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Life Cycle Analysis (LCA) and Life Cycle Cost Analysis (LCCA) Framework of Photovoltaic Systems in the APEC Region

APEC Energy Working Group

April 2019

APEC Project: EWG 06 2017A

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APEC#219-RE-01.7   ISBN: 978-981-14-1313-1

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ACKNOWLEDGEMENT

We want to acknowledge the speakers and participant from universities, policy makers, financial institutions, solar related industries and APEC economies who had given a valuable comments, inputs and reviews on the project. In addition, we want to thank the committee members of the project team for their beneficial work establishment in terms of both economic and life cycle assessment approaches for photovoltaic systems in APEC region towards low-carbon society and for their beneficial input.

ACRONYMS AND ABBREVIATIONS

APEC	Asean-Pacific Economic Cooperation
EWG	Energy Working Group
LCA	Life Cycle Assessment /Life Cycle Analysis
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCCA	Life Cycle Cost Assessment/ Life Cycle Cost Analysis
LCOE	Levelized Cost of Energy
EA	Environmental Assessment
EPBT	Energy Payback Times
GHG	Greenhouse Gases
PV	Photovoltaic
ISO	International Organization for Standard
NS	Net Saving
SIR	Investment Ratio
NPV	Net Present Value
IRR	Internal Rate of Ratio
PB	Payback Period
ROI	Return of Investment
GWP	Global Warming Potential
O&M	Operation & Maintenance
ILCD	Life Cycle Data System
BOS	Balance of System
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Process & Product Use

AFOLO	Agricultural Forestry & Other Land Use

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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. The issue has 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 LCA 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 building 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. According to *Fuller & Petersen*[1] LCCA is a very useful and complete economic analysis tool as it requires more information than analyses based on initial cost or short term considerations. In fact, LCCA put the emphasis on *time value of money* concept when comparing future return flows with the initial investment cost of a project.

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) and life cycle cost analysis (LCCA) framework as well as the Case Study Selection of the project EWG06 2017A.

EXECUTIVE SUMMARY

The goal of LCA is that the environmental performance of products and services be compared as well as succeed in choosing the least burdensome one. The term 'life cycle' refers to the notion that a fair, holistic assessment with key indicators include Energy Payback Times (EPBT), Greenhouse Gas emissions (GHG), criteria pollutant emissions, and heavy metal emissions during raw material production, manufacture, distribution, use and disposal stages.

It was agreed for EWG06 2017A, the project LCA will be conducted in attributional or process-based approach commonly known as "Cradle-to-Grave" which includes assessment of 5 phases , namely Manufacturing of Photovoltaic, System Construction, Transportation, Operation & Maintenance and Dismantling & Disposal. These will be further discussed in this report as the project LCA framework. The project framework is detailed out based on international standards that are applied in the APEC region economies.

For LCCA, it will follow closely the key indicators in LCA in evaluating whether these projects are appropriate from the investor's view, based on reduced energy costs and other cost implications before, during and after completion of project or during investment period.

The selection of case studies will be based on solar power production and connectivity to the grid. Three (3) types of case studies were agreed which would represent typical solar installation within APEC economies. Geography of sites will depends on ease of accessibility and availability of data to ensure transparency and accuracy of data collected.

This report provides the framework of LCA and LCCA as well as the Case Study Selection for this project. The result of this study will be an insight look of PV system application in the APEC region.

1.0 Introduction

The global reliance on renewable energy has grown fond of using photovoltaic technology both for commercial and personal benefits. The Asia and the Pacific region annual photovoltaic installation has hike up in the world trend resulting from the falling of system prices and support from the governments [1]. This development is expected to recuperate better in the near future due to favourable policies emerging in the renewable energy sector, improvement of public awareness, and the sustained use of solar power for rural electrification projects [2].

Photovoltaic system is a favourable technology for tropical climate economies. The components of a photovoltaic system is leads to massive cell production as of today, namely wafer-based crystalline (single crystal and multi-crystalline silicon), compound semiconductor (thin-film), or organic. The key components of a PV power system are various types of photovoltaic cells (often called solar cells) interconnected and encapsulated to form a photovoltaic module (the commercial product), the mounting structure for the module or array, the inverter (essential for grid-connected systems and required for most off-grid systems), the storage battery and charge controller (for off-grid systems but also increasingly for grid-connected ones).

