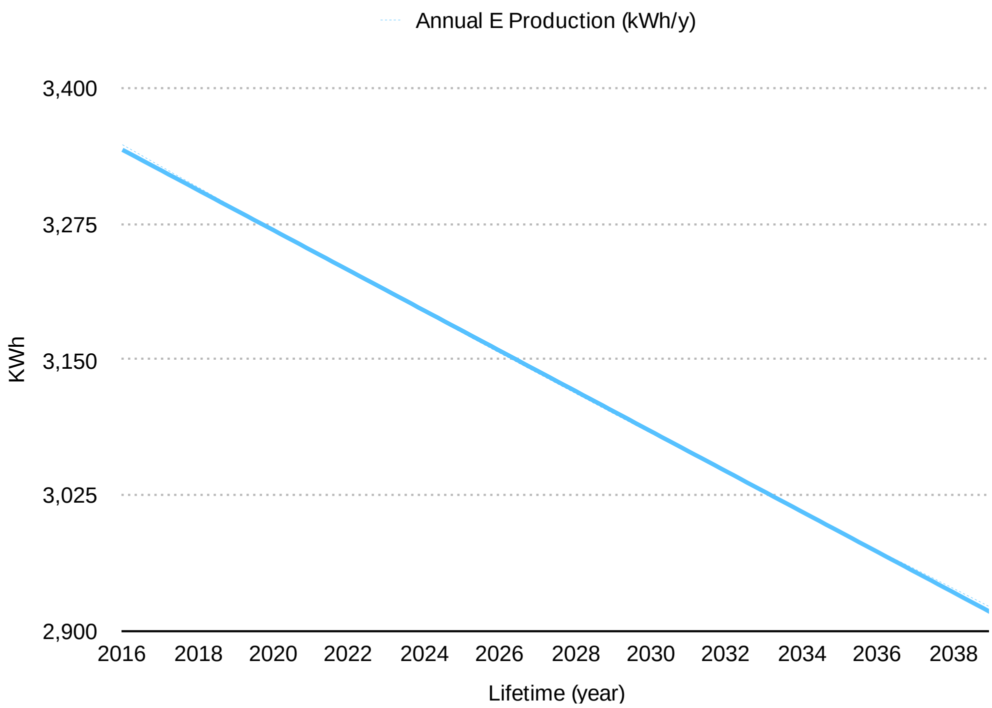


Figure 3. 4 Annual Energy Production Case Study 1, Malaysia

According to the historical data of electricity generation for 2016 and 2017, it is known that the power production has reduced to a factor of 0.59%. This value can be due to PV panel degradation ratio per year and also influenced by the average solar irradiance. The PV panel are expected to degrade over time depending on the production process. Hence, the annual production are forecasted to having similar reduction in the following years.

3.1.2 Solar Rooftop System

Solar rooftop system is a common preferable system since it occupies unused space on a building's roof. It can be mounted on a flat-roof and slanted-roof, this versatility satisfy the purpose of building green upgrade. This system is often mixed up with building integrated photovoltaic (BIPV), there are major differences in the balance of system between the two. Solar rooftop BOS is similar to that of stand-alone system, added to an existing building. However, BIPV BOS is a panel system that are built into the building's façade, windows and roof during its construction.

The typical balance of system for a solar rooftop PV system is as shown in Figure 3.5 below. The system varies in term of scale size and design as to fit the available rooftop position that maximize the solar irradiation per day. Variation of rooftop system has been commercialized, some are connected to battery banks, and others are grid-connected in order to maximize the power production over lower cost, depending on the demand and suitability.

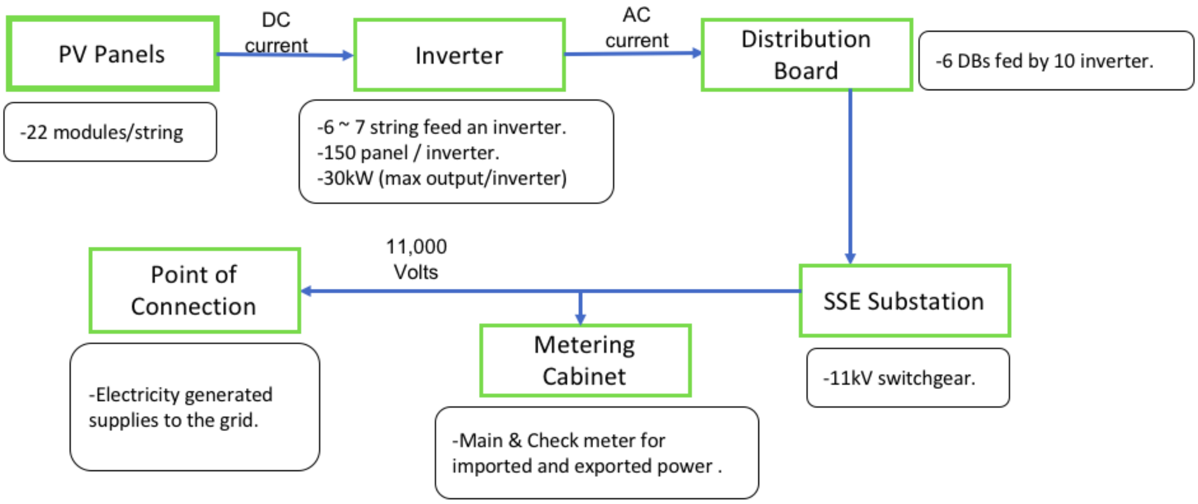


Figure 3. 5 Rooftop PV system components and BOS

The balance of system for a rooftop PV system can be one string or more, in accordance to the market, one string can fit up to 20 PV modules. The generated DC current is convert into AC through the inverter which can uphold about 6 to 7 string. If the system production is big enough, distribution board is needed for load power distribution that can be fed by 10 inverter. If the power production does not reach up to 10 inverter, distribution board are not necessary and are connected via Stand-alone system. SSE substation is required as 11kV switchgear to manage the voltage of the system before being exported to the grid. If necessary, transformer can be include into the loop before exporting the electricity.

Battery bank are typical for a stand-alone system since it store excess energy generated and allow flexible time of usage during nighttime. Then, the electricity is directed to the DC load demand before going to the inverter and convert into AC current for the AC load.

a) Case Study 1: Malaysia

The rooftop system is mounted on a slightly tilted rooftop of SK South Asia Sdn Bhd factory in Seberang Perai, Penang, Malaysia. The system is a collaboration between the factory to provide space and Pensolar to which supply the energy generator. It’s the only factory to which installed this green technology in the industrial area.

Although the area of the rooftop is large and perfect to accommodate this system to its maximum solar harvesting, the industrial area itself contribute a lot of dust and soot which affect the system greatly in term of condition maintenance. Frequent cleaning maintenance is required to keep the system at its full efficiency capacity.

Although the area of the rooftop is large and perfect to accommodate this system to its maximum solar harvesting, the industrial area itself contribute a lot of dust and soot which affect the system greatly in term of condition maintenance. Frequent cleaning maintenance is required to keep the system at its full efficiency capacity.

Figure 3. 6 Large Scale Factory Rooftop PV System, Malaysia

The following parameters were collected according to the Case Study 1:

1)	Location	: SK South Asia Sdn Bhd, Seberang Perai, Penang (5.22’N 100.24’E)
2)	Effective area	: 2138.4 m^2
3)	Irradiation	: 1685.39 kWh/m2/year
4)	Number of PV panel	: 1320 unit
5)	Type of PV panel	: Polycrystalline PV

6) Module-rate efficiency : 15%
7) System's performance : 0.75
8) System timeframe : 2017 - 2042
9) Expected lifetime of BOS
    a) PV module warranties : 25 years with every 3 month of maintenance.
    b) Degradation ratio for PV : 0.23% per year
    c) Inverters (500kW) : 8 unit (25 years with one replacement)
    d) Electric installation : 30 years
    e) Mounting Structure : 30 years
10) Average grid electricity mix {MY} : 46.3% Gas + 41.0% Coal + 10.7% Hydro

Based on the ground energy production since 2017 of system installation, energy generated per year (kWh/year) stretches for 25 years of expected lifetime are as exemplified in Figure 3.7.

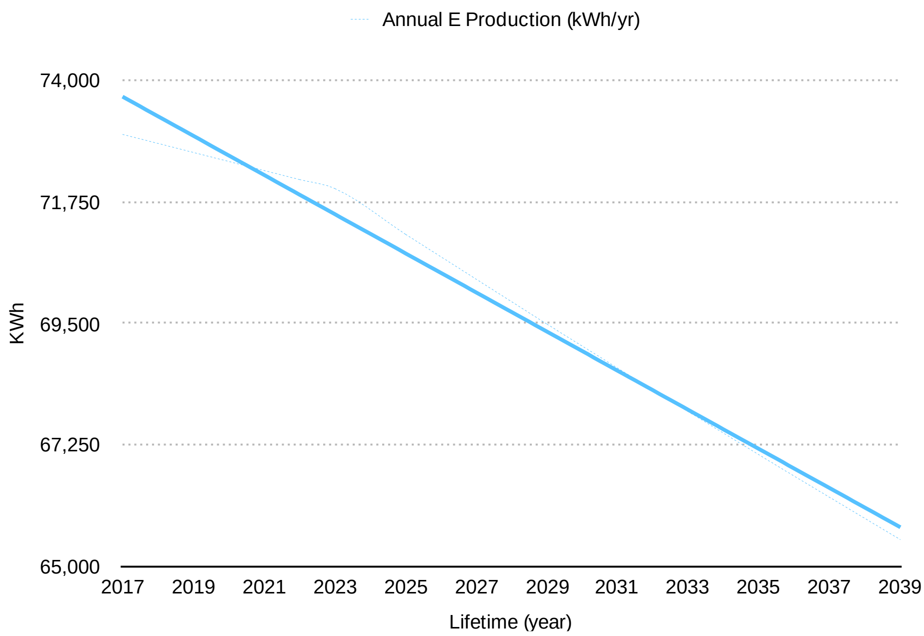


Figure 3. 7 Annual Energy Production Case Study 1, Malaysia

According to the obtained data of electricity generated for 2017 and 2018, it is known that the power production has reduced to a factor of 0.23%. This value can be the PV panel degradation ratio per year and also influenced by the average solar irradiance. The PV panel is expected to degrade overtime according to its production. Hence, the annual production is forecast to be reduce by this amount in the following years.

b) Case Study 2: Thailand

The rooftop system is mounted on a 30' tilted roof of a conference building called as the 'bird house'. The system is located in in the World Green City, Chiang Mai, Thailand as illustrated in Figure 3.8. The system is a part of the community smart grid, community power is defined as decentralized hybrid renewable energy based system from natural resources and agricultural wastes. This system aims to support sustainable livelihood of the Asian Development College for Community Economy and Technology (adiCET) from within the area.

Figure 3. 8 World Green City Community Smart Grid, Chiang Mai, Thailand

Source : https://www.aptep.net/ongoing-projects/technology/chiang-mai-world-green-city/

Decentralized hybrid smart grid require sufficient amount of energy to support the whole green city community, hence, many kind of PV has been implemented for research purposes to maximize the power production. Some parts of the balance of system use for this rooftop PV system are as shown in Figure 3.9.

The building is occupied with conference equipment for seasonal conference purposes as shown in Figure 3.10 below. Shape of the building itself is considered as a green architecture since it is maximize air flow and natural daylight, it is even complete with four air-conditioners. Area of the rooftop which accommodate sufficient amount of panels to supply to the building as well as the grid for excess energy generated. The tilted position of the panel compromise with the maintenance requirement since it is easy to clean and does not accumulate much dust. Panels are facing south to fully utilize the sunlight.

Figure 3. 9 Component of the smart grid PV system, Thailand

Figure 3. 10 Bird House Rooftop PV, Thailand

The following parameters were collected according to the Case Study 2:

1) Location : World Green City, Rajabaht University, Chiang Mai (18.7'N 98.9'E)
2) Effective area : 51.84 m^2

3) Irradiation : 1772 kWh/m2/year
4) Number of PV panel : 32 unit
5) Type of PV panel : Polycrystalline PV
6) Module-rate efficiency : 15%
7) System's performance : 0.70
8) System timeframe : 2011 – 2036
9) Expected lifetime of BOS
    a) PV module warranties : 25 years with every 3 month of maintenance.
    b) Degradation ratio for PV : 0.46% per year
    c) Inverters (2.5kW) : 1 unit (25 years with one replacement)
    d) Electric installation : 30 years
    e) Mounting Structure : 30 years
10) Average grid electricity mix {TH} : 39.3% Oil + 28.2% Gas + 18.4% Bioenergy + 12.9% Coal + 0.4% Hydro.

Based on the ground energy production since 2015 of system installation, energy generated per year (kWh/year) stretches for 25 years of expected lifetime are as exemplified in Figure 3.11 below.

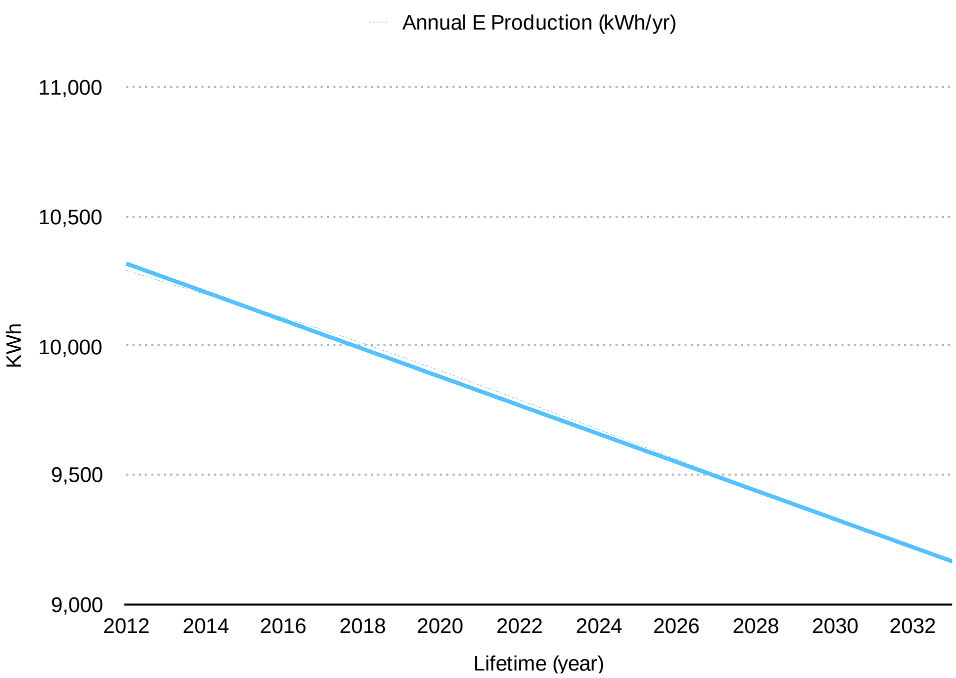


Figure 3. 11 Annual Energy Production Case Study, 2 Thailand

According to the obtained data of electricity generated for 2011 to 2017, it is known that the power production has reduced to a factor of 0.46%. This value can be the PV panel degradation ratio per year and also influenced by the average solar irradiance. The PV panel are expected to degrade overtime according to its production. Hence, the annual production are forecast to be reduce by this amount in the following years.

3.1.3 Solar Farm

Solar Farm system is an energy harvesting plant, where the main purpose is to harvest energy from the sun by using a large scale number of solar panels and sell it to the electricity grid for profit. Solar farm system has attracted many investors into the renewable energy industry through business approach. This shift can enhance the growth of green technology all together.

Large scale solar plant requires massive land area which represent a big drawback to the investors. Numerous study has been conducted to develop system design to optimize the power production with small land requirement such as solar tracker, solar concentrator, floating solar and many others but none yet has been commercialized. These technologies have its pros and cons in fulfilling certain supply and demand needs. Figure 3.12 shows Solar Farm's components and balance of systems (BOS)

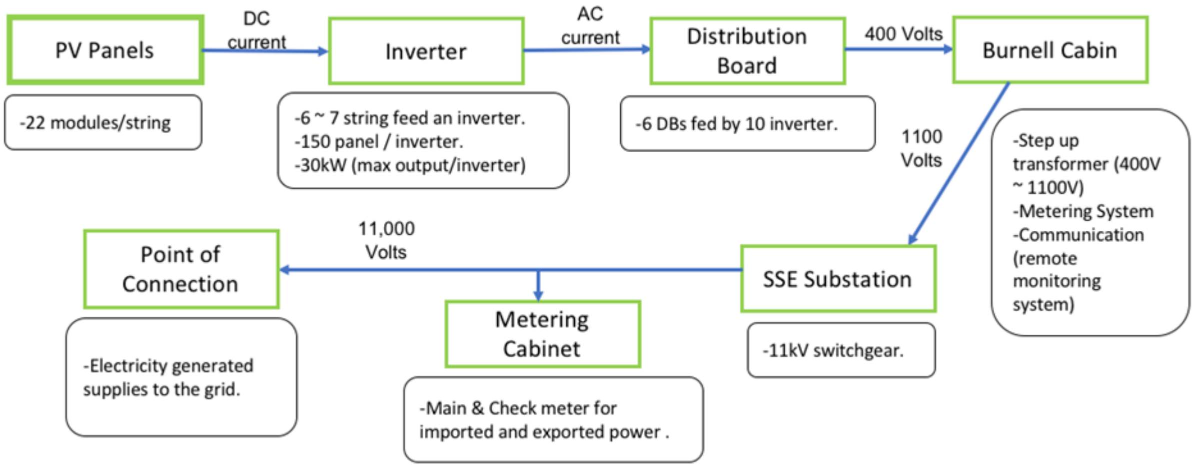


Figure 3. 12 Solar Farm's components and balance of systems (BOS)

The BOS for solar farm are as shown in Figure 3.15 are based on typical system installation. The DC current generated shall be transform into AC current through the inverter. One 30kW inverter can handle 150 panels power production at a time which is equal to 6 to 7 strings. In a solar farm, the amount of panels is overwhelming compared to that of rooftop PV system since its purpose is to sell power to the grid for profit. This system prefer distribution board and a Burnell Cabin bundle that includes a step-up transformer, a metering system and a communication system or so called remote monitoring system). These bundles are able to handle large voltage efficiently.

SSE substation is required as a switchgear to manage the voltage of the system before being exported to the grid. Open-grounded system normally has large sum of electricity generation to be exported. Hence, metering cabinet is needed for recording of power imported and exported. The power finally reach the point of connection, which is the electricity grid for sale.

a) Case Study 1: Malaysia

Kompleks Hijau Solar owned by Gading Kencana Sdn Bhd is a large-scale solar farm system located in Ayer Keroh, Malacca, Malaysia as shown in Figure 3.13. The system is mounted on an open-ground 14 acre of land. This project received commencement approval three years after the initial application and proceed with the construction in the same year of 2013. The system starts to operate on 11 December 2014 with feed-in-tariff (FIT) commencement within the same month. Successfully receive its first FIT income on February 2015.

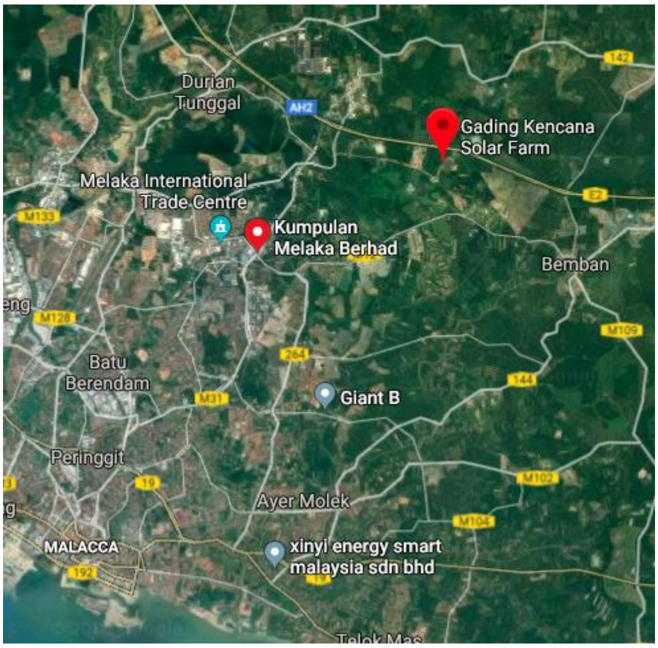


Figure 3. 13 Kompleks Hijau Solar, Malacca, Malaysia

The counter of this, the landscaped has 30 different orientations to obtain the right tilts for the panels and had created six slopes in different directions which explained the photovoltaic positioning in such angles compared all other solar farm. It also, installed two rows of panels at an angle to each other, resembling a pitched roof. This A-shaped mounting enables maximum tapping of sunlight as illustrated in Figure 3.14 below.