Currently, crystalline silicon technologies has dominate the market because the technology has matured, reduction in price and reliable to demand interest in term of both efficiency and life span [3]. Even though the technology has evolve well, the energy production does not tell the entire story.

The main innovation considerations for the second screen are based on the module efficiency, manufacturer, scale of production and module design. According to the up-to-date research within the photovoltaic technology, thin film solar cells are most advance with the highest preferable features. Despite that, the reach of this technology is rather slow towards the industry and large scale applications due to reliability and shortages of supply. The novelty of using these are reflected back by the advancement and trust of the people towards silicon-based photovoltaic that has matured through time.[4]

Photovoltaic technologies consideration under LCA framework in general includes risk manifestation, toxic emission, primary energy, energy payback period, land use and water use. These factors are affecting the photovoltaic development as a whole, in order to deliver the best of kind of the technology. Life cycle analysis takes account minimal changes in real time to manifest further concern of the technology.

Assessing the technology itself includes material choices, manufacturing process, implementation, and disposal or the afterlife. Life cycle thinking provides an objective assessment of different renewable technologies, which is an invaluable tool for both policymakers and engineers. Life Cycle Assessment (LCA) is tool especially useful for the field of renewable energy, life cycle assessment can help objectively compare different types of renewable energy technologies or quantify the impacts of different environmental indicators including greenhouse gas (GHG) emissions [5].

Life cycle thinking requires the consideration of environmental impacts from the inception of the solar panel during the material extraction phase until the final disposal phase of the product. Life cycle assessments for mc-Si solar electricity vary largely based on both location of production due to the grid electricity, which is used in the factory, and location of the study because solar radiation varies across different climates.

The initial phase of LCA is the collection and calculation of Life Cycle Inventory (LCI) data that quantify the material, energy and emission data associated with a functional system. This stage precedes the Life Cycle Impact Assessment (LCIA) stage that involves classifying, characterisation and evaluating these data in relation to ecological impacts. A further possible stage is the interpretation of data and the potential for improvement through modification of the functional systems. ISO standard for LCI calculation was published in 1998. Meanwhile, LCIA and interpretation phase methodologies are under development with ISO standards expected at a later date [6].

At the same time, another assessment involving whatever costs in developing a project is very important. This analysis is named Life Cycle Cost Assessment (LCCA). This analysis is helpful in helping investors in deciding which methods or alternatives are more viable and cost-effective. It evaluates all processes within the project from the start of the project to the end of its life, but in terms of cost. For example, the PV system project, all costs involved from PV panel production until it is disposed [7].Through this, it tells the whole story of a project in terms of cost.

Besides that, there are several economic analysis that lies within LCCA. For example, Life Cycle Cost (LCC), Levelized Cost of Energy (LCOE), Net savings (NS), Savings of Investment Ratio (SIR), Net Present Value (NPV), Internal Rate of Ratio (IRR) and Payback Period (PB). These economic analysis is used in this project to evaluate the photovoltaic system.

1.1 Objectives

a) To develop an impact assessment of photovoltaic systems framework through Life Cycle Analysis (LCA) and Life Cycle Cost Analysis (LCCA) from cradle-to-grave.
b) To identify the most viable photovoltaic systems (Solar Farm, Solar Rooftop and Stand-alone Solar) based on impact assessment indicator Global Warming Potential (GWP) and Return of Investment (ROI).
c) To infuse Life Cycle Analysis (LCA) and Life Cycle Cost Analysis (LCCA) as a tool for photovoltaic systems policy development within the APEC region.

1.2 Goal and 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 system which are a Solar Farm with power production more than 1MWp and are set up on land, a Solar Rooftop with power production within the range of 500kWp to 1MWp. Also, a Stand-alone Solar for Rural Electrification with power production less than 100kWp to 500kWp. LCAs usually do not address such things as social impacts or financial considerations so must be used in conjunction with other decision support tools.

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. Furthermore, the three PV systems are to be compared between the global warming potential (GWP) and energy cycle. The analysis will be using SIMAPro for LCA and Excel spreadsheet for LCCA.

1.3 Scope of Study

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, environmental impact, energy and economic cycle. Positioning properties suffice the following criteria which are a tropical climate economy, equator. The functional unit is global warming potential (GWP) and energy cycle based on ISO standards on power production of 3 types of photovoltaic system under similar weather condition with environmental impact according to Environment & Carbon footprint for 25 years of lifetime.

1.4 Functional Unit

The functional unit of the Life Cycle Assessment study is the Global Warming Potential (GWP) and Energy Cycle based according to ISO standards [1] on power production of three types of Photovoltaic System under similar weather condition, with environmental impact according to Environment [4] and Carbon footprint [5] for 25 years of lifetime.

The reference flow of the functional unit are 1kWp power production from three photovoltaic system namely solar farm, solar rooftop and stand-alone solar. According to pass studies on LCA which only focus whole system as a reference and the production of each type of photovoltaic module. The project has to compare between three different system and forecasting GHG emission for GWP. Thence, by using the minimal reference flow of the three system we take consider of the stand-alone feature and its energy production is 1kWp normalize every system into 1kWp.

Obligatory properties that are quantified in the functional unit are power production, monocrystalline photovoltaic, polycrystalline photovoltaic, environmental impact, economic cycle, Balance of System (BOS) and Maintenance. Meanwhile, the positioning properties are a tropical climate economies, 25 years of lifetime and transportation. These properties are clearly stated to set the boundary for the study.

2.0 Life Cycle Assessment (LCA)

Life Cycle Assessment is the basic formation of the tool. The general framework are as shown in Figure 1 below. The Life Cycle Assessment framework has to fulfill a certain parameter in order to completely verify a case study.

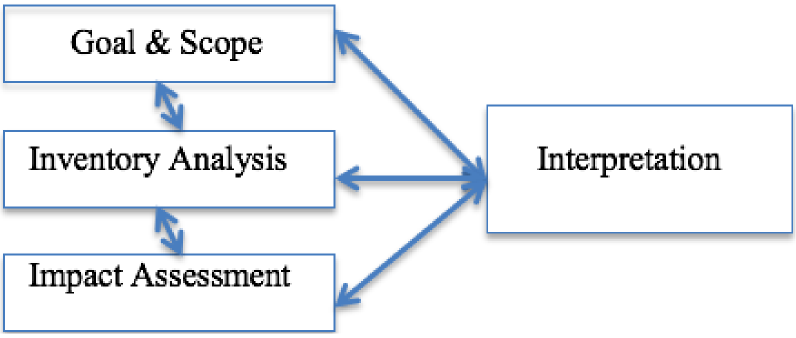

Figure 1: LCA General Framework

There are three classes of steps in the LCA framework divided from the inventory analysis and the impact assessment as illustrated in Figure 2. In a big picture, the upstream class consists technology of manufacturing of the PV cell itself. These take into account all the necessary raw materials and costs for the whole production processes. Next, estimation of environmental impacts resulting from the production processes, starting from the harvesting of raw materials to the end-process of which the emission and by-products, either directly or indirectly generated during manufacturing. Moreover, the manufacturing also covers the components, plant construction and installation of the system to abide the after effect of the primary step [8].

The second class is the on-going steps which consist of all the operation process of the photovoltaic system when it start operating. This would cover the input and output of the system along a definite timeline including the degradation of the PV system and maintenance of system during operation and maintenance (O&M) period. The amount of O&M process will be average out by cases of the three case studies.

Finally, the downstream class of the third step in the LCA framework. It covers all the essential elements that are considered wastes and disposal of the whole PV system. This class includes the environmental impact of the system when it operation ended, including dismantling and disposal of all the product. Whether the product shall be recycled or turned into scheduled waste into landfill.