Figure 3. 14 Solar Farm Case Study 1, Malaysia

The following parameters were collected according to the Case Study 1:

1) Location : Ayer Keroh, Melaka (2.3 N, 102.3 E)
2) Effective area : 47,129 m^2
3) Irradiation : 1371 kWh/m2/year
4) Number of PV panel : 29,092 unit
5) Type of PV panel : Monocrystalline PV
6) Module-rate efficiency : 15%
7) System's performance : 0.75
8) System timeframe : 2014 - 2039
9) Expected lifetime of BOS
   a) PV module warranties : 25 years with every 3 month of maintenance.
   b) Degradation ratio for PV : 0.59% per year
   c) Inverters (500kW) : 10 unit (10 years with one replacement)
   d) Electric installation : 30 years
   e) Mounting Structure : 30 years
10) Average grid electricity mix {MY} : 46.3% Gas + 41.0% Coal + 10.7% Hydro

Based on the ground energy production since 2015 of system installation, energy generated per year (kWh/year) stretches for 25 years of expected lifetime are as exemplified in Figure 3.15 below.

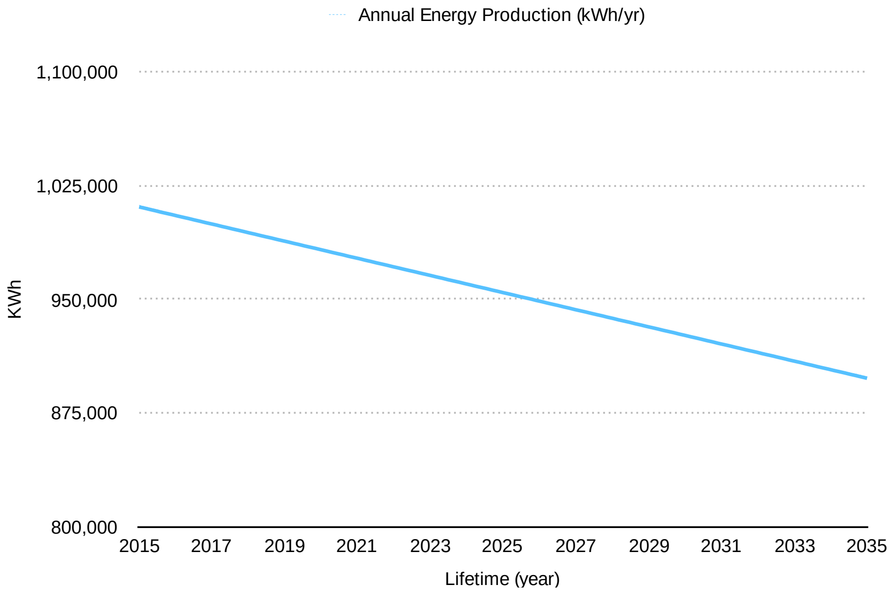


Figure 3. 15 Annual Energy Production Case Study 3, Malaysia

b) Case Study 2: Indonesia

PLTS 2MWp Gorontalo is a solar farm located far into the rural area in Gorontalo, Sulawesi, Indonesia as shown in Photo 3.16. The solar farm system is mounted on an open-ground 11 acre of land. This project received commencement approval three years after the initial application and proceed with the construction in the same year of 2013.

Figure 3. 16 PLTS Sumalata, Gorontalo, Indonesia

The system starts to operate on 11 December 2014 with feed-in-tariff (FIT) commencement within the same month. Successfully receive its first FIT income on February 2015. Rural area is a great place for solar farm where it is far from the transportation and industrial work emission which could pollute and disturb the panel efficiency. The clean air and less busy environment reduce the need of maintenance frequency. This solar farm system is step-up with two transformers before selling the harvested energy to the electricity grid.

The photovoltaic panel as well as its components for balance of systems is all product of Indonesia itself, which is from Adya Surya. This company manages and replaces the failure in the system from time to time as maintenance. The panel as illustrated in Figure 3.17, can be seen to align facing to the south for the maximum solar irradiation over time. Although, we can see in Case Study 1, the panel is arrange in an A-shape position to take in both sunrise and sunset time.

Figure 3. 17 PLTS Gorontalo Solar Farm, Indonesia

The following parameters were collected according to the Case Study 2

1) Location : Sumalata Timur, Gorontalo utara

(1.3 N, 116.3 E)

2) Irradiation : 1888 kWh/m2/year
3) Effective area : 13,880.16 m^2
4) Number of PV panel : 8,568 unit
5) Type of PV panel : Monocrystalline PV
6) Module-rate efficiency : 15%
7) System's performance : 0.75
8) System timeframe : 2014 – 2039
9) Expected lifetime of BOS
    a) PV module warranties : 20 years with low frequency of maintenance.
    b) Degradation ratio for PV : 0.20% per year
    c) Inverters (2.5kW) : 68 unit (10 years with one replacement)
    d) Electric installation : 30 years
    e) Mounting Structure : 30 years
    f) Transformer : 30 years
10) Average grid electricity mix {INA} : 55.6% Coal + 25.8% Gas + 6.7% Oil + 6.4% Hydro + 4.7% Geothermal

Based on the ground energy production since 2015 of system installation, energy generated per year (kWh/year) stretches for 25 years of expected lifetime are as exemplified in Figure 3.18.

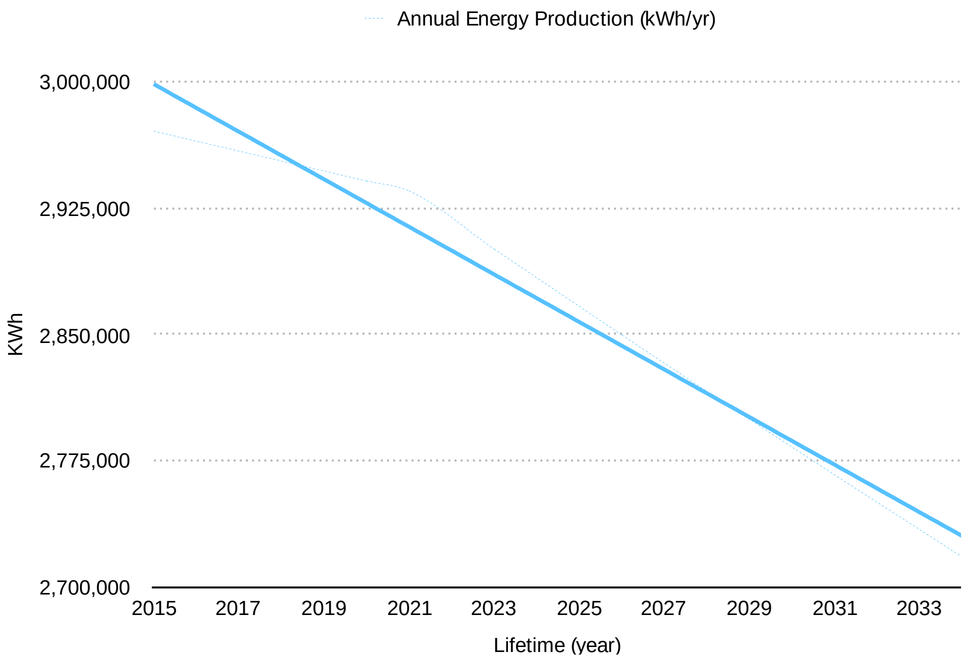


Figure 3. 18 Annual Energy Production Case Study 3, Indonesia

According to the obtained data of electricity generated for 2014 and 2015, it is known that the power production has reduced to a factor of 0.20%. This value can be the PV panel degradation ratio per year and also influenced by the average solar irradiance. The PV panel are expected to degrade overtime according to its production. Hence, the annual production are forecast to be reduce by this amount in the following years.

3.2 Framework

The project methodology is detailed out into six stages. This methodology which comprise these elements:

a) Goal and Scope definition
b) Data collection
c) Data analysis
d) LCCA interpretation
e) Report
f) Critical review

The methodology of LCCA is quite straight forward compared to LCA as illustrated in Figure 3.19 project LCCA methodology. The goal and scope definitions are stated as to understand the overall life cycle cost of the solar technology systems form manufacturing phase towards its disposal phase (cradle-to-grave). The project case studies include three different photovoltaic system which is the solar farm with power capacity more than 1MWp and it is set up on the land, a solar rooftop system with power capacity within the range of 500kWp to 1MWp. While for stand-alone solar system for rural electrification with power capacity less than 100kWp to 500kWp. All of the systems are expected to be matured which at least two years of operation. At the same time, they are a commercial site and within the APEC economies only.

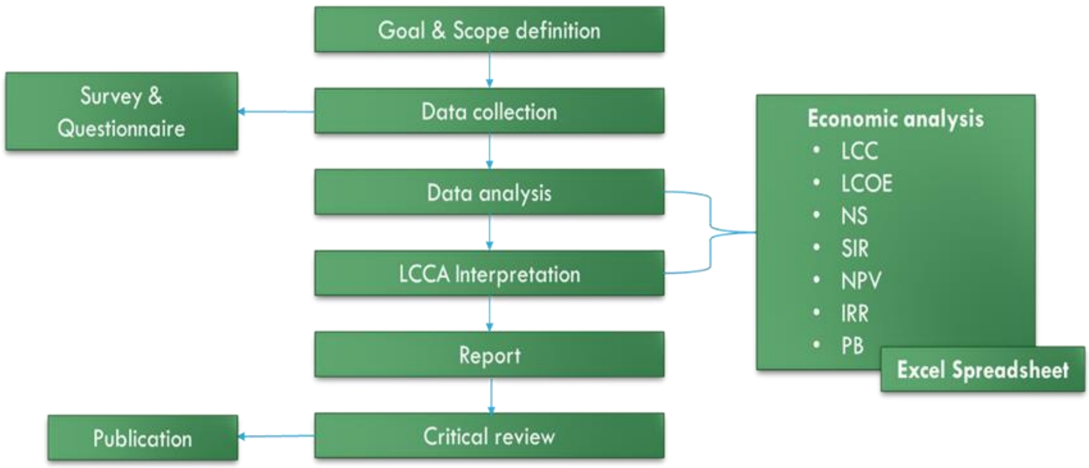


Figure 3. 19 Project LCCA Methodology.

The data from each case studies is obtained by survey and questionnaire during the site visit. All of the data that have been obtained is being analyse and interpreted by LCCA. Several economic analysis will be used in data analysis and interpretation, such as Life Cycle Cost (LCC), Levelized Cost of Energy (LCOE), Net Savings (NS), Savings to Investment Ratio (SIR), Net Present Value (NPV), Internal Rate of Return (IRR) and Payback Period (PB). Microsoft Excel is used as a tool to calculate all the data using these economic analysis. Then identification of the most viable and cost-effective PV systems and alternative solution is reported and developing a critical review paper for publication.

4.0 LIFE CYCLE COST ASSESSMENT (LCCA)

Life cycle cost assessment (LCCA) is a powerful economic assessment method whereby all costs incurred from owning, operating, maintaining, and finally disposing of a project are considered potentially important for the decision. According to [7]. LCCA is a very useful and complete economic analysis tool because this analysis requires more information than analyses based on initial cost or short term considerations. In fact, it also requires analysts who understand the time value of money when comparing future return flows with the initial investment cost of a project.

Therefore, value of the discount and inflation rate plays a significant role in determining the time value of money. Time value of money must be take into consideration because value of money in the present time, will not be the same value in the future. For example, the value of $ 1.00 this year will not be the same as the value of $1.00 in the years to come and in previous years. Discount and inflation rate are the factors that cause the value of the money to vary.

Besides that, through LCCA we can determine whether a project is economically viable and cost effective. LCCA would tell the whole story of a project, and identify the available alternative solution throughout the project i.e. from cradle-to-grave. Energy conservation projects provide excellent examples for LCCA applications. There are many opportunities to improve the performance of building thermal protection components in new and existing buildings to reduce heat loss in the winter and heat gain in the summer. Similarly, there are many alternative heating, ventilating, and air conditioning systems (HVACs) that can maintain the acceptable comfort conditions throughout the year, partly more energy efficient (or use less fuel) than others. When energy conservation projects increase initial start-up capital costs or incur retrofit costs in existing buildings, LCCA can determine whether these projects are appropriate from the investor's view, based on reduced energy costs and other cost implications on the project’s life or investor's length of time.

In LCCA, usually contain several economic analysis which is the life cycle cost (LCC), levelized cost of energy (LCOE), net savings (NS), Savings to investment ratio (SIR), net present value (NPV), internal rate of return (IRR) and payback period (PB). At the same time, this analysis follows five simple steps. This general frameworks illustrates in Figure 4.1 below.

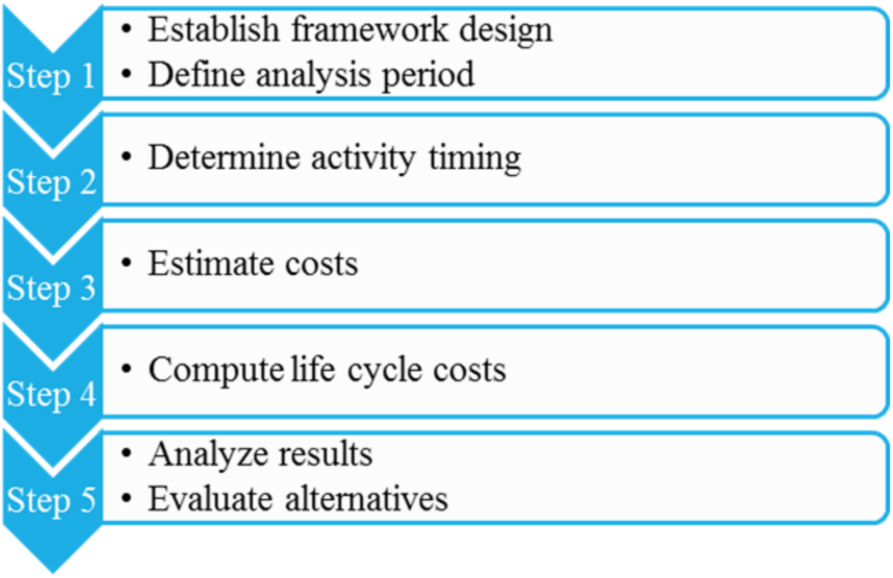


Figure 4. 1 LCCA general framework [8]

LCCA framework comprises of five basic steps [8]. While the steps are generally sequential, the sequence can be altered as per the project requirements. The steps describes as follows:

Step 1: Establish framework design & Define analysis period.

A detailed framework is produced alongside the available alternatives. Alternatives such as photovoltaic systems, photovoltaic system designs, manufacturing methods or types of solar cells. At the same time, analysis periods need to be defined. This is because the LCCA analysis involves the use of time value of money. Therefore, setting the duration of the analysis is very important. Figure 3.2 below shows examples of analysis periods. The analysis period must have these three important points, namely:

- Base Date - the point in which all costs associated with the project are discounted. In simple words, project start date.
- Service Date - the date on which the project is expected to be implemented and operated.
- Planning / construction period - the elapsed time between base date and service date.

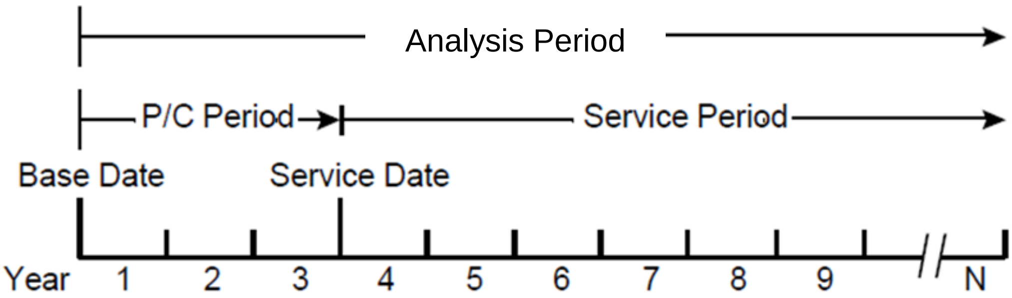


Figure 4. 2 Example of analysis period.

Step 2: Determine activity timing.

It means determining the timing of all activities that need to be done to run LCCA. For example, provide a questionnaire, visit a case study site, collect case study data, analyze data, and present reports.

Step 3: Estimate costs.

The third step in this analysis is to identify and estimate all costs involved in each phase. Among the costs involved will be the cost of materials, equipment, electricity, labor and other related costs.

Step 4: Compute life cycle costs.

Once all data are available, the LCCA calculation can be done in the fourth step. These data are calculated using several economic analyses; life cycle cost (LCC), levelized cost of energy (LCOE), net savings (NS), savings to investment ratio (SIR), net present value (NPV), internal rate of return (IRR) and payback period (PB). These calculations can be done using Microsoft Excel.

Step 5: Analyse results & Evaluate alternatives.

In this last step, the cause of high cost contributors can be identified. In addition, comparisons between alternatives can determine which alternatives are best and can save more cash. At the same time, alternative evaluations are also carried out, which will bring more processes that are most viable and cost-effective for a project.

4.1 Life Cycle Cost (LCC)

Life cycle costs are tools for estimating the overall cost of the project including start-up costs, fuel costs, operating and maintenance costs, repair costs, replacement costs, residual values, finance charges, and other non-financial benefits. Equation 3.1 shows how to calculate the cost of life cycle [9].

$$LCC = C_I + C_{OMR} + C_{rep} + C_O - C_{res}$$

This cost is influenced by several parameters such as investment cost (C_I), operating cost, maintenance and repair (C_{OMR}), replacement cost (C_{rep}), other costs (C_O), and residual value (C_{res}).

Investment cost (C_I) refers to the initial investment of power plants such as land, photovoltaic modules, transmission, system design and installation costs. Operational, maintenance and repair costs (C_{OMR}) refer to operator's pay, inspection, insurance, property taxes and repair costs. The replacement cost (C_{rep}) is the total cost for replacement of equipment required during the life of the system. Other costs (CO) include energy, water and other associated costs during the life of the system. The residual value (C_{res}) refers to the resale value and the residual value; this value is the net value of the system in the last year for the life cycle period.

4.2 Levelized Cost of Energ (LCOE)

LCOE is the most commonly used tool for comparing alternative technologies with different scale of investment, operating time or economic conditions [5]. LCOE only considers the cost of life cycle and the amount of energy generated during the period; it can eliminate favouritism or bias between technologies. To calculate LCOE, the data from the LCC calculation has been used as shown in equation below.

$$LCOE = \frac{LCC}{LEP}$$

Where LEP is the amount of energy generated during the life of the power plant. Low LCOE is better because it shows that less money is needed to produce one unit of energy.

4.3 Supplementary Financial Measures

The main role of supplementary measures is an addition economic analysis to strengthen the main economic analysis which is the LCC and LCOE.

a. Net Savings (NS)

This data was derived from the project cash flow. It can be calculated by subtracting total savings (TS) with operating, maintenance and repair costs (C_{OMR}). NS is calculated using the following equation [10].

$$NS = TS - C_{OMR}$$

Net savings can be used to evaluate the effectiveness of a project. Higher net savings is better.

b. Savings of Investment Ratio (SIR)

SIR is a popular economic tool used in the analysis of rating a project. In simple terms, SIR is a ratio between net savings and investment. SIR has been calculated using the following equation [10]:

$$SIR = \frac{NS}{IRS} = \frac{NS}{C_I + C_{rep} - C_{res}}$$

The IRS is the present value of the total investment cost (C_I) plus the replacement cost (C_{rep}) deducted with the residual value (C_{res}). The higher SIR is better because it means the average income is bigger for every dollar spent.

c. Net Present Value (NPV)

NPV is the present value of future cash flows. The concept of discount is introduced in NPV. Discounting is a process for verifying the present value of cash flows that will be obtained in the future. Equation below has been used to determine the NPV of a project. NPV is calculated using the following equation [10]:

$$NPV = \sum_{t=1}^{n} CF\left(PVIF_{k,n}\right) - C_I$$

Where CF is cash flows, while $PVIF_{k,n}$ is the present value or present value at k% interest for period n. C_I refers to the initial outflow or initial investment cost.

d. Internal Rate of Ratio (IRR)

IRR is the interest rate or discount rate where the present value of future cash flows is the same as the initial investment of the project. The larger the IRR, the more likely the project will be for investment. IRR is calculated using the following equation [10]

$$C_I = \overline{CF}\left(PVIFA_{IRR,n}\right)$$

Where $\overline{\text{CF}}$ is the average cash flow of the project while $\text{PVIFA}_{\text{IRR},n}$ is the present value of the interest factor with an annuity at the interest rate or discount rate which is considered equal to the IRR for the period n.

e. Payback Period (PB)

Payback period is essentially the number of years required to recover the initial investment or early outflow. The short PB is highly coveted because capital gains will be available early and will reduce the risk of investment. Equation below has been used to obtain a refund period. PB is calculated by using following equation [10]:

$$PB = (n-1) + \left[\frac{\left(C_I - \text{Cumulative cash flow before } n\right)}{\text{Current cash flow } n}\right]$$

Where n is a recovery year when in the year cash flow exceeds initial investment. There are two types of payback periods in the economic analysis performed is the short payback period and the payback period of the discount. The short payback period is a payback period that does not take into account the time value of the money. Whereas, the payback period of the discount takes into account the time value of the money.