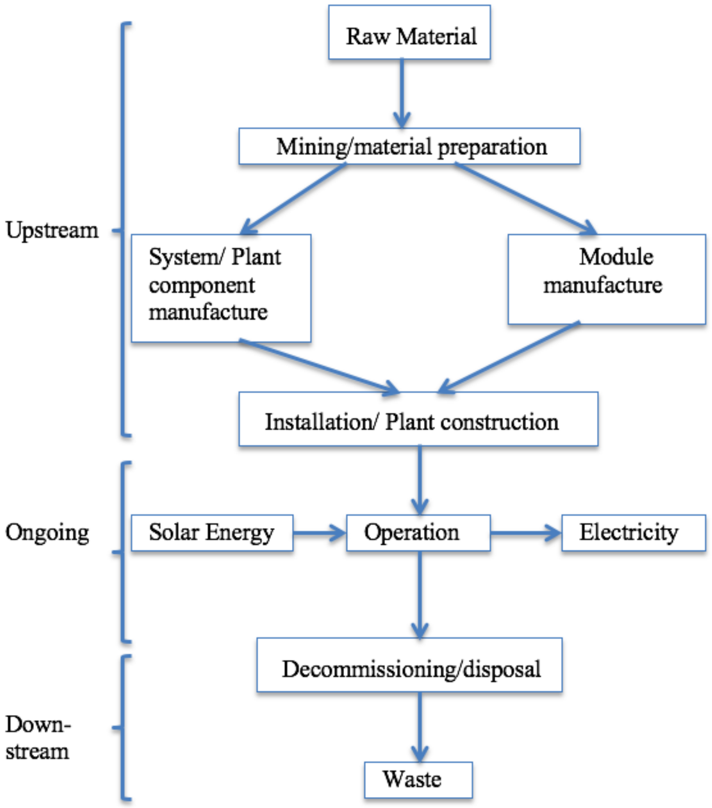

Figure 2: LCA Framework (Upstream, Ongoing and Downstream)

LCA is the ass of the environmental impact of a given product or service throughout its lifespan and it is one of the most well-known analysis methods. The goal of LCA is that the environmental performance of products and services be compared as well as succeed in choosing the least burdensome one. The term 'life cycle' refers to the notion that a fair, holistic assessment requires the assessment of raw material production, manufacture, distribution, use and disposal.

The approaches for Life Cycle Assessment varied extensively but for this project, it will be based on general framework provided by ISO 14040 and 14044:2006. The International Reference of Life Cycle Data System (ILCD) are used to fill this gap as decision makers in government, public administration and business rely on consistent and quality-assured life cycle data and robust assessments in the context of Sustainable Consumption and Production [10].

Life Cycle Assessment (LCA) has many different approaches depending on the key issue addressed and what are to be practice. There are 3 levels of study classification on this which are Micro-Level, Meso/Macro-Level and Accounting Level. These forms the baseline to which managing the boundary of the whole Life Cycle study [11].

These levels are set to be the baseline of life cycle study development. For this project, the study will utilise data until the Meso/ Macro-Level as the baseline for study of three photovoltaic systems, Solar farm, Building Integrated Photovoltaic and Stand-alone Solar.

Meso/macro-level decision support at a strategic level for raw materials strategies, technology scenarios, policy options. It is assumed to have also structural consequences outside the decision-context. For instance, changing the available production capacity would results in large-scale consequences in the background system or other parts of the techno sphere [3].

Thus, as mentioned above, the project LCA will also take into account all the phases which is commonly known as *Cradle-to-Grave* approach. Cradle-to-Grave includes assessment of 5 phases:

i. ***Manufacturing of Photovoltaic,***
ii. ***System Construction,***
iii. ***Transportation,***
iv. ***Operation & Maintenance and***
v. ***Dismantling & Disposal***.

All of these will be further discussed in detailed later in this report.

2.1 Life Cycle Inventory (LCI)

Every study using the ISO standards has an inventory analysis phase, as for LCA it requires a more comprehensive inventory which is known as the Life Cycle Inventory (LCI). The LCI analyses is necessary in order to support impact assessment of the whole study stages. As a tangible example, the system boundary that covers the whole each unit processess from both input and output, wastes and also co-products. Each unit process will be in a chain called flow of processes as illustrated in Figure 3.

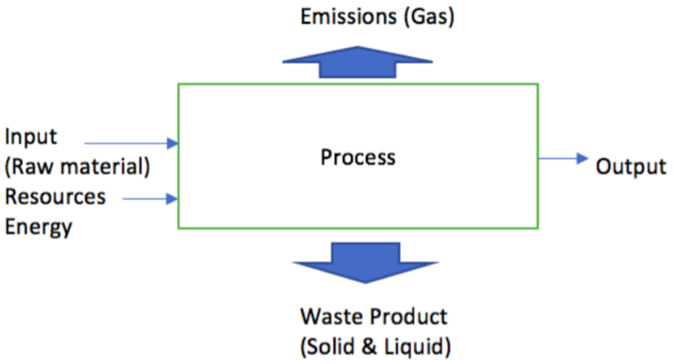

Figure 3: Unit processess

The limitation of the LCI according to the above mention is the data availability and accessibility. Based on the study methodology if LCI data is unable to be obtain, then the data shall be taken in from the Eco-invent database as per known as secondary data. If it is unavailable then the product system, system boundary, or goal may need to be modified.