4.4 System Boundary

The boundary system for this project has two main divisions namely the environmental system and the project system. In the project system there are five main phases for each PV system which is the manufacturing phase, the transport phase, the construction phase, the operation and maintenance phase, and the phase and disposition phase. Figure 4.3 below shows the boundary system for this project.

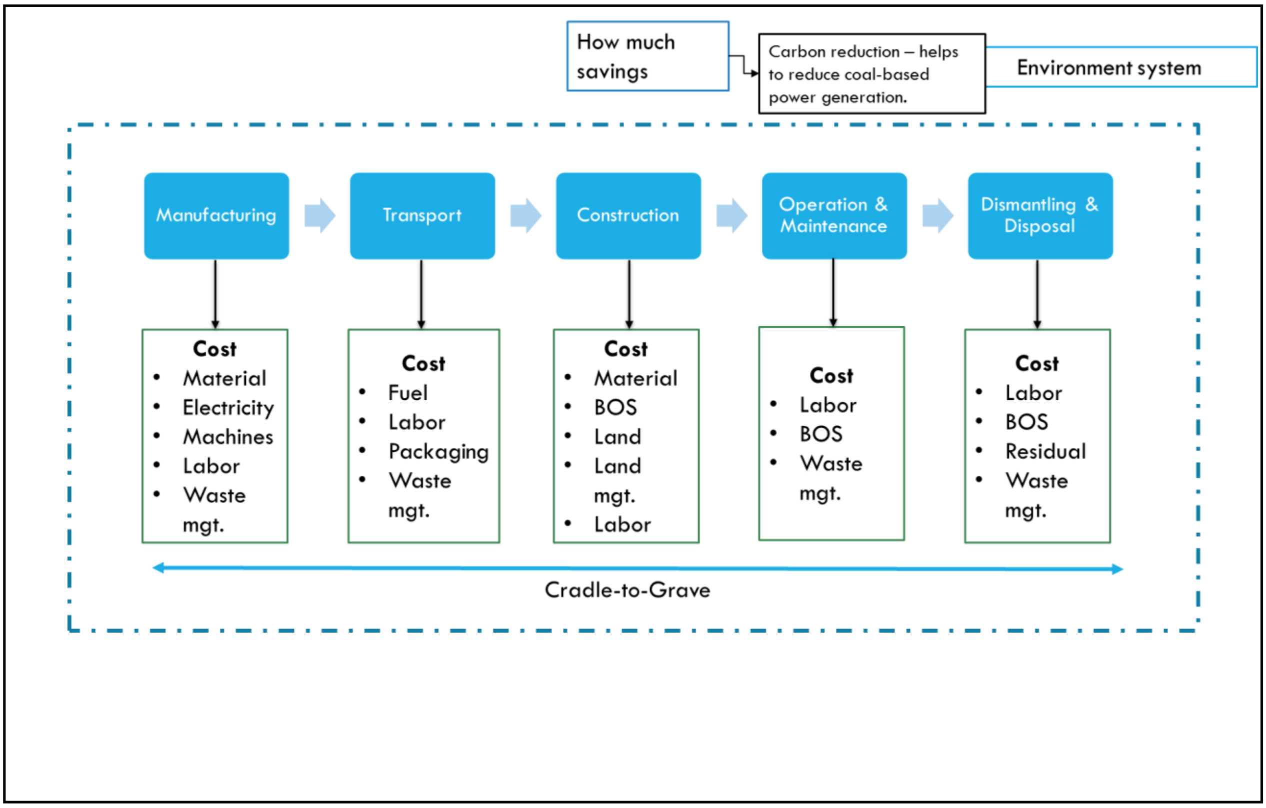


Figure 4. 3 System boundary for LCCA

Everything that involves the cost in each phase is taken into account. In the manufacturing phase, the costs involved are cost of materials, electricity, machinery, labour and waste management. The primary data collection will not include silicon mining, since the initiation from that stage also contributes to other product manufacturing, each BOS component production, machinery manufacturing and infrastructure manufacturing for the construction set up.

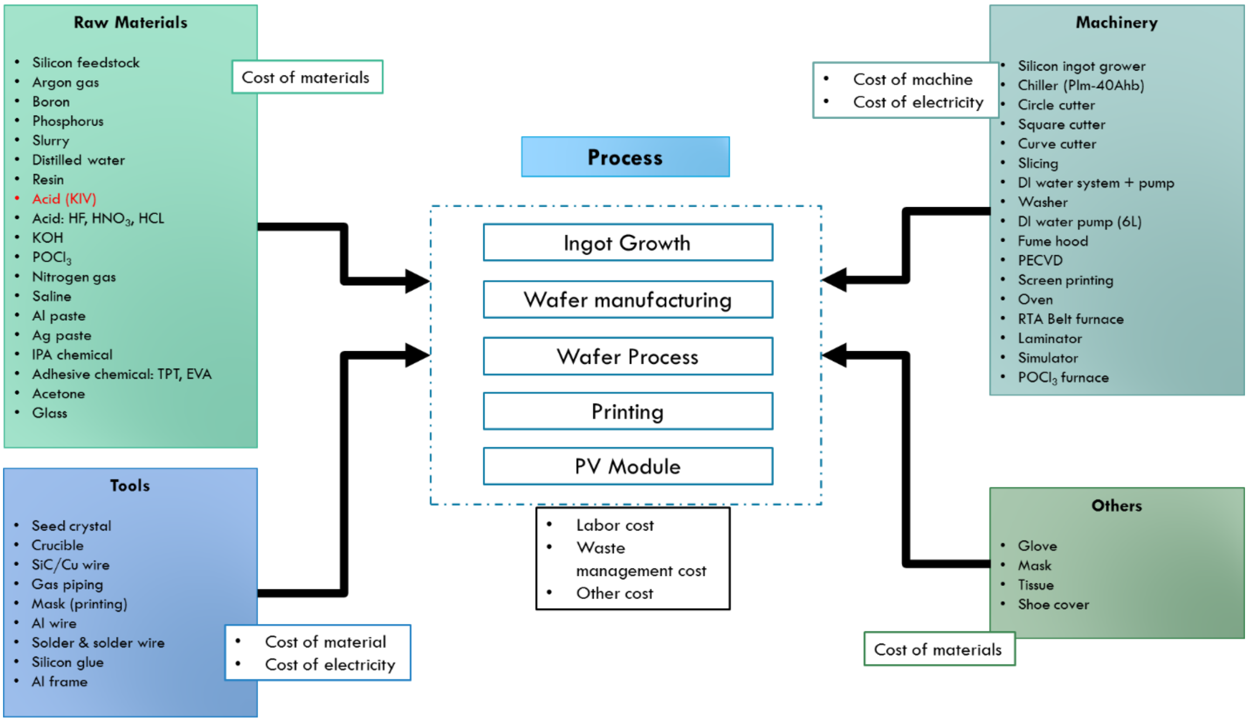


Figure 4. 4 Manufacturing process and item involved.

Besides that, transportation phase only take into account the fuel cost, labor cost, packaging cost and waste management cost. The transportation of each case study will be from the silicon feedstock supplier to manufacturing site, from manufacturing site to the case study site, from BOS manufacturing site to case study site, from case study site to disposal site.

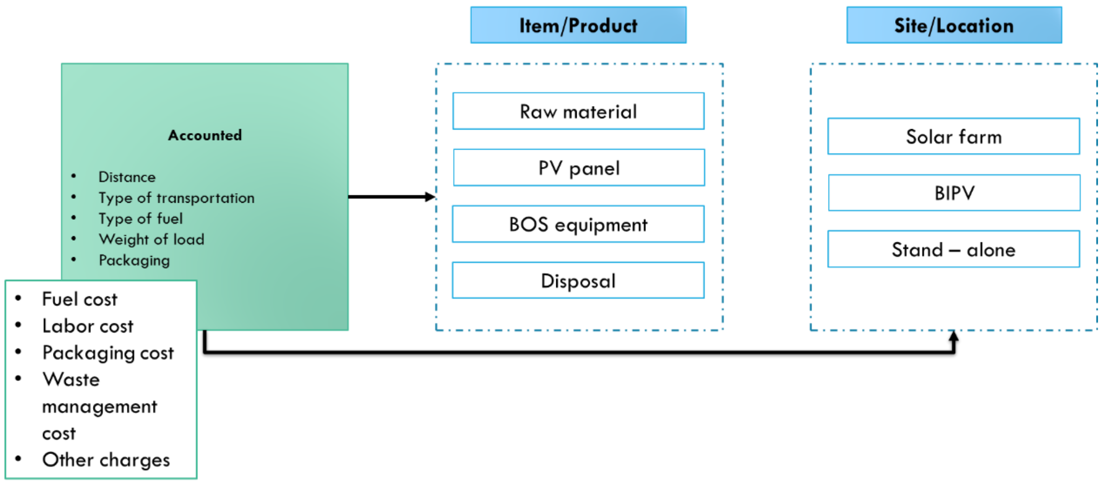


Figure 4. 5 Items that are involved in transportation phase.

The construction phase shall account the infrastructure material (metal works, balance of system), energy consumption from machinery, purchase of the land and land management.

This phase will not consider social and geographical influence over general land management which means how they retrieve the land either from deforestation or any other methods.

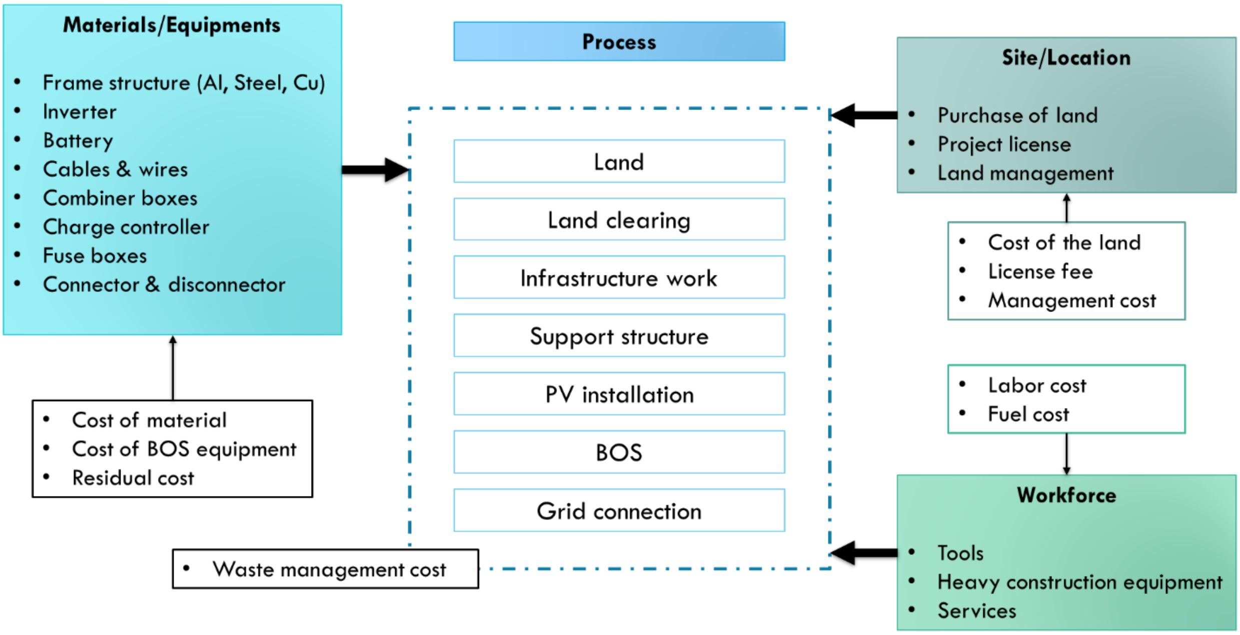


Figure 4. 6 Construction process and items that is involved in construction phase.

Furthermore, operation, maintenance and replacement phase will be under labour cost, BOS cost and waste management cost into account.

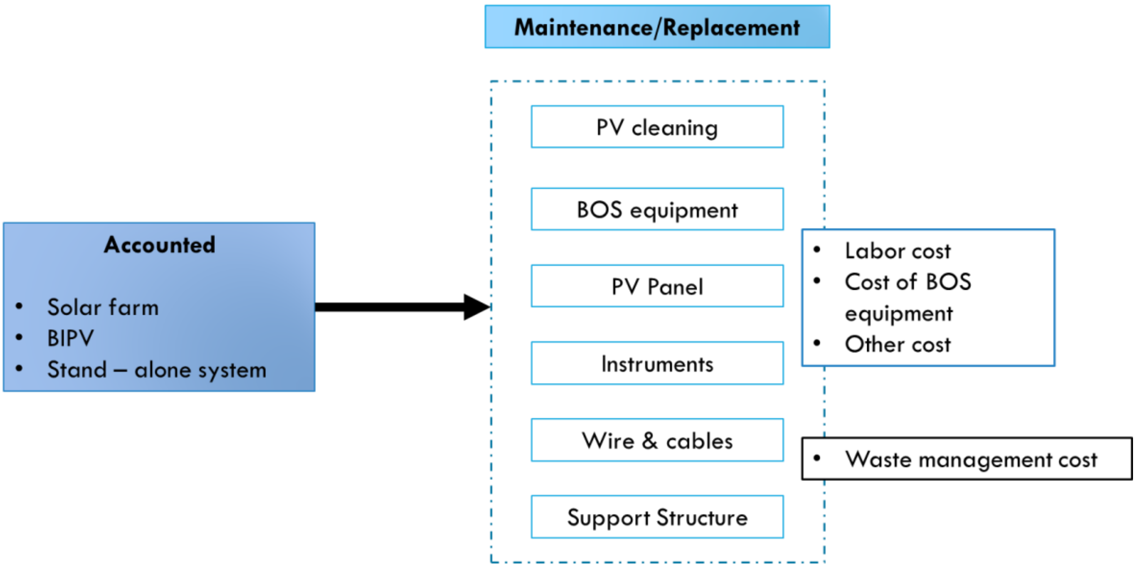


Figure 4. 7 The items that is involved in operation, maintenance and replacement phase.

Then for dismantling and disposal phase will include the cost for labour, BOS cost, residual cost and waste management cost. Figure 4.8 show the items that involved in dismantling and disposal phase.

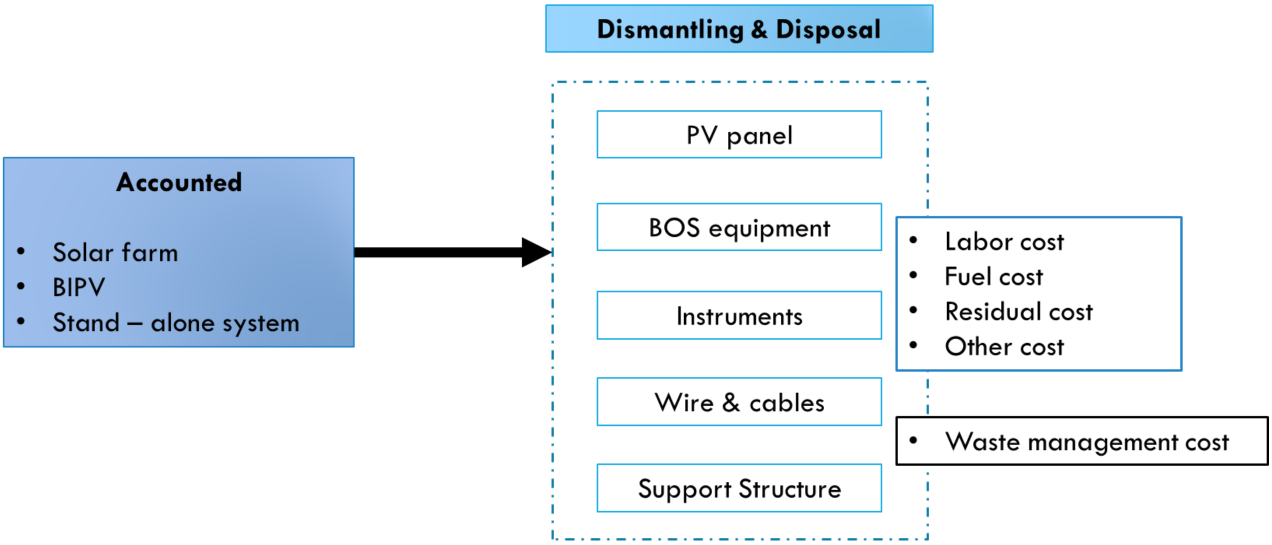


Figure 4. 8 show the items that involved in dismantling and disposal phase.

5.0 RESULTS AND DISCUSSION

5.1 Case Study Data

This section lists the details that have obtained from the surveys covering technical and financial data. The survey was conducted by a one-day visit to the project site for each case studies that was mentioned in Section 3.1. The technical data is shown in Section 5.1.1 while the financial data is in Section 5.1.2. All financial related details in Section 5.1.2 are presented regardless of the time value of money. Financial details that take into consideration the time value of money are presented in the economic analysis found in Section 5.2.

5.1.1 Technical Data

Technical data is very important in this study, the purpose of technical data is to determine the design of PV system, the potential and performance of the system. These data can be used to compare the different systems involved with this case studies with other systems. The data can also be used as a benchmark for sensitivity analysis.

a) Stand-alone PV (SAPV) system

i) Stand-alone PV Case Study 1 (SAPV 1)

SAPV 1 is located in Malaysia. The project was built for a house in a ranch which located in Lenggeng, Negeri Sembilan (2° 43’ N, 101° 57’ E). The electricity produced from this 3 kWp SAPV is supplied to a bungalow houses which situated in the ranch. The system start its operation in May of 2016.

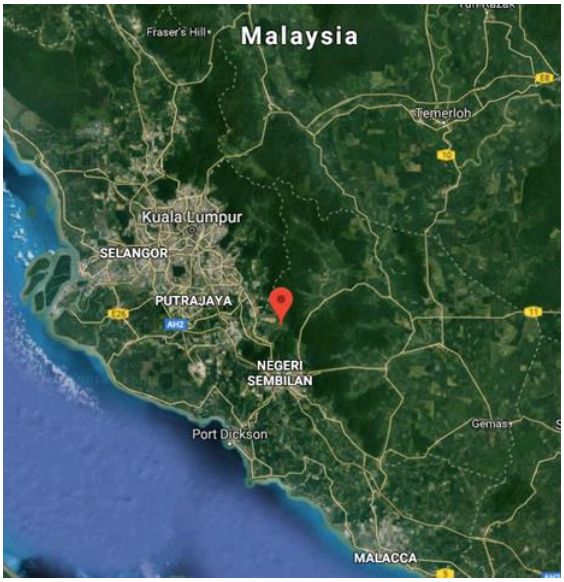


Figure 5. 1 Lenggeng, Seremban, Malaysia

This system consisted of 12 unit monocrystalline PV module, an inverter, a charge controller, and 12 unit of batteries. The BOS equipment (inverter, charge controller and batteries) is stored in a small outdoor store beside to the house. While, the 12 unit of PV modules is mounted on the roof of the store. The PV module-rate efficiency is about 15% and the system's performance is 0.75. Besides that, it is said that the degradation ratio for PV is 0.59% per year. Table 5.1 below illustrate the technical details of the SAPV system in Lenggeng, Negeri Sembilan.

Table 5. 1 Technical details of the Smart House

Item	**Details**
Location	Lenggeng, Negeri Sembilan (2° 43' N, 101° 57' E)
Irradiation	1573.15 kWh/m2/year [NASA]
Number of PV panels	12 unit
Type of PV panels	Monocrystalline PV
Module-rate efficiency	15%
System's performance	0.75
System timeframe	May 2016 – May 2041
System capacity	3.0 kWp
Annual energy production	3488 kWh/year

The system maximum annual energy production is 3488 kWh/year. Hence, most of the electrical energy is supplied to the house electrical appliances which it consumed about 127.23 kWh/month. The highest energy consumed electrical equipment and appliance in the house is the refrigerators. Then, it is followed by the ceiling fan and television. Table 5.1 below show the load inside the house.

Table 5. 2 The load inside the house.

Area in the House/Electrical Appliances	Quantity	Power Rating (W)	Power Rating (kW)	Monthly Energy Consumption (kWh/month)
Living Hall & Dining Area				
LED bulb	14	8.0000	0.1120	2.0160
Ceiling fan	2	20.0000	0.0400	8.6400
Stand Fan	1	50.0000	0.0500	3.0000
Television	1	110.0000	0.1100	4.9500
Xbox	1	90.4000	0.0904	2.7120
Flourescent lamp	8	18.0000	0.1440	1.7280
Master Bedroom & Toilet				
Ceiling Fan	1	20.0000	0.0200	0.4800
Light bulb	3	18.0000	0.0540	0.6075
Bedroom 1 & Toilet				
Ceiling fan	1	20.0000	0.0200	0.4800
Light bulb	2	18.0000	0.0360	0.4050
Light bulb (toilet)	1	18.0000	0.0180	0.0014
Bedroom 2 & Toilet				
Ceiling fan	1	20.0000	0.0200	0.4800
Light bulb	2	18.0000	0.0360	0.4050
Light bulb (toilet)	1	18.0000	0.0180	0.0014
Kitchen & Toilet				
LED bulb	4	8.0000	0.0320	0.4320
Refrigerator	1	110.0000	0.1100	47.5200
Refrigerator	1	100.0000	0.1000	43.2000
Microwave	1	800.0000	0.8000	0.0000
Rice Cooker	1	400.0000	0.4000	0.9600
Ceilang Fan	1	20.0000	0.0200	0.1200
Washing Machine	1	420.0000	0.4200	1.8900
Light bulb	1	18.0000	0.0180	0.0014
Outdoor				
Spotlight	3	30.0000	0.0900	5.4000
Other				
Phone Charger	4	5.0000	0.0200	1.8000
Total Monthly Energy Consumption (kWh/Month)				**127.2296**

b) Rooftop PV system

i) Rooftop PV Case Study 1 (RPV 1)

RPV 1 located in Malaysia. The project was built and mounted on the roof of RK South Asia Sdn Bhd factory which is chain manufacturing factory for motorcycle, bicycle and industrial chain. It is located at Seberang Perai, Penang, Malaysia (5.22° N, 100.24°E). The system holds capacity about 200 kWp and the electricity produced is sell to TNB under FiT. The system started its operation in 2017.

This system consisted of 1320 unit polycrystalline PV module, eight inverters, and a large charge controller. The BOS equipment (inverter and charge controller) is placed at outside wall of the factory under a larger roof and near the loading dock. The PV module-rate efficiency is about 15% and the system's performance is 0.75. Besides that, it is said that the degradation ratio for PV is 0.23% per year. Table 5.3 below illustrate the technical details of the rooftop system.

Table 5. 3 Technical details of the RK South Asia Sdn Bhd rooftop system.

Item	Details
Location	RK South Asia Sdn Bhd, Seberang Perai, Penang (5.22° N, 100.24° E)
Irradiation	1685.39 kWh/m2/year [NASA]
Number of PV panels	1320 unit
Type of PV panels	Polycrystalline PV
Module-rate efficiency	15%
System's performance	0.75
System timeframe	2016 – 2041
System capacity	200 kWp
Annual energy production	478592.40 kWh/year

In terms of technical potential, the 200 kWp solar power plant uses 1320 solar module units bring the total effective area of 2561.26 m^2. Using a polycrystalline type solar module with a conversion efficiency of up to 15%, 478592.40 kWh of energy can be generated by the system within one year. Figure 5.2 below show the rooftop PV system at RK South Asia Sdn Bhd factory.

Figure 5. 2 The rooftop PV system at RK South Asia Sdn Bhd factory

ii) Rooftop PV Case Study 2 (RPV 2)

Besides that, RPV 2 is the located in World Green City, Chiang Mai, Thailand. Which is situated in Chiang Mai Rajabaht University's new campus (18.7° N, 98.9° E). The system is fully manage by Asian Development College for Community Economy and Technology (adiCET). This 7.9 kWp solar system is mounted on the roof of a hall-like building called 'Bird House'. The project started in 2011 and started its operation since 2012. This solar farm consisted of 32 unit polycrystalline PV module, one unit inverter, and a charge controller. The PV module-rate efficiency is about 15% and the system's performance is 0.75. Besides that, it is said that the degradation ratio for PV is 0.46% per year. Table 5.4 below illustrate the technical details of the Bird House.

Table 5. 4 Technical details of the Smart House

Item	**Details**
Location	World Green City, Chiang Mai Rajabaht University, Chiang Mai, Thailand (18.7° N, 98.9° E)
Irradiation	1772 kWh/m2/year [NASA]
Number of PV panels	32 unit
Type of PV panels	Polycrystalline PV
Module-rate efficiency	15%
System's performance	0.75
System timeframe	2011 – 2036
System capacity	200 kWp
Annual energy production	10290.61 kWh/year

In terms of technical potential, the 7.9 kWp solar power plant uses 32 solar module units bring the total effective area of 52.38 m^2. Using a polycrystalline type solar module with a conversion efficiency of up to 15%, 478592.40 kWh of energy can be generated by the system within one year. Figure 5.3 below show the rooftop PV system of Bird House.

Figure 5. 3 Bird House rooftop PV system

c) Solar Farm system

i) Solar Farm Case Study 1 (SF 1)

The geographical details of the project site were taken and shown in Table 5.5. The SF 1 project was established in Ayer Keroh, Melaka which is located 2.3 °N and 102.3 °E. Its height from sea level is 43 meters. While the absorption of solar radiation is reflected back to space or albedo is 0.20. This means that 80% of light absorbed will reach the surface of the earth where the project site is located and the remaining 20% is reflected by the object on the surface.

Table 5. 5 Geographical detail of the project site.

Item	Details
Location	Ayer Keroh, Melacca
Latitude	2.3 °N
Longitude	102.3 °E
Altitude	43 m above sea level
Albedo	0.20

The 14-acre Solar Green Complex houses an 8 MW solar plant and an office building that serves as the administrative and monitoring centre for the solar farm. The solar farm is also the most efficient solar field in terms of resource use. This is because Gading Kencana Sdn. Bhd. manages to build a 1 MW solar plant for every 1.5 acres of land compared to 1 MW for every 5 acres of land commonly used.

However, it is not easy to load a 1 MW PV system in 1.5 acres of land. During site cleaning work, a bowl-shaped soil contour with a depth of 30 meters was found. Due to the lack of land area, the teams designing solar estates need to rethink the entire design of the solar plant. Furthermore, SEDA has approved a solar plant with a capacity of 8 MW, so the team needs to figure out how to load the 8 MW capacity system in a small area.

Finally, the construction team filled the valley shaped like a bowl with 300,000 cubic meters of land. As a result, the valley was successfully elevated altitude to 43 meters above sea level. Additionally, they have also embedded the project site into six different slopes of direction. This is done to allow the flow of water to flow into the detention pond rather than accumulate and subsequently erode the land of the project site.

To be loaded on smaller sites, the solar modules need to be fixed with minimal shading. The design team has reviewed 30 different orientations to get the best tilt for the modules. They have found that the best orientation is to assemble two lines of solar modules facing each other like the A-shaped roof in Figure 5.4. This design allows maximum light absorption as well as accommodating 29,092 monocrystalline type solar panel forming 8 MW system. The design team has also studied the wind direction and positioned the solar panels so that wind blows produce good ventilation and thereby reducing the heat formation in which it is able to give an indication of the efficiency of the system.

Figure 5. 4 The orientation of the solar module line at Solar Green Complex.

In terms of technical potential, the 8 MW solar power plant at Green Complex uses 29,092 solar module units to cover 12 acres of land. Using a monocrystalline type solar module with a conversion efficiency of up to 14%, 10,120 MWh of energy can be generated by the system within one year. Table 5.6 shows a summary of the technical details of the solar plant.

Table 5. 6 Technical detail of the solar farm in Solar Green Complex.

Item	**Details**
Capacity PV system	8 MW
Area of the system	12 acre
Number of PV panel	29092 unit
Type of PV	Monocrystalline
Efficiency	14%
Average annual irradiation	1693 (kWh/m^2)
Annual energy production	10120 MWh

ii) Solar Farm Case Study 2 (SF 2)

Besides that, SF 2 is the located in Sumalata, Gorontalo, Indonesia. Which is situated at the north Sulawesi great island (1.3 N, 116.3 E). The project started in 2014 and started its operation since 2015. This solar farm consisted of 8568 unit monocrystalline PV module, 68 unit inverter, two unit of transformer and several other BOS equipment. The PV module-rate efficiency is about 15% and the system's performance is 0.75. Besides that, it is said that the degradation ratio for PV is 0.20% per year. Table 5.7 below illustrate the technical details of the solar farm.

Table 5. 7 Technical detail of the PLTS Solar Farm.

Item	**Details**
Location	Sumalata, Gorontalo (1.3 N, 116.3 E)
Irradiation	1888 kWh/m2/year [NASA]
Number of PV panels	8,568 unit
Type of PV panels	240 W Monocrystalline PV
Module-rate efficiency	15%
System's performance	0.75
System timeframe	Feb 2014 – Feb 2039
System capacity	2.0 MWp
Annual energy production	2970.72 MWh/year

The 11.12-acre solar farm holds a 2 MWp solar plantation and an office building that serves as the administrative and monitoring centre for the solar farm. In terms of technical potential, the 2 MW solar power plant uses 8568 solar module units to cover about 10 acres of land. Using a monocrystalline type solar module with a conversion efficiency of up to 15%, 2970.72 MWh of energy can be generated by the system within one year. Figure 5.5 below show the solar farm in Sumalata, Gorontalo, Indonesia.

Figure 5. 5 Solar farm in Sumalata, Gorontalo, Indonesia.

5.1.2 Financial Data

Financial data is very important to study the economic performance of a system in addition to the technical data of the technology. Financial data shows cash flows encompassing incoming and outgoing money from the savings of a PV system developer.

a) Stand-alone PV system.

i) Initial Investment Cost

The following is a breakdown of the initial investment cost of the SAPV 1 in Malaysia (Table 5.8 and Figure 5.6). Overall, the system cost \$ 6,650.00 as an initial investment cost (C_I). \$ 5,825.00 of the total is the price of a major component of the PV system comprising solar PV modules, PV mounting structures, electrical systems, charge controller, inverters and batteries.

Besides that, the other cost is also included into the investment cost. Such as, the transportation cost, labour service and the cost of the store room. In life cycle cost assessment (LCCA), these cost cannot be ignored and must take into account. This is very important because the cause of error can be avoided and reduced. So, LCCA is a perfect method for economic analysis of a specific project especially project that involving with energy technology.

Table 5. 8 Initial investment cost breakdown, C_I of SAPV 1

Items	Price (\$)
PV module	2,100.00
Battery	2,400.00
Charge controller	75.00
Inverter	625.00
Support structure & BOS room	625.00
Transportation	75.00
Labour service	750.00
Total	**6,650.00**

All of the item in the initial investment cost is considered occurred in 2015. This is because 2015 is the year which the money is used for paying the initial investment cost.

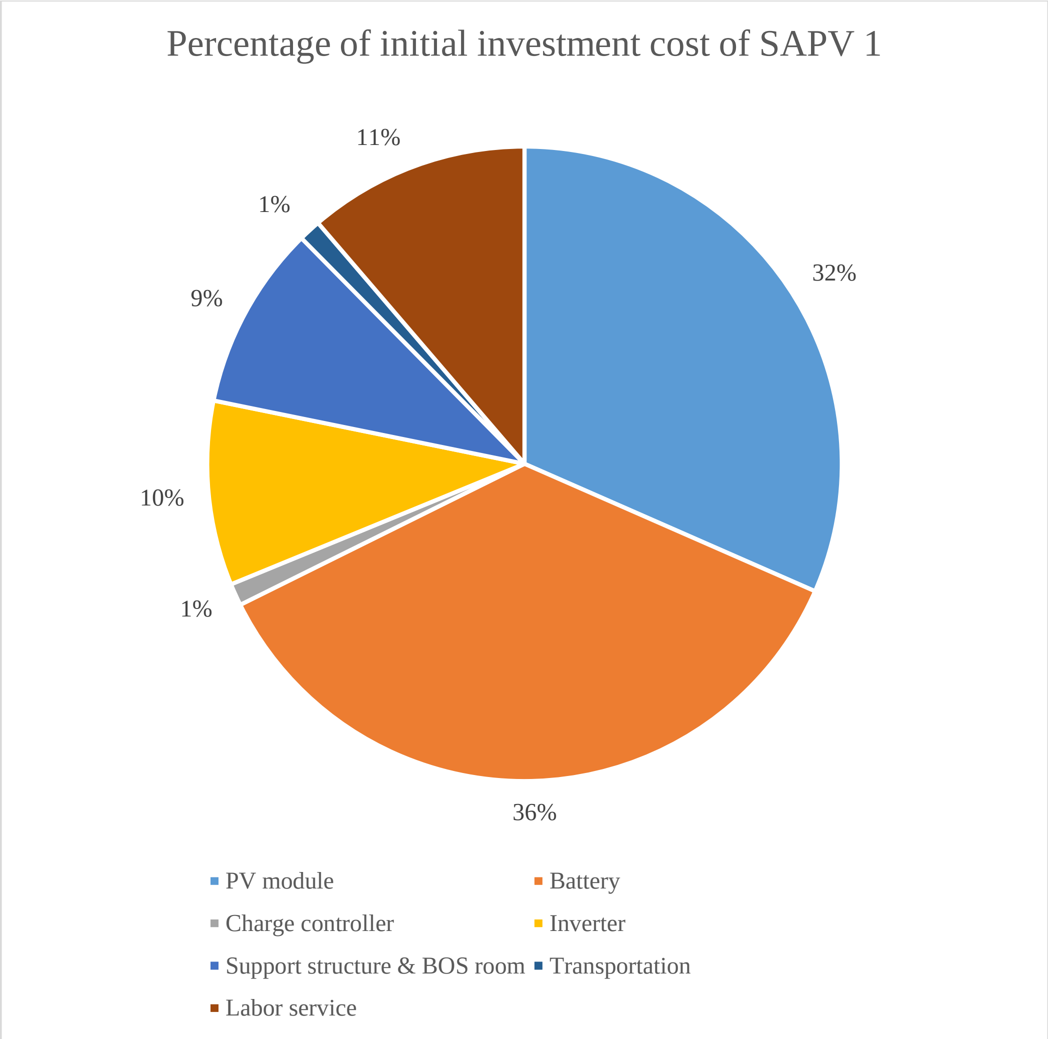


Figure 5. 6 Percentage of initial investment cost of SAPV 1

ii) Cost Throughout its Operation

SAPV 1 will operate about 25 years starting from the service date (SD) which is in 2016 and will end its operation in the year 2041. Within that period, there are two type of cost that is involved. The costs is operation, maintenance and repair cost, C_{OMR} and also the replacement cost, C_{rep} for the replacement of inverters and batteries. The C_{OMR} is expected to occur annually while for C_{rep} occur for every 10 years (inverters) and every 3 years (batteries). Table 5.9 show the cost that involved throughout the SAPV 1 lifetime.

Table 5. 9 The cost that involved throughout the SAPV 1 lifetime

Cost	Price for one time ($)	Price throughout project operation ($)
Operation, Maintenance and Repair cost, C_{OMR}	50.00	976.00

Replacement cost, Crep (Inverter)	625.00	933.33
Replacement cost, Crep (Batteries)	2,400.00	14,832.51
Total		**16,741.84**

iii) Residual Value

The residual value for SAPV 1 is estimated about 20% from the initial investment cost which is $ 1,525.00. This value is needed to be estimated because the residual is not occur yet during the base date (BD) which is in 2015. This value is assumed to occur during the last operation year of the PV system which in 2041, which is 26 years from the BD.

iv) Income/Saving from Energy Production

For SAPV 1, the system did not generate any income from the energy produced. This is because the system is not under feed-in-tariff (FiT) or any regulation for selling the energy that has been produced. The system is only for self-consumed for the house. Thus, help to save money from paying the utility bill to the energy authority company, which is Tenaga Nasional Berhad (TNB).

The system is capable to produced energy an annual average 3,121.34 kWh. But, the annual energy production will degrade about 0.59% each year. The total amount of energy production throughout its lifetime is 78,033.60 kWh. Besides that, as mentioned in Table 5.2, the house consumed about 127.23 kWh every month. By solely use from solar energy, the house can save about $ 83.21 each month. Roughly, SAPV 1 just only save about $ 2,080.25 throughout its operation. Table 5.10 shows the annual energy production and savings obtain from SAPV 1.

Table 5. 10 Annual energy production and savings obtain from SAPV 1.

Year	Annual energy production (kWh/year)	Savings ($)
2015-2016	0.00	-
2016-2017	3,348.00	83.21
2017-2018	3,328.25	83.21
2018-2019	3,308.61	83.21
2019-2020	3,289.09	83.21
2020-2021	3,269.68	83.21
2021-2022	3,250.39	83.21
2022-2023	3,231.22	83.21
2023-2024	3,212.15	83.21
2024-2025	3,193.20	83.21
2025-2026	3,174.36	83.21

2026-2027	3,155.63	83.21
2027-2028	3,137.01	83.21
2028-2029	3,118.50	83.21
2029-2030	3,100.11	83.21
2030-2031	3,081.81	83.21
2031-2032	3,063.63	83.21
2032-2033	3,045.56	83.21
2033-2034	3,027.59	83.21
2034-2035	3,009.72	83.21
2035-2036	2,991.97	83.21
2036-2037	2,974.31	83.21
2037-2038	2,956.77	83.21
2038-2039	2,939.32	83.21
2039-2040	2,921.98	83.21
2040-2041	2,904.74	83.21
Total	**78,033.60**	**2,080.25**

b) Rooftop PV system

i) Initial Investment Cost

The following is a breakdown of the initial investment cost of the RPV 1 in Malaysia (Table 5.11 and Figure 5.7). Overall, the system cost \$ 700,000.00 as an initial investment cost (C_I). \$ 656,160.00 of the total is the price of a major component of the PV system comprising solar PV modules, PV mounting structures, electrical systems, charge controller and inverters.

Besides that, the other cost is also included into the investment cost. Such as, the transportation cost and labour service. In life cycle cost assessment (LCCA), these cost cannot be ignored and must take into account. This is very important because the cause of error can be avoided and reduced. So, LCCA is a perfect method for economic analysis of a specific project especially project that involving with energy technology.

Table 5. 11 Initial investment cost breakdown, C_I of RPV 1.

Items	Price ($)
PV module	116,160.00
Inverter	40,000.00
Support structure & BOS	500,000.00
Others (Include Transport & Labour)	43,840.00

Total	**700,000.00**

All of the item in the initial investment cost is considered occurred in 2016. This is because 2016 is the year which the money is used for paying the initial investment cost.

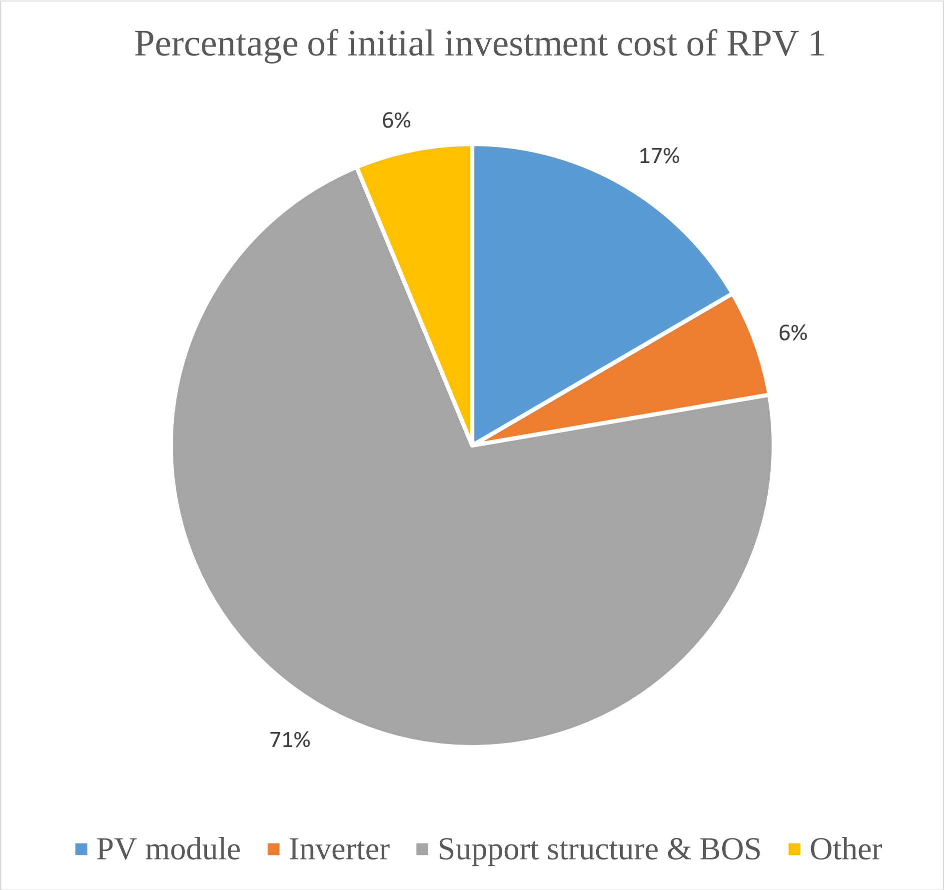


Figure 5. 7 Percentage of initial investment cost of RPV 1

In the other hand, for RPV 2, the initial investment cost (C_I) is a total of $ 10,475.00. The total price of major component in this Case Study 2 is about $ 9,650.00. At the same time, the other cost which include the transportation cost and the labour service cost also is included into the initial investment cost. Table 5.12 below illustrate the initial investment cost breakdown of RPV 2.