Specifically, the inventory process of the study will be seperated by phases:

a) Manufacturing

The Manufacturing phase is the Monocrystalline and Polycrystalline photovoltaic production, which comprise of energy supply and raw material used during the production as the input. The process output in term of both emission to air and waste product as shown in Figure 4.

However, the data for silicon mining, BOS production, machinery production and infrastructures production shall be taken in as a secondary data using the Eco-Invent database.

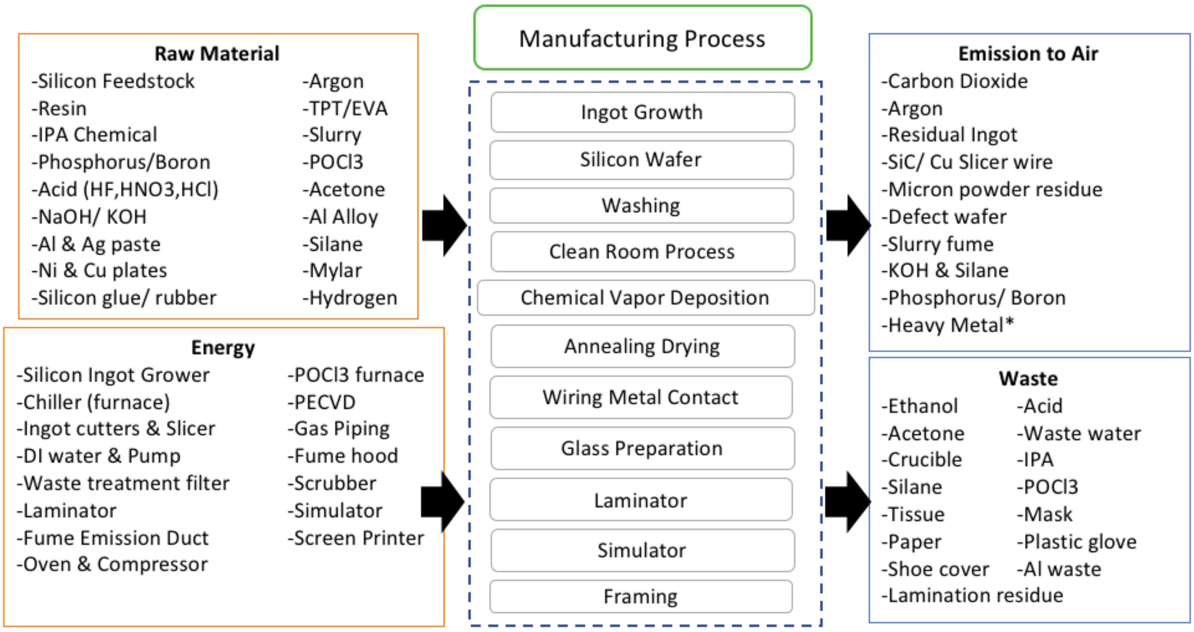

Figure 4: Manufacturing Process Inventory

b) Transport

The transportation phase includes the transportation of all purchase items and product displacement. This comprise direct distance of travel, type of freight used, fuel consumption by the transport and the packaging of the product in transfer.

For ease of calculation, the travel shall be assumed without any possibility of accident and spill of product throughout the transportation phase. The transportation process is illustrated as Figure 5.