Table 5. 12 Initial investment cost breakdown, C_I of RPV 2

Items	Price ($)
PV module	8,000.00
Charge controller	75.00
Inverter	1,500.00
Support structure	75.00

Others (Include Transport & Labour)	825.00
Total	**10,475.00**

All of the item in the initial investment cost is considered occurred in 2011. This is because 2011 is the year which the money is used for paying the initial investment cost.

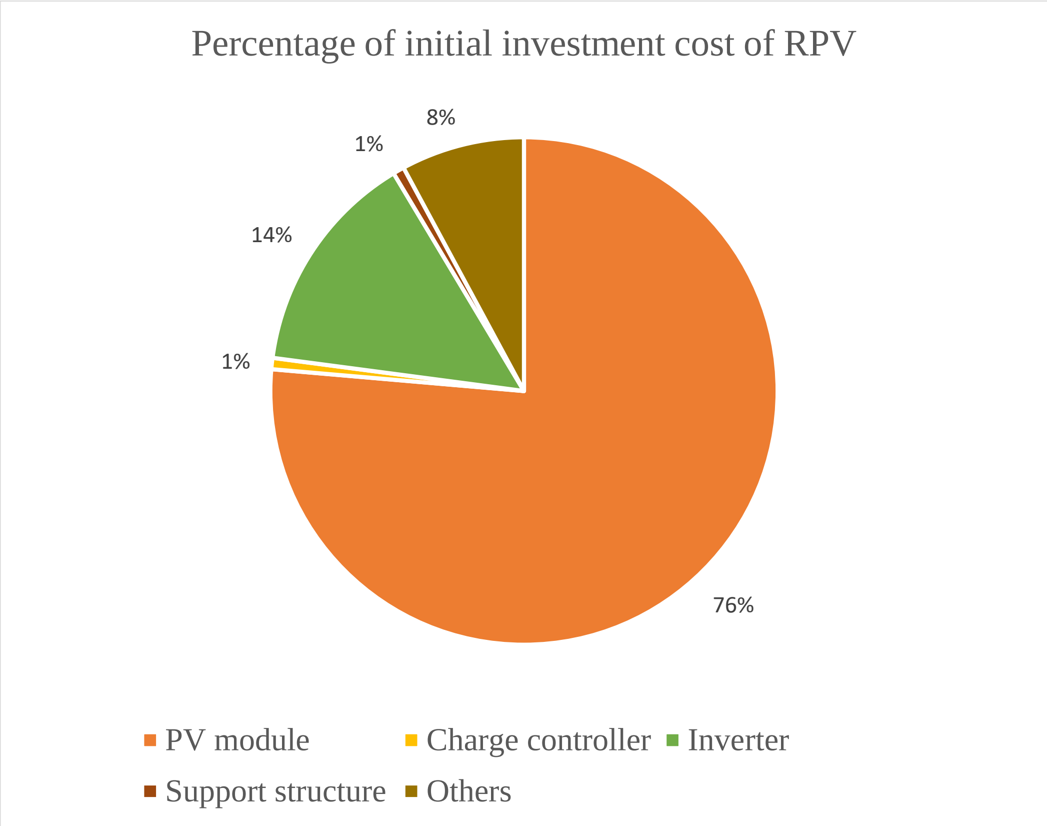


Figure 5. 8 Percentage of initial investment cost of RPV 2

ii) Cost Throughout its Operation

RPV 1 will operate about 25 years and starting from the SD which is in 2017 and will end its operation in the year 2042. Within that period, there are two type of cost that is involved. The costs is operation, maintenance and repair cost, C_{OMR} and also the replacement cost, C_{rep} for the replacement of inverters. The C_{OMR} is expected to occur annually while for C_{rep} occur for every 10 years (inverters). Table 5.13 show the cost that involved throughout the RPV 1 lifetime.

Table 5. 13 The cost that involved throughout the RPV 1 lifetime

Cost	Price for one time ($)	Price throughout project operation ($)
Operation, Maintenance and Repair cost, C_{OMR}	50.00	976.17
Replacement cost, Crep (Inverter)	40,000.00	59,732.79
Total		**60,708.96**

While for RPV 2, the system also will operate for 25 years and starting from the SD which is in 2012 and end its operation in the year 2037. Same as Case Study 1, the cost that involve within this period is the C_{OMR} and C_{Rep}. The C_{OMR} will occur annually while for C_{Rep} (inverters) will occur every 10 years. Table 5.14 show the cost that involved throughout the RPV 2 lifetime.

Table 5. 14 The cost that involved throughout the RPV 2 lifetime

Cost	Price for one time ($)	Price throughout project operation ($)
Operation, Maintenance and Repair cost, C_{OMR}	50.00	976.17
Replacement cost, Crep (Inverter)	1,500.00	2,239.98
Total		**3,216.15**

iii) Residual Value

The residual value for both RPV 1 and RPV 2 is estimated about 20% from their initial investment cost which is $ 140,000.00 and $ 2,095.00. These values is needed to be estimated because the residual is not occur yet during the base date (BD) which is in 2016 and 2011 respectively. This value is assumed to occur during the last operation year of the PV system which in 2042 and 2037 respectively, which is 26 years from the BD.

v) Income/Saving from Energy Production

For RPV 1, the system do generate income from the energy produced. This is because the system is under feed-in-tariff (FiT). The system is capable to produced energy an annual average 478,592.40 kWh. But, the annual energy production will degrade about 0.59% each year. The total amount of energy production throughout its lifetime is 11,640,331.37 kWh. The FiT rate for RPV 1 is 0.1745 $/kWh. Generally, $ 2,031,237.82 can be obtained throughout its operation period. Table 5.15 shows the annual energy production and income obtain from RPV 1.

While, RPV 2 also do generate income from the energy produced. The system is capable to produced energy an annual average 10290.61 kWh. But, the annual energy production will degrade about 0.46% each year. The total amount of energy production throughout its lifetime is 243,552.50 kWh. It sell its energy with the rate of 0.1300 $/kWh. This system can obtained its income about $ 24,842.93 throughout its operation period. Table 5.16 shows the annual energy production and income obtain from RPV 2.

Table 5. 15 Annual energy production and income obtain from RPV 1

Year	Annual energy production (kWh/year)	FIT rate ($/kWh)	Revenue($)
2016-2017	0	0	0
2017-2018	478,592.40	0.1745	83,514.37
2018-2019	477,491.64	0.1745	83,322.29
2019-2020	476,393.41	0.1745	83,130.65
2020-2021	475,297.70	0.1745	82,939.45
2021-2022	474,204.52	0.1745	82,748.69
2022-2023	473,113.85	0.1745	82,558.37
2023-2024	472,025.69	0.1745	82,368.48
2024-2025	470,940.03	0.1745	82,179.03
2025-2026	469,856.87	0.1745	81,990.02
2026-2027	468,776.20	0.1745	81,801.45
2027-2028	467,698.01	0.1745	81,613.30
2028-2029	466,622.30	0.1745	81,425.59
2029-2030	465,549.07	0.1745	81,238.31
2030-2031	464,478.31	0.1745	81,051.47
2031-2032	463,410.01	0.1745	80,865.05
2032-2033	462,344.17	0.1745	80,679.06
2033-2034	461,280.78	0.1745	80,493.50
2034-2035	460,219.83	0.1745	80,308.36
2035-2036	459,161.32	0.1745	80,123.65
2036-2037	458,105.25	0.1745	79,939.37
2037-2038	457,051.61	0.1745	79,755.51
2038-2039	456,000.39	0.1745	79,572.07
2039-2040	454,951.59	0.1745	79,389.05
2040-2041	453,905.20	0.1745	79,206.46
2041-2042	452,861.22	0.1745	79,024.28
Total	**11,640,331.37**		**2,031,237.82**

Table 5. 16 Annual energy production and income obtain from RPV 2

Year	Annual energy production (kWh/year)	FIT rate ($/kWh)	Revenue($)
2011-2012	0	0	0
2012-2013	10,290.61	0.1300	1,337.78
2013-2014	10,243.27	0.1300	1,331.62
2014-2015	10,196.15	0.1300	1,325.50
2015-2016	10,149.25	0.1300	1,319.40
2016-2017	10,102.56	0.1300	1,313.33
2017-2018	10,056.09	0.1300	1,307.29
2018-2019	10,009.83	0.1300	1,301.28
2019-2020	9,963.79	0.1300	1,295.29
2020-2021	9,917.95	0.1300	1,289.33
2021-2022	9,872.33	0.1300	1,283.40
2022-2023	9,826.92	0.1300	1,277.50
2023-2024	9,781.71	0.1300	1,271.62
2024-2025	9,736.72	0.1300	1,265.77
2025-2026	9,691.93	0.1300	1,259.95
2026-2027	9,647.35	0.1300	1,254.15
2027-2028	9,602.97	0.1300	1,248.39
2028-2029	9,558.79	0.1300	1,242.64
2029-2030	9,514.82	0.1300	1,236.93
2030-2031	9,471.06	0.1300	1,231.24
2031-2032	9,427.49	0.1300	1,225.57
2032-2033	9,384.12	0.1300	1,219.94
2033-2034	9,340.96	0.1300	1,214.32
2034-2035	9,297.99	0.1300	1,208.74
2035-2036	9,255.22	0.1300	1,203.18
2036-2037	9,212.64	0.1300	1,197.64
Total	**243,552.50**		**24,842.93**

c) Solar Farm system

i) Initial Investment Cost

Table 5.17 and Figure 5.9 is the initial investment cost breakdown and the percentage of initial investment cost of SF 1 respectively. Overall, the complex cost $ 21,000,000.00 as initial investment cost (C_I). $ 15,750,000.00 from the total investment is the price of major component of PV system. It comprises the solar PV module, PV mounting structures, electrical system and inverters.

Besides that, the other cost is also included into the investment cost. Such as, the land purchasing, land management cost, road construction cost, infrastructure works, building construction works and other cost. In life cycle cost assessment (LCCA), these cost cannot be ignored and must take into account. This is very important because the cause of error can be avoided and reduced. So, LCCA is a perfect method for economic analysis of a specific project especially project that involving with energy technology.

Table 5. 17 The initial investment cost breakdown of SF 1.

Cost	Price ($)
PV Module	8,820,000.00
PV Mounting Structure	2,520,000.00
Electrical System	2,310,000.00
Inverters	2,100,000.00
Land Management	1,680,000.00
Land	1,050,000.00
Advancement	1,050,000.00
Main Road Access	630,000.00
Infrastructure Works	420,000.00
Electric & Mechanical Building	210,000.00
Works at Main Building	210,000.00
Jumlah	**21,000,000.00**

All of the item in the initial investment cost is considered occurred in 2014. This is because 2014 is the year which the money is used for paying the initial investment cost.

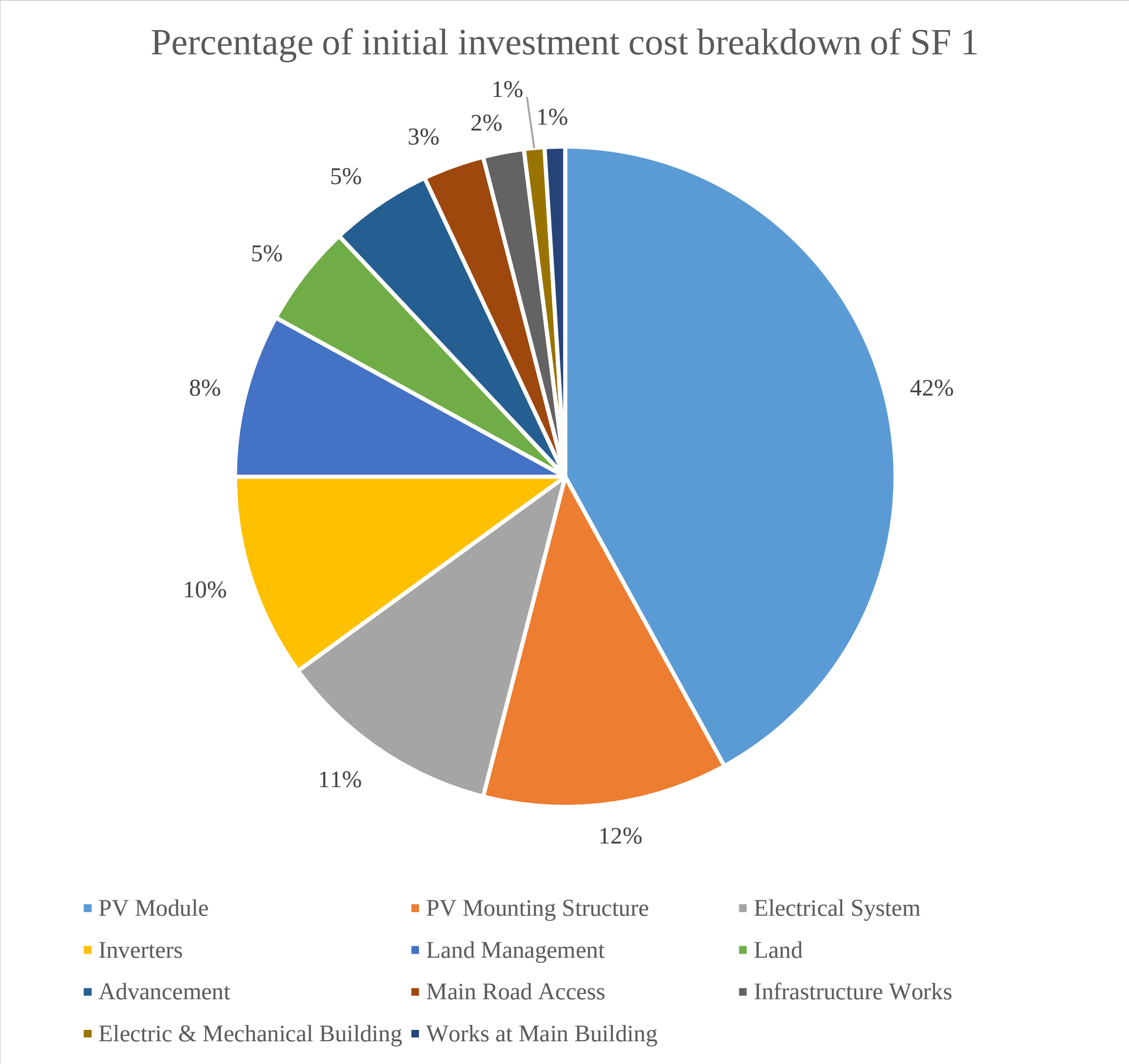


Figure 5. 9 Percentage of initial investment cost breakdown of SF 1.

For SF 2, overall, the power plant cost $ 4,247,214.05 as initial investment cost (C_I). $ 2,898,635.97 from the total investment is the price of major component of PV system. It comprises the solar PV module, PV mounting structures, electrical system, inverters and transformers. Table 5.18 and Figure 5.10 is the initial investment cost breakdown and the percentage of initial investment cost of Case Study 2 solar farm respectively.

Table 5. 18 The initial investment cost breakdown of SF 2.

Items	Price ($)
PV Module	2,061,886.11
Inverter	374,249.11
Monitoring system	17,488.96
Electrical system	451,264.46
Transformer	33,134.78
Facilities	16,479.80

Civil works	411,214.25
Transportation + packaging	171,600.00
Installation	43,661.41
Others	38,384.10
Land purchasing	170,888.40
Land permit	127,745.00
SLO & Interconnection JTM	59,204.64
Testing - Comissioning	46,759.46
Review design	18,983.47
Overhead/Contegency	104,270.10
Total	**4,247,214.05**

All of the item in the initial investment cost is considered occurred in 2014. This is because 2014 is the year which the money is used for paying the initial investment cost.

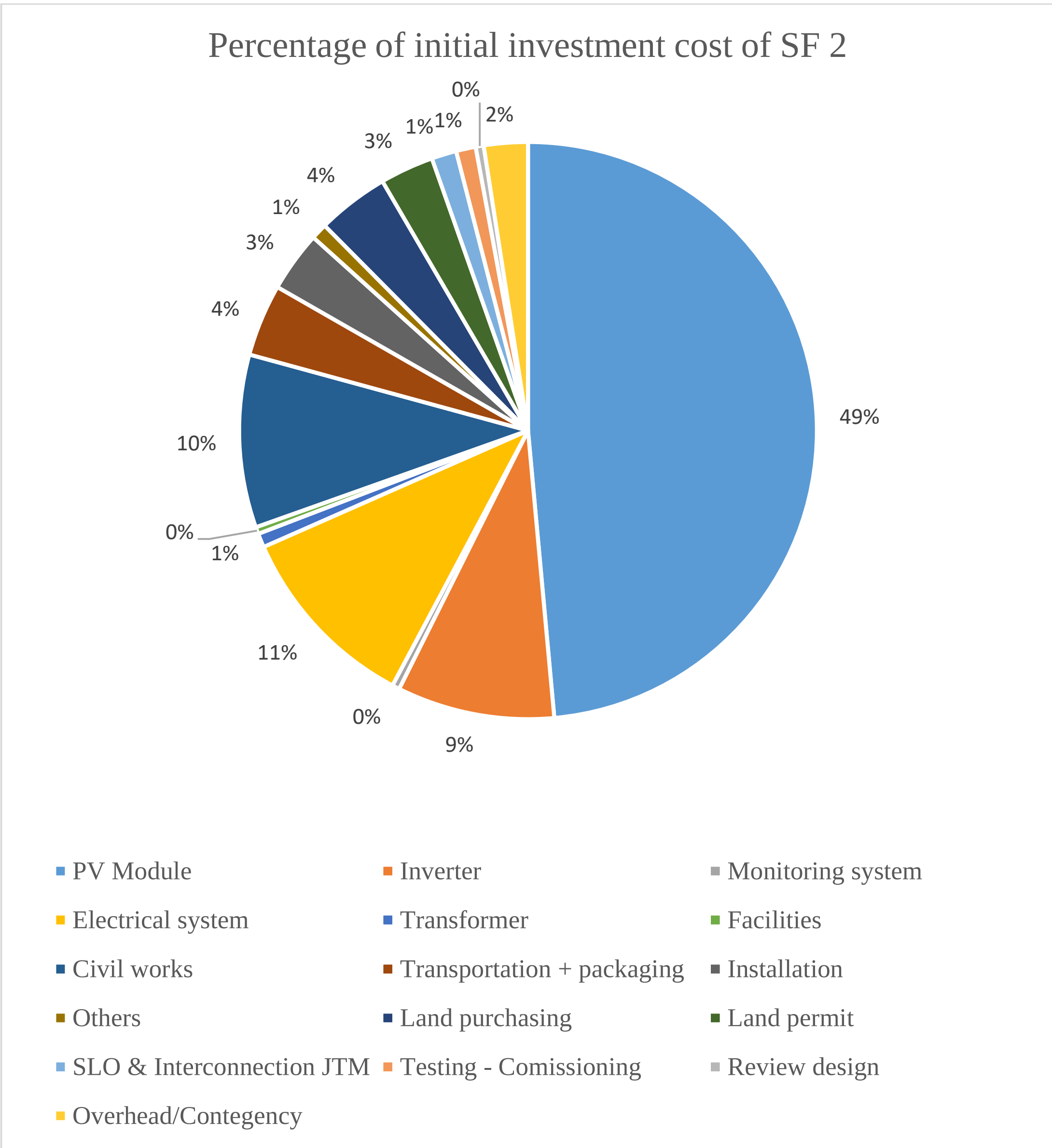


Figure 5. 10 Percentage of initial investment cost of Case Study solar farm

ii) Cost Throughout its Operation

SF 1 will operate about 25 years and starting from the SD which is in 2015 and will end its operation in the year 2040. Within that period, there are two type of cost that is involved. The costs is operation, maintenance and repair cost, C_{OMR} and also the replacement cost, C_{rep} for the replacement of inverters. The C_{OMR} is expected to occur annually while for C_{rep} occur for every 10 years (inverters). Table 5.19 show the cost that involved throughout the SF 1 lifetime.

Table 5. 19 The cost that involved throughout the SF 1 lifetime.

Cost	Price for one time ($)	Price throughout project operation ($)
Operation, Maintenance and Repair cost, C_{OMR}	233,500.00	4,558,727.09
Replacement cost, Crep (Inverter)	2,100,000.00	3,135,971.23
Total		**7,694,698.32**

While for SF 2, the system also will operate for 25 years starting from the SD which is in 2015 and end its operation in the year 2040. Same as Case Study 1, the cost that involve within this period is the C_{OMR} and C_{Rep}. The C_{OMR} will occur annually while for C_{Rep} (inverters) will occur every 10 years. Table 5.20 show the cost that involved throughout the SF 2 lifetime.

Table 5. 20 The cost that involved throughout the SF 2 lifetime.

Cost	Price for one time ($)	Price throughout project operation ($)
Operation, Maintenance and Repair cost, C_{OMR}	47,144.08	920,415.39
Replacement cost, Crep (Inverter)	374,249.11	558,873.54
Total		**1,479,288.93**

iii) Residual Value

The residual value for both SF 1 and SF 2 is estimated about 20% from their initial investment cost which is $ 21,000,000.00 and $ 4,247,214.00. These values is needed to be estimated because the residual is not occur yet during the base date (BD) for both case studies which is in 2014. This value is assumed to occur during the last operation year of the PV system which in 2040, which is 26 years from the BD.

iv) Income/Saving from Energy Production

For SF 1, the system do generate income from the energy produced. This is because the system is under feed-in-tariff (FiT). The system is capable to produced energy an annual average 10,120.00 MWh. But, the annual energy production will degrade about 0.59% each year. The total amount of energy production throughout its lifetime is 235,872,184.26 kWh. The FiT rate for this Case Study is 0.2185 $/kWh. Generally, $ 51,538,072.26 can be obtained throughout its operation period. Table 5.21 shows the annual energy production and income obtain from SF 1.

While, SF 2 also do generate income from the energy produced and same as SF 1 which is also under the FiT. The system is capable to produced energy an annual average 2,970.72 MWh. The annual energy production will degrade just only about 0.20 % each year. The total amount of energy production throughout its lifetime is 72,512,600.50 kWh. It sell its energy with FiT rate of 0.2295 $/kWh. This system can obtained its income about $ 16,641,641.81 throughout its operation period. Table 5.22 shows the annual energy production and income obtain from SF 2.

Table 5. 21 Annual energy production and income obtain from SF 1

Year	Annual energy production (kWh/year)	FIT rate ($/kWh)	Revenue($)
2014-2015	0	0	0
2015-2016	10,120,000.00	0.2185	2,211,220.00
2016-2017	10,060,292.00	0.2185	2,198,173.80
2017-2018	10,000,936.28	0.2185	2,185,204.58
2018-2019	9,941,930.75	0.2185	2,172,311.87
2019-2020	9,883,273.36	0.2185	2,159,495.23
2020-2021	9,824,962.05	0.2185	2,146,754.21
2021-2022	9,766,994.77	0.2185	2,134,088.36
2022-2023	9,709,369.50	0.2185	2,121,497.24
2023-2024	9,652,084.22	0.2185	2,108,980.40
2024-2025	9,595,136.93	0.2185	2,096,537.42
2025-2026	9,538,525.62	0.2185	2,084,167.85
2026-2027	9,482,248.32	0.2185	2,071,871.26
2027-2028	9,426,303.05	0.2185	2,059,647.22
2028-2029	9,370,687.86	0.2185	2,047,495.30
2029-2030	9,315,400.81	0.2185	2,035,415.08

2030-2031	9,260,439.94	0.2185	2,023,406.13
2031-2032	9,205,803.35	0.2185	2,011,468.03
2032-2033	9,151,489.11	0.2185	1,999,600.37
2033-2034	9,097,495.32	0.2185	1,987,802.73
2034-2035	9,043,820.10	0.2185	1,976,074.69
2035-2036	8,990,461.56	0.2185	1,964,415.85
2036-2037	8,937,417.84	0.2185	1,952,825.80
2037-2038	8,884,687.07	0.2185	1,941,304.12
2038-2039	8,832,267.42	0.2185	1,929,850.43
2039-2040	8,780,157.04	0.2185	1,918,464.31
Total	**235,872,184.26**		**51,538,072.26**

Table 5. 22 Annual energy production and income obtain from SF 2

Year	Annual energy production (kWh/year)	FIT rate ($/kWh)	Revenue($)
2014-2015	0	0	0
2015-2016	2,970,720.00	0.2295	681,780.24
2016-2017	2,964,778.56	0.2295	680,416.68
2017-2018	2,958,849.00	0.2295	679,055.85
2018-2019	2,952,931.30	0.2295	677,697.73
2019-2020	2,947,025.44	0.2295	676,342.34
2020-2021	2,941,131.39	0.2295	674,989.65
2021-2022	2,935,249.13	0.2295	673,639.68
2022-2023	2,929,378.63	0.2295	672,292.40
2023-2024	2,923,519.87	0.2295	670,947.81
2024-2025	2,917,672.83	0.2295	669,605.92
2025-2026	2,911,837.49	0.2295	668,266.70
2026-2027	2,906,013.81	0.2295	666,930.17
2027-2028	2,900,201.79	0.2295	665,596.31
2028-2029	2,894,401.38	0.2295	664,265.12
2029-2030	2,888,612.58	0.2295	662,936.59
2030-2031	2,882,835.35	0.2295	661,610.71
2031-2032	2,877,069.68	0.2295	660,287.49
2032-2033	2,871,315.54	0.2295	658,966.92
2033-2034	2,865,572.91	0.2295	657,648.98
2034-2035	2,859,841.77	0.2295	656,333.69
2035-2036	2,854,122.08	0.2295	655,021.02
2036-2037	2,848,413.84	0.2295	653,710.98
2037-2038	2,842,717.01	0.2295	652,403.55
2038-2039	2,837,031.58	0.2295	651,098.75

2039-2040	2,831,357.51	0.2295	649,796.55
Total	**72,512,600.50**		**16,641,641.81**

5.2 Economic Analysis

In this section, the performance of all the case studies for each category of PV systems is discussed here. Analysing the economic aspects of the PV power system are critical as it can provide important information to measure the success of the systems as well as to give investors an overview worthiness.

A summary of the findings is shown in the Table 5.23 and Table 5.24 below. Table 5.23 shows the summary of the main analysis which is life cycle cost (LCC) and levelized cost of energy (LCOE). A summary of supplementary financial measures which consist of net savings (NS), saving to income ratio (SIR), net present value (NPV), internal rate of return (IRR), simple payback period (SPB) and discounted payback period (DPB). The monetary value shown in this section has been converted to monetary value on BD.

All of the case studies undergoes the same approach of analyse. But, for SAPV 1 will have an additional scenario marked as SAPV 1*. This is due to SAPV 1 that the economic performance of SAPV 1 is very poor (as illustrate in Appendix 1) since the system did not generate any income. SAPV 1 turn out to be the lowest at every economic analysis performed. It has the lowest NS value, SIR and generate negative NPV. Other than that, the IRR and the PB (SPB and DPB) is unidentified.

Thus, an improved scenario is developed to know the minimum performance of SAPV system to be cost effective and viable. The C_I is increased from $ 6,650.00 to $ 7,350.00 since the number of PV modules has been increased to 16 unit. In SAPV 1, the 12 unit of PV panel only produce 3,348.00 kWh/year of energy. This limits the energy consumption of house. Hence, lead to low in savings in each year, since the savings depends on how much it can save cash from paying to utility grid. Anyhow, further detailed discussion for this scenario will be discuss in this section.

Table 5. 23 Findings summary: main analysis

		Life Cycle Cost, LCC ($)			Levelized Cost of Energy, LCOE ($/kWh)		
Category	**Discount rate**	2%	4%	6%	2%	4%	6%
	Stand-alone PV						
	SAPV 1	22,480.70	19,310.94	16,959.09	0.2881	0.2475	0.2173
	SAPV 1*	23,180.70	20,010.95	17,659.09	0.2328	0.2001	0.1774
	Rooftop PV						
	RPV 1	677,047.86	695,562.66	704,673.74	0.0582	0.0598	0.0605
	RPV 2	12,439.22	12,198.39	11,958.97	0.0511	0.0501	0.0491
	Solar farm						
	SF 1	26,184,865.32	25,509,958.23	24,889,130.50	0.111	0.1082	0.1055
	SF 2	5,218,893.56	5,100,949.46	4,988,828.95	0.072	0.0703	0.0688

Table 5. 24 Findings summary: supplementary financial measures

Category	Discount rate	NS ($)	SIR	NPV ($)	IRR (%)	SPB (yr)	DPB (yr)
Stand-alone PV							
SAPV 1	2%	648.37	0.03	(5,025.45)	-	-	-
	4%	518.81	0.03	(5,350.09)	-	-	-
	6%	424.54	0.03	(5,586.30)	-	-	-
SAPV 1*	2%	5,226.23	0.24	(1,147.00)	-	23.14	26.27
	4%	4,181.84	0.22	(2,387.06)	-	23.14	-
	6%	3,421.94	0.20	(3,288.89)	-	23.14	-
Rooftop PV							
RPV 1	2%	1,589,042.66	2.35	890,018.83	10.85	8.45	9.36
	4%	1,274,377.70	1.83	575,158.81	10.85	8.45	10.55
	6%	1,045,013.69	1.48	345,652.86	10.85	8.45	12.20
RPV 2	2%	23,866.76	2.08	14,367.93	11.59	7.96	8.77
	4%	19,187.26	1.68	9,493.37	11.59	7.96	9.80
	6%	15,769.70	1.39	5,933.87	11.59	7.96	11.22
Solar farm							
SF 1	2%	35,933,783.34	1.66	19,492,510.43	8.86	9.75	10.98
	4%	28,940,865.81	1.32	11,588,621.48	8.86	9.75	12.69
	6%	23,826,281.17	1.09	5,811,194.84	8.86	9.75	15.32
SF 2	2%	12,102,372.14	2.82	8,775,573.48	15.44	6.26	6.76
	4%	9,704,419.40	2.22	6,193,693.94	15.44	6.26	7.36
	6%	7,956,716.84	1.81	4,312,162.36	15.44	6.26	8.10

5.2.1 Life Cycle Cost (LCC)

Life cycle cost (LCC) for all case studies in each category PV systems has been calculated based on different discount rate 2%, 4% and 6%. As seen from Figure 5.11, 5.12, 5.14, 5.15 and 5.16, the LCC value decreases as the discount rate increase. All of the case studies follows this trend except for RPV 1, which the LCC value increase as the discount rate increase. Figure 5.13 shows the opposite trends of RPV 1 form others.

Furthermore, the LCC values is not influenced by the economic situation (presence of FiT) studied, meaning that the existence of FiT will not change the value of those costs. LCC value decreases as the discount rate increase due to the present value factor in 2% discount rate is greater compared to 4% and 6%. The present value factor can be seen in the Appendix 2.

For RPV 1, the reason for having opposite trends is due to its total cost of operational, maintenance and repair cost (C_{OMR}), replacement cost (C_{rep}) and residual value (C_{res}) at 2% (-$ 22,952.14) are much less than at 4% and 6% which is -$ 4,437.34 and $ 4,673.74 respectively. This means at 2% discount rate the inflow of cash (C_{res} value) is greater than of at 4% and 6% discount rate.

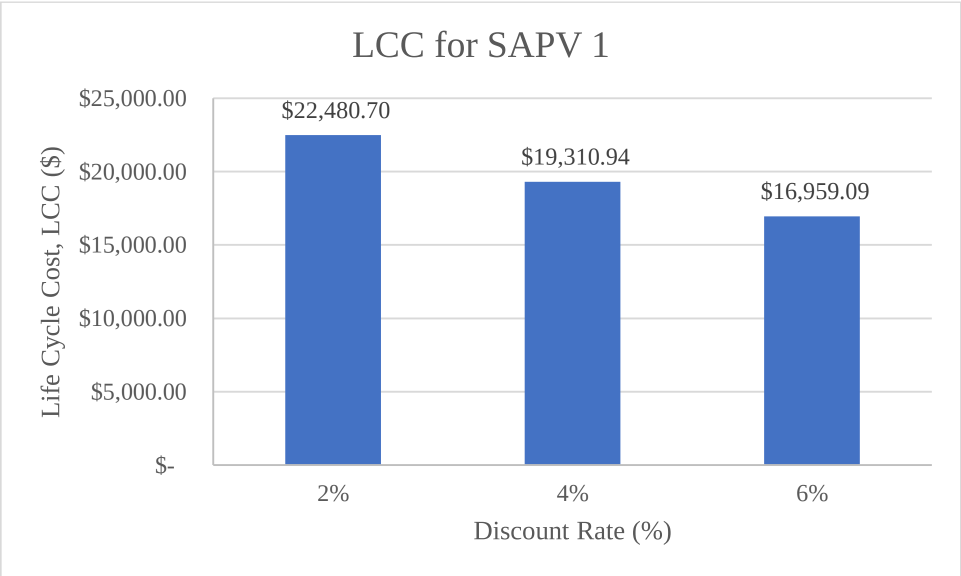


Figure 5. 11 Life cycle cost (LCC) for SAPV 1

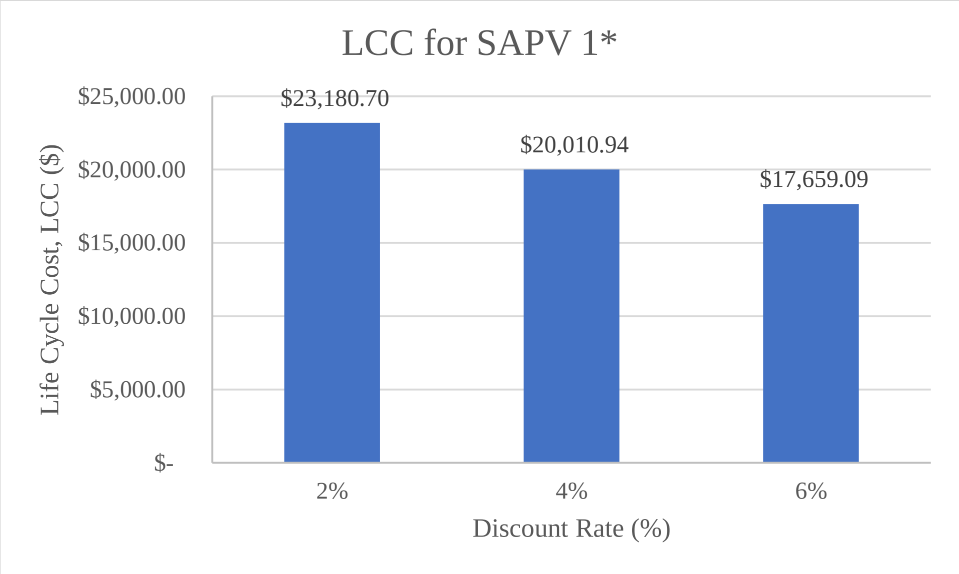


*Figure 5. 12 Life cycle cost (LCC) for SAPV 1**

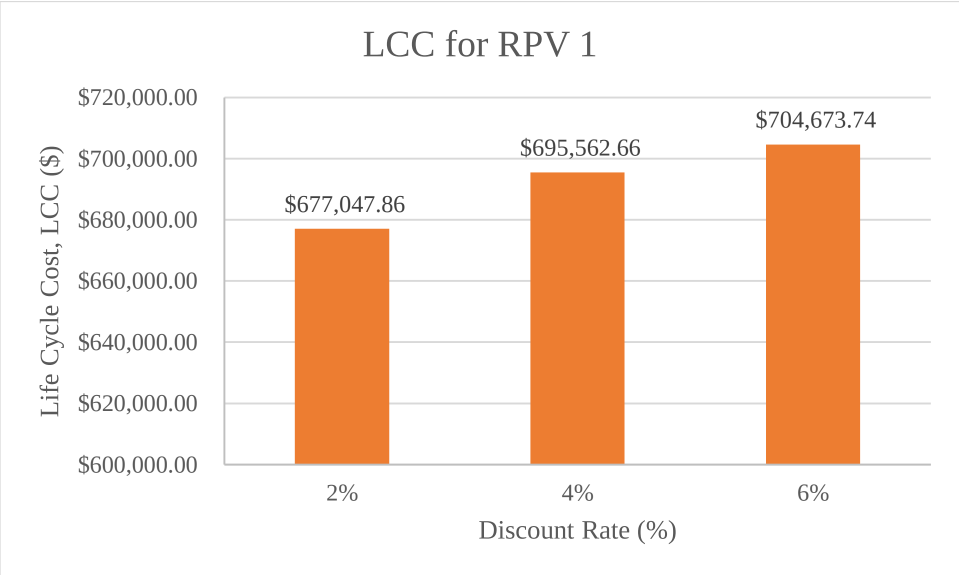


Figure 5. 13 Life cycle cost (LCC) for RPV 1

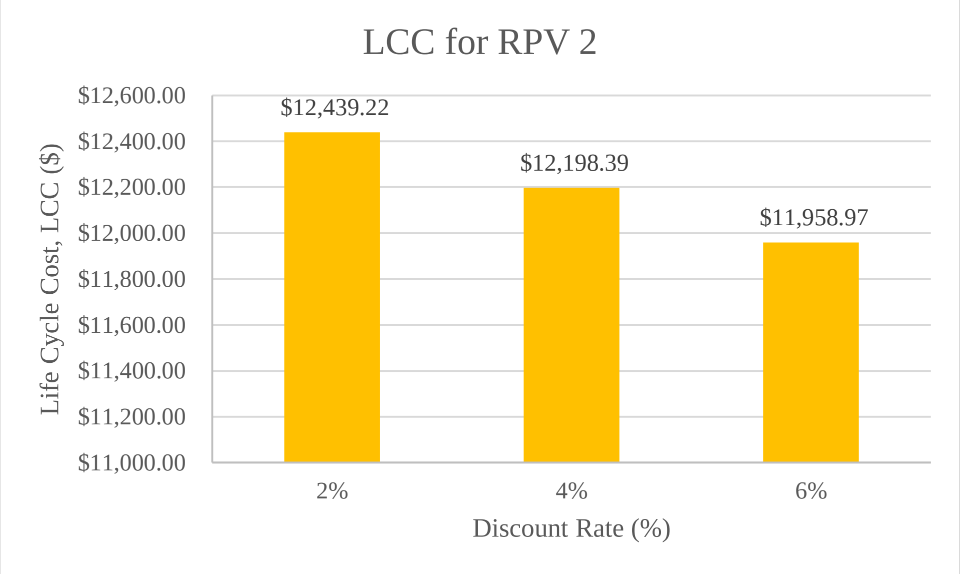


Figure 5. 14 Life cycle cost (LCC) for RPV 2

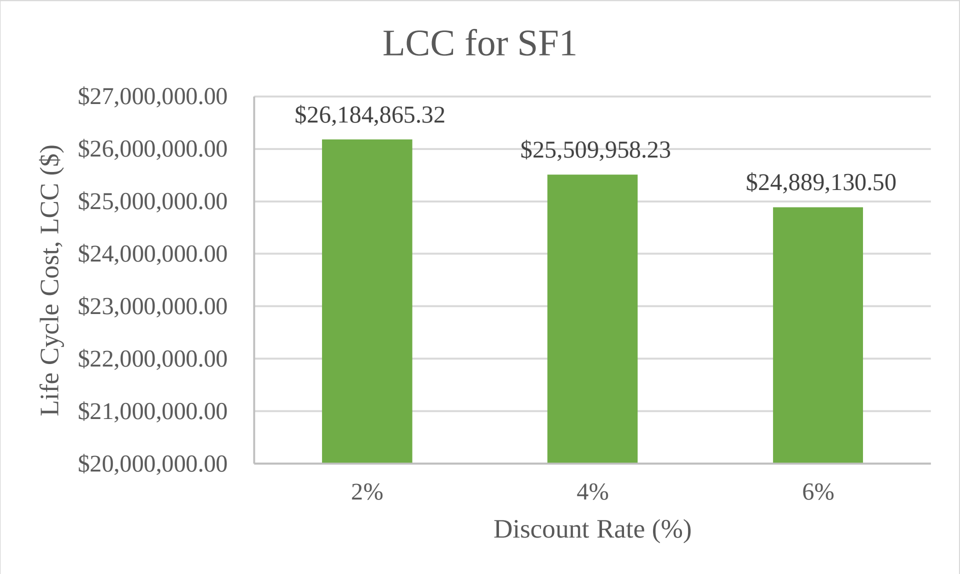


Figure 5. 15 Life cycle cost (LCC) for SF 1

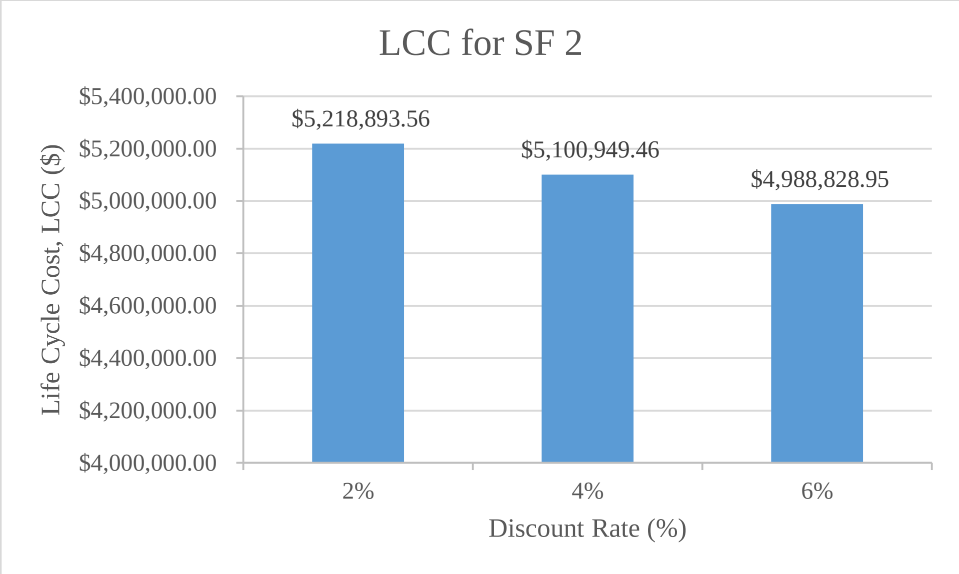


Figure 5. 16 Life cycle cost (LCC) for SF 2

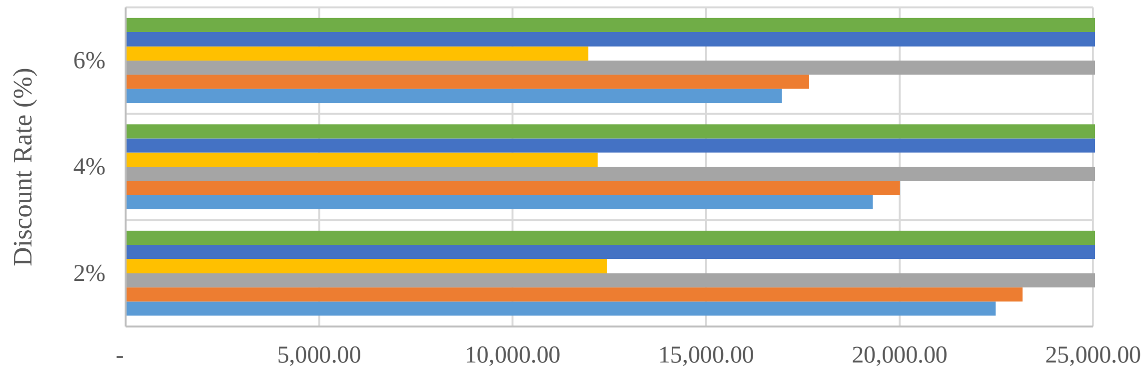
For all cases, generally costs C_{OMR}, C_{rep}, and C_{res} decreases as the discount rate increases. This is because these cost occur after the BD. Hence, the monetary value need to be converted to present value and the factor is the single present value (Appendix 2) for the cost that not occur annually. For costs that occur annually will use the annuity present value which shown in Appendix 3. Both appendix show the value of the factor decrease as discount rate increase. While for C_I is set at BD, which the factor is 1.00 for every discount rate. Therefore, all the monetary value for C_I will be the same as discount rate increase. Table 5.25 show the present value of LCC for all case studies.