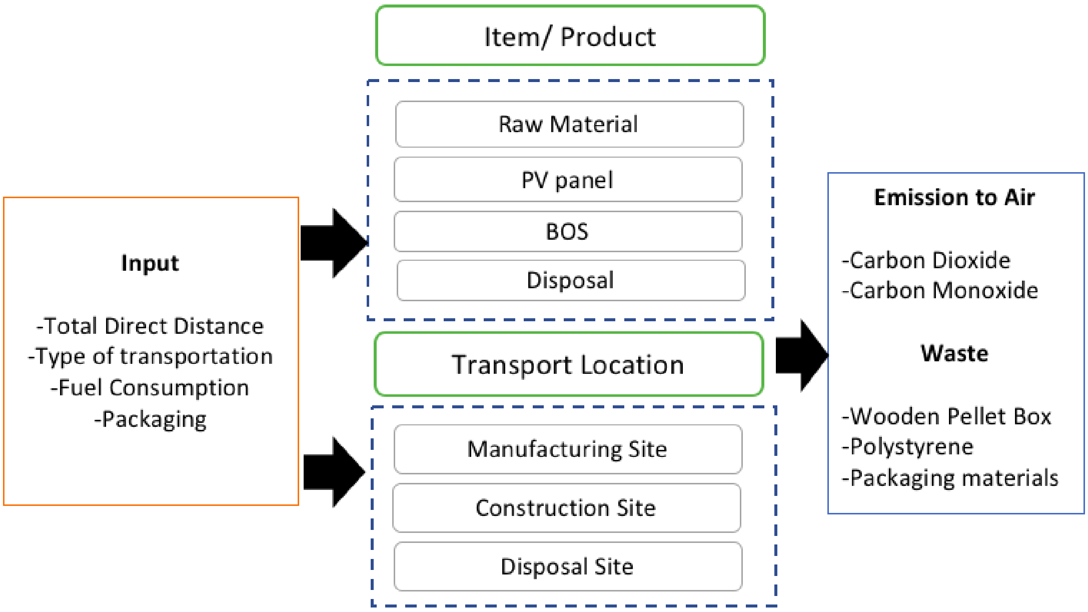

Figure 5: Transportation Process Inventory

c) Construction

The construction phase focusses specifically on case study sites i.e. Solar Farm, Solar Rooftop and Stand-alone Solar setups. The process take into account infrastructure material used and energy supplied during the process as the input. While, emission to air and waste product as its output.

Moreover, this phase also considers the ecological impact affected by the land management at the construction site. Nevertheless, accident and unsual activities shall be excluded. The phase is as shown in Figure 6.

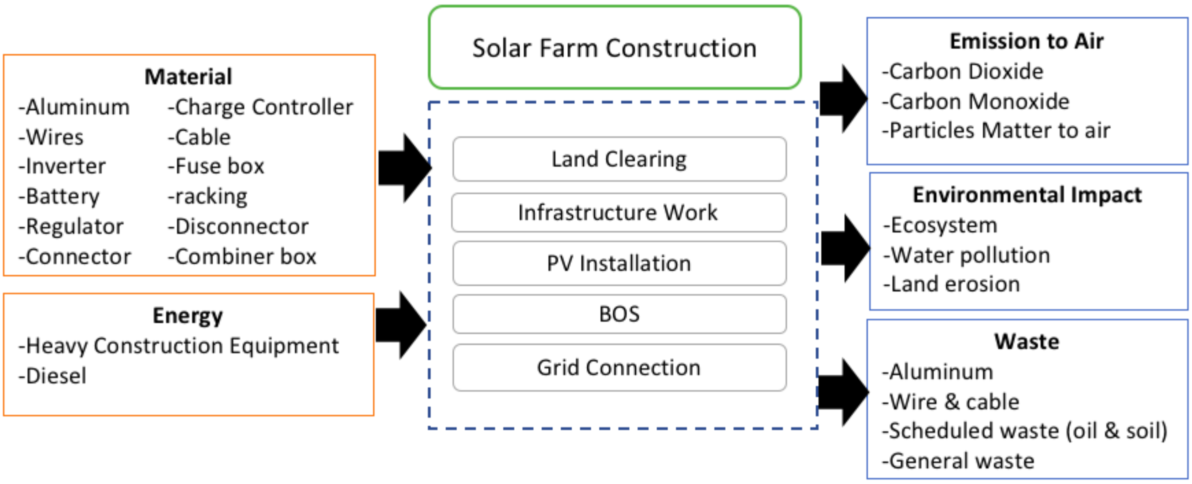

Figure 6: Construction Process Inventory

d) Operation and Maintenance

Operation and maintenance (O&M) phase takes the least measured phase for impact assessment but it stretches over a long time span. Hence, this process numbers will be averaged out throughout the three case studies for maintenance and replacement of instruments. Also, the waste product as the output of the process is as illustrated in Figure 7.