Table 5. 25 The present value of LCC for all case studies

Category	Discount rate	Present value of cost ($)				Total cost ($)
		C_I	C_{OMR}	C_{rep}	C_{res}	
Stand-alone PV						
SAPV 1	2%	6,650.00	976.17	15,765.84	(911.31)	22,480.70
	4%	6,650.00	781.10	12,429.89	(550.05)	19,310.94
	6%	6,650.00	639.17	10,005.13	(335.21)	16,959.09
SAPV 1*	2%	7,350.00	976.17	15,765.84	(911.31)	23,180.70
	4%	7,350.00	781.10	12,429.89	(550.05)	20,010.94
	6%	7,350.00	639.17	10,005.13	(335.21)	17,659.09
Rooftop PV						
RPV 1	2%	700,000.00	976.17	59,732.79	(83,661.10)	677,047.86
	4%	700,000.00	781.10	45,278.04	(50,496.49)	695,562.66
	6%	700,000.00	639.17	34,807.98	(30,773.40)	704,673.74
RPV 2	2%	10,475.00	976.17	2,239.98	(1,251.93)	12,439.22
	4%	10,475.00	781.10	1,697.93	(755.64)	12,198.39
	6%	10,475.00	639.17	1,305.30	(460.50)	11,958.97
Solar farm						
SF 1	2%	21,000,000.00	4,558,727.09	3,135,971.23	(2,509,833.00)	26,184,865.32
	4%	21,000,000.00	3,647,755.67	2,377,097.34	(1,514,894.78)	25,509,958.23
	6%	21,000,000.00	2,984,913.66	1,827,418.96	(923,202.12)	24,889,130.50
SF 2	2%	4,247,214.05	920,415.39	558,873.54	(507,609.43)	5,218,893.56
	4%	4,247,214.05	736,488.59	423,631.70	(306,384.88)	5,100,949.46
	6%	4,247,214.05	602,659.57	325,671.39	(186,716.05)	4,988,828.95

When comparing all case studies for each category, the highest LCC value is SF 1 and followed by SF 2 and RPV 1. Solar farms cost the most because mostly solar farm is built in large-scale, which required purchasing of land, cost for land clearing and management, built facilities, road access and others. For example, SF 1, these costs consumed about 20% ($ 4,200,000.00) from the initial investment. Then, of course large-scale PV system need enormous amount of PV modules, inverters, good support structures and electrical system. These costs consumed $ 15,750,000.00 which is 75% from initial investment cost. Same goes to SF 2, PV modules and other BOS system cost the most.

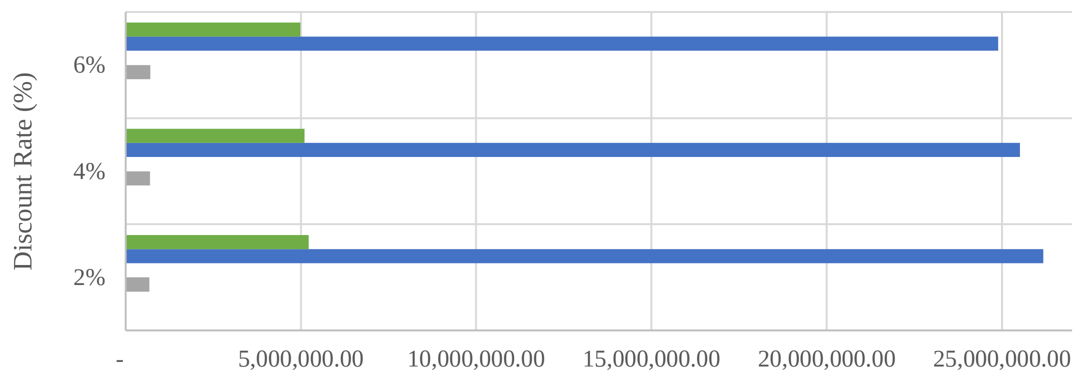
On the other hand, the lowest LCC value is the RPV 2 and followed by SAPV 1 and SAPV 1*. The reason RPV 2 is the lowest, this system possess small amount of equipment when compared to RPV 1. It only consist 32 unit of PV modules, an inverter and a charge controller. While, RPV 1 consist 1320 unit of PV modules, eight inverters and large BOS systems which cost a lot. When, compared to SAPV 1 & 1*, RPV 2 did not use any batteries although the amount PV module (which component cost the most) is much greater than SAPV case studies. Batteries contribute a lot to LCC value because batteries need to be replace every three year due to its lifetime. Figure 5.17 shows the bar chart of LCC values for all case studies.



	2%	4%	6%
SF 2	5,218,893.56	5,100,949.46	4,988,828.95
SF 1	26,184,865.32	25,509,958.23	24,889,130.50
RPV 2	12,439.22	12,198.39	11,958.97
RPV 1	677,047.86	695,562.66	704,673.74
SAPV 1*	23,180.70	20,010.94	17,659.09
SAPV 1	22,480.70	19,310.94	16,959.09

Life Cycle Cost, LCC ($)

Figure 5. 17 LCC values for all case studies (cut off at $ 25,000.00)



	2%	4%	6%
SF 2	5,218,893.56	5,100,949.46	4,988,828.95
SF 1	26,184,865.32	25,509,958.23	24,889,130.50
RPV 2	12,439.22	12,198.39	11,958.97
RPV 1	677,047.86	695,562.66	704,673.74
SAPV 1*	23,180.70	20,010.94	17,659.09
SAPV 1	22,480.70	19,310.94	16,959.09

Life Cycle Cost, LCC ($)

Figure 5. 18 LCC values for all case studies

5.2.2 Levelized Cost of Energy (LCOE)

LCC has a direct impact on LCOE. This can be seen in Figure 5.21. If referred back to the equation in section 4.2, LCOE is directly proportional to LCC and inversely proportional to LEP which the amount of energy generated during the lifetime of the power plant. LEP is fixed and is not influenced by such basic economic factors. But, it will change in the event of a long-term climate change that gives an effect to the amount of irradiation or the occurrence of an interruption to the PV system or both. In this study, those factors is neglected. Thus, the value LEP for every case studies are as follows:

i. **Stand-alone PV**
   a. Case Study 1 (Malaysia) - 78,033.60 kWh
   b. Case Study 1 (Improve) - 99,569.76 kWh

ii. **Rooftop PV**
   a. Case Study 1 (Malaysia) - 11,640,331.37 kWh
   b. Case Study 2 (Thailand) - 243,552.50 kWh

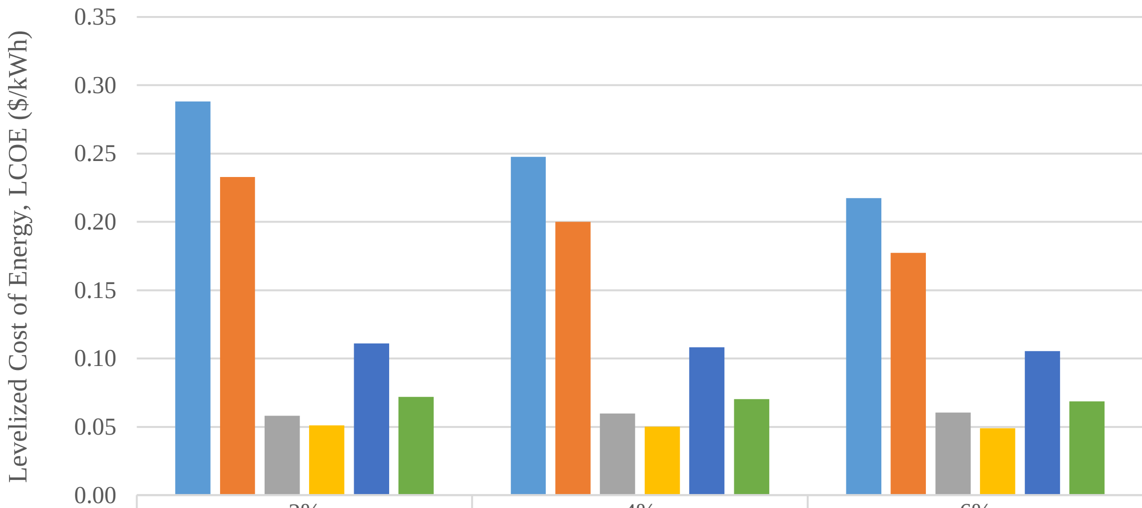
iii. **Solar Farm**
   a. Case Study 1 (Malaysia) - 235,872,184.26 kWh
   b. Case Study 2 (Indonesia) - 72,512,600.50 kWh

Because discount rates play an important role in the calculation of LCC, it also plays a common role in LCOE. The LCOE for all case studies can be seen in Table 5.26 and Figure 5.19. It shown that, LCOE of SAPV system is the highest compared to other category of PV systems. SAPV 1 has the highest LCOE value among others, which is 0.2881, 0.2475 and 0.2173 $/kWh at discount rate of 2%, 4% and 6% respectively. SAPV system produce high LCOE value because the amount of energy produced throughout its lifetime (LEP) is too low when compared to their LCC value. In this case, SAPV 1 just only produce 78,033.60 kWh throughout its lifetime, but the LCC value is too high (at 2%, 4% and 6%). Thus, produce high LCOE value. SAPV 1* have a slightly improve in LCOE value, this is due to it have improvement in LEP value. Although, it have some improvement, the LCOE value is still high among other PV system.

The lowest LCOE value goes to the Rooftop PV system. For both cases, shows good performance in LCOE value, especially RPV 2. Rooftop PV system can achieve low LCOE value, because they can produce large amount LEP. For example, RPV 2 capable to produce 243,552.50 kWh in 25 years of its operation compared to SAPV 1 and 1* just only 78,033.60 kWh and 99,569.76 kWh respectively; which is too low for their LCC value. While, for RPV 1, it capable to produce 11,640,331.37 kWh. It is just like a solar farm but mounted on the roof of a building. Another factor rooftop can achieve low LCOE is they have low LCC value compare to LEP value. As, they did not required any land, thus is save up a lot of their investment. This eventually lowered the LCC value. Unlike solar farm, purchasing a land give an extra cost which contribute to high LCC value. Table 5.26 LCOE for all case studies.

Table 5. 26 LCOE for all case studies

		Levelized Cost of Energy, LCOE ($/kWh)		
Category	**Discount rate**	2%	4%	6%
	Stand-alone PV			
	SAPV 1	0.2881	0.2475	0.2173
	SAPV 1*	0.2328	0.2001	0.1774
	Rooftop PV			
	RPV 1	0.0582	0.0598	0.0605
	RPV 2	0.0511	0.0501	0.0491
	Solar farm			
	SF 1	0.111	0.1082	0.1055
	SF 1	0.072	0.0703	0.0688



	2%	4%	6%
SAPV 1	0.2881	0.2475	0.2173
SAPV 1*	0.2328	0.2001	0.1774
RPV 1	0.0582	0.0598	0.0605
RPV 2	0.0511	0.0501	0.0491
SF 1	0.1110	0.1082	0.1055
SF 1	0.0720	0.0703	0.0688

Discount rate (%)

Figure 5. 19 LCOE for all case studies

5.2.3 Supplementary Financial Measures

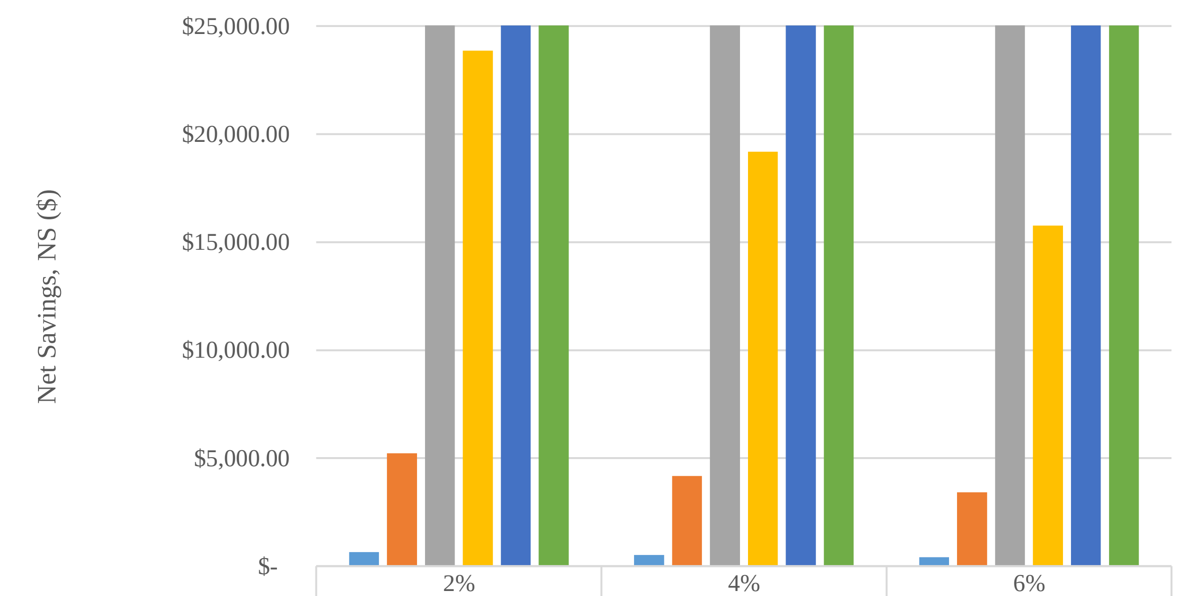
The results of supplementary financial measures analysis are useful for measuring the feasibility of a project in a particular economic environment. Findings summary of these analysis has been shown in Table 5.24. It comprises net savings (NS), savings-to-investment ratio (SIR), net present value (NPV), internal rate of return (IRR), simple payback period (SPB) and discounted payback period (DPB). There were 18 sensitivity analyses conducted in this study. The 18 analyses of the sensitivity is based on the six case studies and three different financial scenario of discounted rate (2%, 4% and 6%). Assessment has been made based on the following selection criteria:

i. Largest NS
ii. SIR > 1
iii. Positive and largest NPV value
iv. IRR > discount rate
v. Fastest SPB
vi. Fastest DPB

a) Net Saving (NS)

Net savings is the income or savings that can be used by the developer company. Figure 5.20 and Figure 5.23 shows net income for each situation in sensitivity analysis. The existence of policy or policy assistance mechanisms can boost the net income. For example, SAPV 1 and SAPV 1* does not have any income from the energy they produced. This because the system are not under FiT and generate some savings solely from not using electricity from the utility grid. Thus, brings SAPV 1 has the lowest NS which is $ 648.37, $ 518.81 and $ 424.54 at discount rate 2%, 4% and 6% respectively. For SAPV 1* have improve (increase of 706.06%) in their NS which is $ 5,226.23, $ 4,181.84 and $ 3,421.94 at discount rate 2%, 4% and 6% respectively. It improve due to the system can produce more energy, thus more electric energy can be consumed. Since the savings are based on the electrical consumption to the electric utility grid. The limitation for SAPV system is the amount of energy they can generate. If less energy can be generate, less electrical consumption. Hence, less savings.

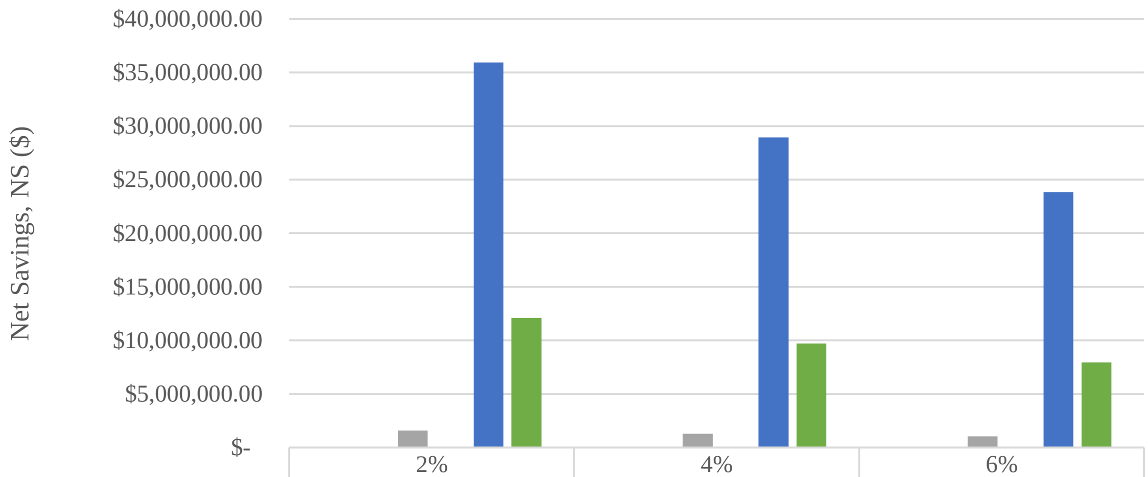
For others, they are under FiT policy and sell their energy for a certain tariff. Income from selling their energy production boost their income about 30% and above. In addition, the minimum discount rate will generate maximum revenue. This is because the present value of the total income (NS) decreases more significantly when the discount rate increases. It is known by changing the value of income from energy sales in Table 5.15, 5.16, 5.21 and 5.22 to value in the BD.



	2%	4%	6%
SAPV Case 1 (Malaysia)	$648.37	$518.81	$424.54
SAPV Case 1 (Improve)	$5,226.23	$4,181.84	$3,421.94
Rooftop Case 1	$1,589,042.66	$1,274,377.70	$1,045,013.69
Rooftop Case 2	$23,866.76	$19,187.26	$15,769.70
Solar Farm Case 1	$35,933,783.34	$28,940,865.81	$23,826,281.17
Solar Farm Case 2	$12,102,372.14	$9,704,419.40	$7,956,716.84

Discount rate (%)

Figure 5. 20 NS for all case studies (cut off at $ 25,000.00)



	2%	4%	6%
SAPV Case 1 (Malaysia)	$648.37	$518.81	$424.54
SAPV Case 1 (Improve)	$5,226.23	$4,181.84	$3,421.94
Rooftop Case 1	$1,589,042.66	$1,274,377.70	$1,045,013.69
Rooftop Case 2	$23,866.76	$19,187.26	$15,769.70
Solar Farm Case 1	$35,933,783.34	$28,940,865.81	$23,826,281.17
Solar Farm Case 2	$12,102,372.14	$9,704,419.40	$7,956,716.84

Discount rate (%)

Figure 5. 21 NS for all case studies

b) Savings-to-Investment Ratio (SIR)

Referring to Table 5.24, SIR exceeding 1.00 (meet criteria) was successfully recorded by both Rooftop PV system and both Solar Farm system. The highest SIR that have been recorded is the SF 2 which is 2.82 at 2% discount rate. Then, followed by RPV 1 (2%) and SF 2 (4%) with SIR value of 2.35 and 2.22 respectively. The systems that does not meet the criteria is the SAPV systems. All SAPV system scored below than 1.00. While, the only highest SIR for this system is 0.24 (SAPV 1*).

This suggests that profitability is earned for every dollar invested in an economy with a basic aid mechanism such as FiT. On the contrary, losses will result in an economy without the existence of a basic aid mechanism. In terms of discount rates, lower rates will give a higher SIR. It simply happens that because higher discount rates will reduce the value of money converted into its value in the base year more significantly. Thus, the minimum discount rate produces maximum SIR.

c) Net Present Value (NPV)

NPV is the present value of future cash flows. Based on Table 5.24, there are roughly 12 conditions that generate a positive NPV. All of case study generates positive except for the SAPV systems. In terms of position, the largest NPV generated by SF 1 (2%) with NPV of $ 19,492,510.43, followed by SF 1 (4%) and SF 2 (2%) with NPV of $ 11,588,621.48 and $

8,775,573.48 respectively. The negative NPV shows the cost of investment, C_I is higher than the total revenue. This refers to both case studies of SAPV systems.

The sequence of positions is due to two factors. The FiT's existence could increase the cash flow of the annual income from non-FiT, and the low discount rate yields the current value of the cash flows of the higher annual earnings than the higher discount rates.

d) Internal Rate of Ratio (IRR)

Internal rate of return, IRR is used to analyse the risk of an investment with the higher IRR concept than the discount rate, the less risk of investment. Based on Table 5.24, the highest IRR of 15.44% was recorded by SF 2, which this system is under FiT which can assist solar farm being examined from a financial point of view. The rank then followed by the RPV 2 and RPV 1 with IRR of 11.59% and 10.85%.

The manipulated rate in this study has no effect on the IRR as it is a discount rate that equates the present value of expected cash flows to the initial investment of the project. In other words, it is required to be compared to the discounted rates. For example, the IRR 15.44% means the discount rate of a project should amount to 15.44% to generate the total cash flow from energy sales (NS) equal to the total cost of investment (C_I).

For both cases in SAPV system, IRR cannot be determined due to cash flow for both cases are too low and even after 25 years of operation the present value of their savings they did not reach equilibrium to their initial investment. Thus, calculating IRR is impossible.

Table 5. 27 IRR and its difference with discount rate

Category	IRR (%)	Discount Rate (%)	Difference (%)
Stand-alone PV			
SAPV 1	-	2	-
	-	4	-
	-	6	-
			-
SAPV 1*	-	2	-
	-	4	-
	-	6	-
			-
Rooftop PV			
RPV 1	10.85	2	8.85
	10.85	4	6.85
	10.85	6	4.85

RPV 2	11.59	2	9.59
	11.59	4	7.59
	11.59	6	5.59
Solar farm			
SF 1	8.86	2	6.86
	8.86	4	4.86
	8.86	6	2.86
SF 2	15.44	2	13.44
	15.44	4	11.44
	15.44	6	9.44

e) Payback Period

There are two payback periods that have been analysed in this study, i.e. the simple payback period (SPB) and the discounted payback period (DPB). The discount rate does not give SPB the difference because cash flows are not discounted to current value. But the discount rate affects the DPB as cash flows are discounted to the present value.

The fastesr SPB is recorded by the SF 2 which 6.26 years (for 2%, 4% and 6%) of payback, then RPV 2 with 7.96 years (for 2%, 4% and 6%), RPV 1 with 8.45 years (for 2%, 4% and 6%), SF 1 with 9.75 (for 2%, 4% and 6%) and SAPV 1* with the slowest payback period (for 2%, 4% and 6%). For SAPV 1, payback is impossible to attained this is because, at the last year operation which is the 25th year of operation, the savings just only $ 1,624.55. It need to reach $ 6,650.00 to attain SPB.

For DPB, the fastest is from SF 2 at 2% discount rate with DPB of 6.76 years, followed by SF 2 at 4% with DPB of 7.36 years and SF 2 at 6% with DPB of 8.1 years. While, for the slowest DPB is the SAPV 1* at 2% with DPB of 26.27 years. For others, their DPB at the average range of DPB of 8 – 16 years. Except for SAPV 1 (at 2%, 4% and 6%) and SAPV 1* (at 4% and 6%). These cases, the payback is impossible to attain this is because, their present value savings are too low. Their savings just only reach roughly about 24% of its initial investment on the 25th year of their operation. Thus, calculating DPB is impossible.

5.3 Summary of Analysis

According to key analysis (Section 5.2.1 and Section 5.2.2) LCC and LCOE are not affected by the basic aid mechanism. This is because they are related to PV system costs and there is no relationship with the energy sales proceeds. Then the discount rate plays an important role here. The minimum discount rate will result in minimum LCC and LCOE. In other words, the lower discount rate is better as it reduces the overall cost of the PV system thus reducing the cost of producing one unit of energy.

In addition, supplementary financial measures, both the policy aid mechanism and the discount rate affects the analysis results except the simple repayment period (SPB) and the internal rate of return (IRR) that are only influenced by the basic aid mechanism. But for performance evaluations, the IRR value that is found should be compared to the discount rate of the case. This means that discount rates should also be taken into account in assessing IRR's position or performance. Hence, only SPBs have nothing to do with discount rates.

Table 5. 28 Ranking case performance based on the economic analysis

Category	Discount rate	NS ($)	SIR	NPV ($)	IRR (%)	SPB (yr)	DPB (yr)
Stand-alone PV							
SAPV 1	2%	16	16	16	-	-	-
	4%	17	17	17	-	-	-
	6%	18	18	18	-	-	-
SAPV 1*	2%	13	13	13	-	13	13
	4%	14	14	14	-	14	-
	6%	15	15	15	-	15	-
Rooftop PV							
RPV 1	2%	7	2	7	7	7	5
	4%	8	5	8	8	8	7
	6%	9	9	9	9	9	10
RPV 2	2%	10	4	10	4	4	4
	4%	11	7	11	5	5	6
	6%	12	10	12	6	6	9
Solar farm							

SF 1	2%	1	8	1	10	10	8
	4%	2	11	2	11	11	11
	6%	3	12	5	12	12	12
SF 2	2%	4	1	3	1	1	1
	4%	5	3	4	2	2	2
	6%	6	6	6	3	3	3

Based on Table 5.28, FiT are seen to support the PV system financially. Especially, for Solar Farms and Rooftop PV cases. Most of the top 10 ranks are from this two categories of PV system. Under the policy availing mechanism such as FiT, higher tariffs helps these high investment cost projects financially. This allows for increased revenue through energy sales achieved. Based on the analysis, the best performance is achieved by PV system with FiT at the lowest discount rate of 2%. It is followed by at 4% and at 6% discount rate. Without the basic aid mechanism, the solar farm PV system is less viable due to the lack of revenue from energy sales. This is especially occur with the SAPV system cases, which solely rely on their savings without selling their energy. Thus, the main key is if there selling of energy, all of PV system can be more viable and cost effective.

6.0 CONCLUSION

All case studies from Malaysia, Thailand and Indonesia for each PV systems have been successfully conducted. Technical and financial details have also been obtained during a case study conducted through a survey form (Appendix 3). Accordingly, it can be concluded that all research objectives have been achieved. Firstly, the economic assessment based on life cycle cost analysis (LCCA) method has been successfully carried out. In this analysis, life cycle costs (LCC), levelized costs of energy (LCOE), net savings (NS), savings-to-investment (SIR) ratio, net present value (NPV), internal rate of return (IRR) payback period (SPB and DPB) have successfully calculated. The assessment was conducted on seven case studies having three different economic condition, at 2%, 4% and 6% discount rate.

For LCC and LCOE analysis, the best system comes from the Rooftop PV system. Both cases in Rooftop PV system recorded the lowest value of LCC and LCOE. LCOE value of RPV 2 is the best with 0.0491 $/kWh and followed by RPV 1 with 0.0582 $/kWh. Besides that, the best performance financially in the supplementary financial measures, SF 2 (2%) perform the best. SF 2 recorded the top in the SI, IRR, SPB and DPB analysis as shown in Table 5.28. Thus, Solar Farm system is more viable compared to Rooftop PV system. In order Rooftop PV system to be financially viable and taking the advantage of their low LCC and LCOE value, Rooftop PV system need to be in large-scale (like Solar Farm) with higher capacity in order to produce even higher energy production. However, for Solar Farm to be more cost-effective and achieving low LCOE value, usage of PV module with low degradation rate below 0.20% is highly recommended.

For SAPV system with no income this make the system not viable. With the usage of batteries this will make it even worse since LCC would be high compared to LEP eventually will lead to high LCOE. SAPV systems are solely for self-consumption with no real financial benefits

Lastly, it can be seen that LCCA is a very powerful tool to be included in policy making and development of PV project in APEC economies. LCCA would allow, not only looking the financial viability of a PV project but also the LCOE production within the solar energy producer. LCOE is important as it allows apple to apple comparison between different types of renewable energy production.

7.0 REFERENCE

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8.0 APPENDIX

Appendix 1 Initial Investment Cost for SAPV 1*

Items	Unit	Price ($)
PV module	16	2,800.00
Battery	12	2,400.00
Charge controller	1	75.00
Inverter	1	625.00
Support structure & BOS room	1	625.00
Other		825.00
Total		**7,350.00**

Appendix 2 Table of Single Present Value Factor

Tahun, n	Kadar Faedah, r (%)														
	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1	0.9901	0.9804	0.9709	0.9615	0.9524	0.9434	0.9346	0.9259	0.9174	0.9091	0.9009	0.8929	0.8850	0.8772	0.8696
2	0.9803	0.9612	0.9426	0.9246	0.9070	0.8900	0.8734	0.8573	0.8417	0.8264	0.8116	0.7972	0.7831	0.7695	0.7561
3	0.9706	0.9423	0.9151	0.8890	0.8638	0.8396	0.8163	0.7938	0.7722	0.7513	0.7312	0.7118	0.6931	0.6750	0.6575
4	0.9610	0.9238	0.8885	0.8548	0.8227	0.7921	0.7629	0.7350	0.7084	0.6830	0.6587	0.6355	0.6133	0.5921	0.5718
5	0.9515	0.9057	0.8626	0.8219	0.7835	0.7473	0.7130	0.6806	0.6499	0.6209	0.5935	0.5674	0.5428	0.5194	0.4972
6	0.9420	0.8880	0.8375	0.7903	0.7462	0.7050	0.6663	0.6302	0.5963	0.5645	0.5346	0.5066	0.4803	0.4556	0.4323
7	0.9327	0.8706	0.8131	0.7599	0.7107	0.6651	0.6227	0.5835	0.5470	0.5132	0.4817	0.4523	0.4251	0.3996	0.3759
8	0.9235	0.8535	0.7894	0.7307	0.6768	0.6274	0.5820	0.5403	0.5019	0.4665	0.4339	0.4039	0.3762	0.3506	0.3269
9	0.9143	0.8368	0.7664	0.7026	0.6446	0.5919	0.5439	0.5002	0.4604	0.4241	0.3909	0.3606	0.3329	0.3075	0.2843
10	0.9053	0.8203	0.7441	0.6756	0.6139	0.5584	0.5083	0.4632	0.4224	0.3855	0.3522	0.3220	0.2946	0.2697	0.2472
11	0.8963	0.8043	0.7224	0.6496	0.5847	0.5268	0.4751	0.4289	0.3875	0.3505	0.3173	0.2875	0.2607	0.2366	0.2149
12	0.8874	0.7885	0.7014	0.6246	0.5568	0.4970	0.4440	0.3971	0.3555	0.3186	0.2858	0.2567	0.2307	0.2076	0.1869
13	0.8787	0.7730	0.6810	0.6006	0.5303	0.4688	0.4150	0.3677	0.3262	0.2897	0.2575	0.2292	0.2042	0.1821	0.1625
14	0.8700	0.7579	0.6611	0.5775	0.5051	0.4423	0.3878	0.3405	0.2992	0.2633	0.2320	0.2046	0.1807	0.1597	0.1413
15	0.8613	0.7430	0.6419	0.5553	0.4810	0.4173	0.3624	0.3152	0.2745	0.2394	0.2090	0.1827	0.1599	0.1401	0.1229
16	0.8528	0.7284	0.6232	0.5339	0.4581	0.3936	0.3387	0.2919	0.2519	0.2176	0.1883	0.1631	0.1415	0.1229	0.1069
17	0.8444	0.7142	0.6050	0.5134	0.4363	0.3714	0.3166	0.2703	0.2311	0.1978	0.1696	0.1456	0.1252	0.1078	0.0929
18	0.8360	0.7002	0.5874	0.4936	0.4155	0.3503	0.2959	0.2502	0.2120	0.1799	0.1528	0.1300	0.1108	0.0946	0.0808
19	0.8277	0.6864	0.5703	0.4746	0.3957	0.3305	0.2765	0.2317	0.1945	0.1635	0.1377	0.1161	0.0981	0.0829	0.0703
20	0.8195	0.6730	0.5537	0.4564	0.3769	0.3118	0.2584	0.2145	0.1784	0.1486	0.1240	0.1037	0.0868	0.0728	0.0611
21	0.8114	0.6598	0.5375	0.4388	0.3589	0.2942	0.2415	0.1987	0.1637	0.1351	0.1117	0.0926	0.0768	0.0638	0.0531
22	0.8034	0.6468	0.5219	0.4220	0.3418	0.2775	0.2257	0.1839	0.1502	0.1228	0.1007	0.0826	0.0680	0.0560	0.0462
23	0.7954	0.6342	0.5067	0.4057	0.3256	0.2618	0.2109	0.1703	0.1378	0.1117	0.0907	0.0738	0.0601	0.0491	0.0402
24	0.7876	0.6217	0.4919	0.3901	0.3101	0.2470	0.1971	0.1577	0.1264	0.1015	0.0817	0.0659	0.0532	0.0431	0.0349
25	0.7798	0.6095	0.4776	0.3751	0.2953	0.2330	0.1842	0.1460	0.1160	0.0923	0.0736	0.0588	0.0471	0.0378	0.0304
26	0.7720	0.5976	0.4637	0.3607	0.2812	0.2198	0.1722	0.1352	0.1064	0.0839	0.0663	0.0525	0.0417	0.0331	0.0264
27	0.7644	0.5859	0.4502	0.3468	0.2678	0.2074	0.1609	0.1252	0.0976	0.0763	0.0597	0.0469	0.0369	0.0291	0.0230
28	0.7568	0.5744	0.4371	0.3335	0.2551	0.1956	0.1504	0.1159	0.0895	0.0693	0.0538	0.0419	0.0326	0.0255	0.0200
29	0.7493	0.5631	0.4243	0.3207	0.2429	0.1846	0.1406	0.1073	0.0822	0.0630	0.0485	0.0374	0.0289	0.0224	0.0174
30	0.7419	0.5521	0.4120	0.3083	0.2314	0.1741	0.1314	0.0994	0.0754	0.0573	0.0437	0.0334	0.0256	0.0196	0.0151

Appendix 3 Table of Annuity Present Value Factors

Tahun, n	Kadar Faedah, r (%)														
	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.9901	0.9804	0.9709	0.9615	0.9524	0.9434	0.9346	0.9259	0.9174	0.9091	0.9009	0.8929	0.8850	0.8772	0.8696
2	1.9704	1.9416	1.9135	1.8861	1.8594	1.8334	1.8080	1.7833	1.7591	1.7355	1.7125	1.6901	1.6681	1.6467	1.6257
3	2.9410	2.8839	2.8286	2.7751	2.7232	2.6730	2.6243	2.5771	2.5313	2.4869	2.4437	2.4018	2.3612	2.3216	2.2832
4	3.9020	3.8077	3.7171	3.6299	3.5460	3.4651	3.3872	3.3121	3.2397	3.1699	3.1024	3.0373	2.9745	2.9137	2.8550
5	4.8534	4.7135	4.5797	4.4518	4.3295	4.2124	4.1002	3.9927	3.8897	3.7908	3.6959	3.6048	3.5172	3.4331	3.3522
6	5.7955	5.6014	5.4172	5.2421	5.0757	4.9173	4.7665	4.6229	4.4859	4.3553	4.2305	4.1114	3.9975	3.8887	3.7845
7	6.7282	6.4720	6.2303	6.0021	5.7864	5.5824	5.3893	5.2064	5.0330	4.8684	4.7122	4.5638	4.4226	4.2883	4.1604
8	7.6517	7.3255	7.0197	6.7327	6.4632	6.2098	5.9713	5.7466	5.5348	5.3349	5.1461	4.9676	4.7988	4.6389	4.4873
9	8.5660	8.1622	7.7861	7.4353	7.1078	6.8017	6.5152	6.2469	5.9952	5.7590	5.5370	5.3282	5.1317	4.9464	4.7716
10	9.4713	8.9826	8.5302	8.1109	7.7217	7.3601	7.0236	6.7101	6.4177	6.1446	5.8892	5.6502	5.4262	5.2161	5.0188
11	10.3676	9.7868	9.2526	8.7605	8.3064	7.8869	7.4987	7.1390	6.8052	6.4951	6.2065	5.9377	5.6869	5.4527	5.2337
12	11.2551	10.5753	9.9540	9.3851	8.8633	8.3838	7.9427	7.5361	7.1607	6.8137	6.4924	6.1944	5.9176	5.6603	5.4206
13	12.1337	11.3484	10.6350	9.9856	9.3936	8.8527	8.3577	7.9038	7.4869	7.1034	6.7499	6.4235	6.1218	5.8424	5.5831
14	13.0037	12.1062	11.2961	10.5631	9.8986	9.2950	8.7455	8.2442	7.7862	7.3667	6.9819	6.6282	6.3025	6.0021	5.7245
15	13.8651	12.8493	11.9379	11.1184	10.3797	9.7122	9.1079	8.5595	8.0607	7.6061	7.1909	6.8109	6.4624	6.1422	5.8474
16	14.7179	13.5777	12.5611	11.6523	10.8378	10.1059	9.4466	8.8514	8.3126	7.8237	7.3792	6.9740	6.6039	6.2651	5.9542
17	15.5623	14.2919	13.1661	12.1657	11.2741	10.4773	9.7632	9.1216	8.5436	8.0216	7.5488	7.1196	6.7291	6.3729	6.0472
18	16.3983	14.9920	13.7535	12.6593	11.6896	10.8276	10.0591	9.3719	8.7556	8.2014	7.7016	7.2497	6.8399	6.4674	6.1280
19	17.2260	15.6785	14.3238	13.1339	12.0853	11.1581	10.3356	9.6036	8.9501	8.3649	7.8393	7.3658	6.9380	6.5504	6.1982
20	18.0456	16.3514	14.8775	13.5903	12.4622	11.4699	10.5940	9.8181	9.1285	8.5136	7.9633	7.4694	7.0248	6.6231	6.2593
21	18.8570	17.0112	15.4150	14.0292	12.8212	11.7641	10.8355	10.0168	9.2922	8.6487	8.0751	7.5620	7.1016	6.6870	6.3125
22	19.6604	17.6580	15.9369	14.4511	13.1630	12.0416	11.0612	10.2007	9.4424	8.7715	8.1757	7.6446	7.1695	6.7429	6.3587
23	20.4558	18.2922	16.4436	14.8568	13.4886	12.3034	11.2722	10.3711	9.5802	8.8832	8.2664	7.7184	7.2297	6.7921	6.3988
24	21.2434	18.9139	16.9355	15.2470	13.7986	12.5504	11.4693	10.5288	9.7066	8.9847	8.3481	7.7843	7.2829	6.8351	6.4338
25	22.0232	19.5235	17.4131	15.6221	14.0939	12.7834	11.6536	10.6748	9.8226	9.0770	8.4217	7.8431	7.3300	6.8729	6.4641
26	22.7952	20.1210	17.8768	15.9828	14.3752	13.0032	11.8258	10.8100	9.9290	9.1609	8.4881	7.8957	7.3717	6.9061	6.4906
27	23.5596	20.7069	18.3270	16.3296	14.6430	13.2105	11.9867	10.9352	10.0266	9.2372	8.5478	7.9426	7.4086	6.9352	6.5135
28	24.3164	21.2813	18.7641	16.6631	14.8981	13.4062	12.1371	11.0511	10.1161	9.3066	8.6016	7.9844	7.4412	6.9607	6.5335
29	25.0658	21.8444	19.1885	16.9837	15.1411	13.5907	12.2777	11.1584	10.1983	9.3696	8.6501	8.0218	7.4701	6.9830	6.5509
30	25.8077	22.3965	19.6004	17.2920	15.3725	13.7648	12.4090	11.2578	10.2737	9.4269	8.6938	8.0552	7.4957	7.0027	6.5660