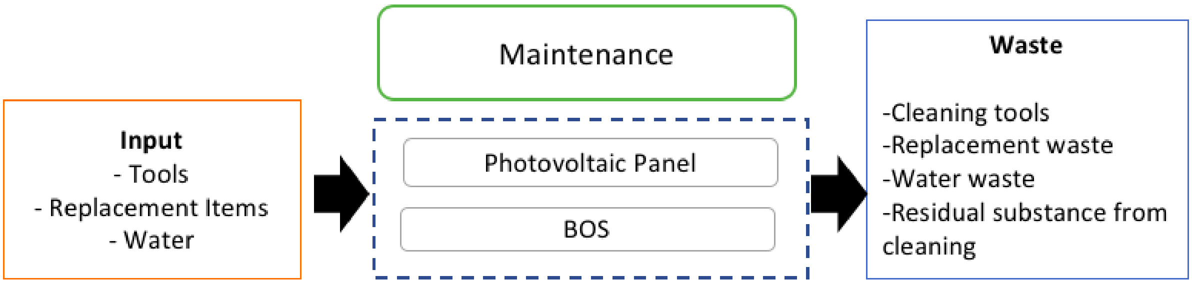

Figure 7: Operation and Maintenance Process Inventory

e) Dismantling and Disposal

The dismantling and disposal phase will have the tools used as its input and energy supply for the dismantling activities. The output of the process is the emission to air and waste management during the disposal of product as shown in Figure 8.

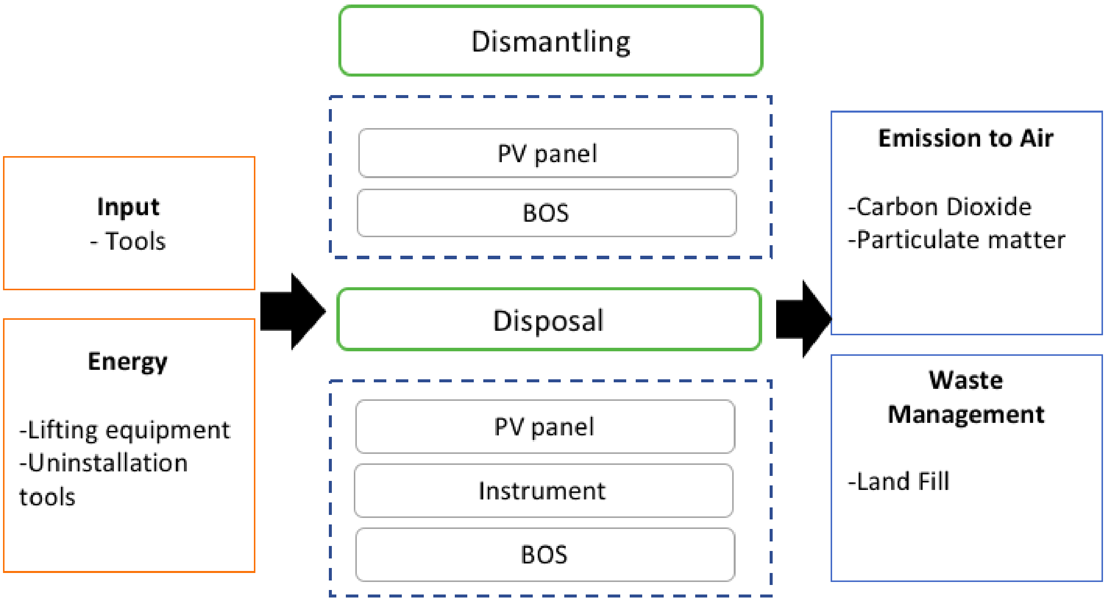

Figure 8 Dismantling and Disposal Process Inventory

2.2 Life Cycle Impact Assessment (LCIA)

The environmental footprint impact categories refer to specific categories of environmental impacts considered in an Organisation Environmental Footprint study. It is generally associated to the resources use for process input or output such as emissions of greenhouse gases or toxic chemicals. The impact assessment methods for quantifying is grounded by an already established models so that the is a correlation between the inputs and output of each unit process with organisational activities. Each impact category hence has an associated, stand-alone environmental footprint impact assessment method [12].

Specifically for this study, the default environmental footprint impact categories and impact assessment models for Organisation Environmental Footprint studies focusing towards climate change category. Forecasting the Global Warming Potential (GWP) is by using common Bern model over a 100 year time horizon based on Intergovernmental Panel on Climate Change, 2007 [13,14].

Direct GHG emissions are calculated based on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories [15] and include carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF6), and nitrogen trifluoride (NF3). These emissions are divided into 5 sectors, which are Energy, Industrial Process and Product Use (IPPU), Agriculture Forestry and Other Land Use (AFOLO), waste, and others [14].

Therefore, this study focuses on main GHG emissions in each sector with the Global Warming Potential on the forth assessment report of the IPCC (AR4) [15] and economy statistic activity data from each department. The GHG emissions projection for each sector also used the linear regression method.[16]

The basic equation used to calculate GHG emissions is as follows:

$$GHG\ Emissions = Activity\ data \times Emission\ factor$$

The greenhouse gases emission key parameter comprises conversion efficiency, performance ratio, irradiation, lifetime and the source information feeds from manufacturer, data collector and relevant to the age of data.

CO_2 Equivalent emission/kWh

$$G = \frac{W}{I \times \eta \times PR \times LT \times A}$$

Where,
I = irradiation ($kWh/m^2/year$)
η = conversion efficiency
PR = performance ratio
LT = Lifetime (year)
A = area of the module (m^2)

Other factor contribute to overall CO_2 emission.

$$CO_2 = (P)\ x\ \left(\frac{GDP}{P}\right)\ x\ \left(\frac{E}{GDP}\right)\ x\ \left(\frac{CO_2}{E}\right)$$

P = population
CO2/E = carbon emission/unit energy consumed
GDP/P = population/capita
E/GDP = energy intensity/unit GDP

There are four steps to life cycle impact analysis LCIA. This involves intepretation of life cycle inventory to forecast for the midpoint or endpoint of the study in order to know the environmental impact of the whole process [4].

a. Classification

Classification involves assigning specific environmental impacts to each component of the LCIA. It is here where decisions made during the scope and goal phase about what environmental impact categories are of interest come into play. The figure below shows one well-known set of classifications, called midpoint categories, and how they map to domains of damage they cause. For this study, the final result shall be in midpoint categories of the life cycle inventory which is the global warming. Based on the system boundary, this study will not forecast for damage categories [17].

b. Characterization

Once the impact categories have been identified, conversion factors generally known as characterization or equivalency factors, the data shall use specific formulas to convert the LCI results into directly comparable impact indicators. This allows different types of plastics and metals to be compared as to their impacts on Global Warming. The Table 1.0 below gives some commonly used characterization factors for each impact category [18].

Table 1: Impact Categories for Global Warming [18]

Impact Category	Scale	Example of LCI data	Characterization factor	Characterization description
Global Warming	Global	Carbon Dioxide (CO2) Nitrogen Dioxide (NO2) Methane (CH4) Chlorofluorocarbons (CFCs) Hydro chlorofluorocarbons (HCFCs) Methyl Bromide (CH3Br)	Global Warming Potential (GWP)	Converts LCI data to carbon dioxide (CO2) equivalents Note: global warming potentials can be 50, 100, or 500 year potentials.

c. Normalization

Some practitioners choose to normalize the impact assessment by scaling the data by a reference factor, such as the region's per capita environmental burden. This helps to clarify the relative impact of a substance in a given context. For instance, if global warming contributions are already high in the context in which the product is being assessed, a reference factor would normalize whatever the product's global warming contributions are in order to clarify its relative impacts [17].

d. Weighting

This process entails combining all of the indicators together, each with its own weighting, to create a single "score" that reflects a certain prioritization of the importance of each type of impact. Weighting is more of a political than scientific process since the global warming's score more weight than acidification's is a values-based decision. The decision follows difference view within the field [17].

2.3 Framework

The project specific methodology has been detailed out to compliment the process-based method LCA as illustrated in Figure 9.

a) Goal & Scope Definitions
b) Data Collection as per Reference flow
c) Data Validation as per ISO standards
d) Data Verification as per Eco-Invent Database
e) Inventory Analysis
f) Life Cycle Inventory and Life Cycle Analysis result interpretation
g) Impact Assessment
h) Reporting
i) Critical Review
j) Publication

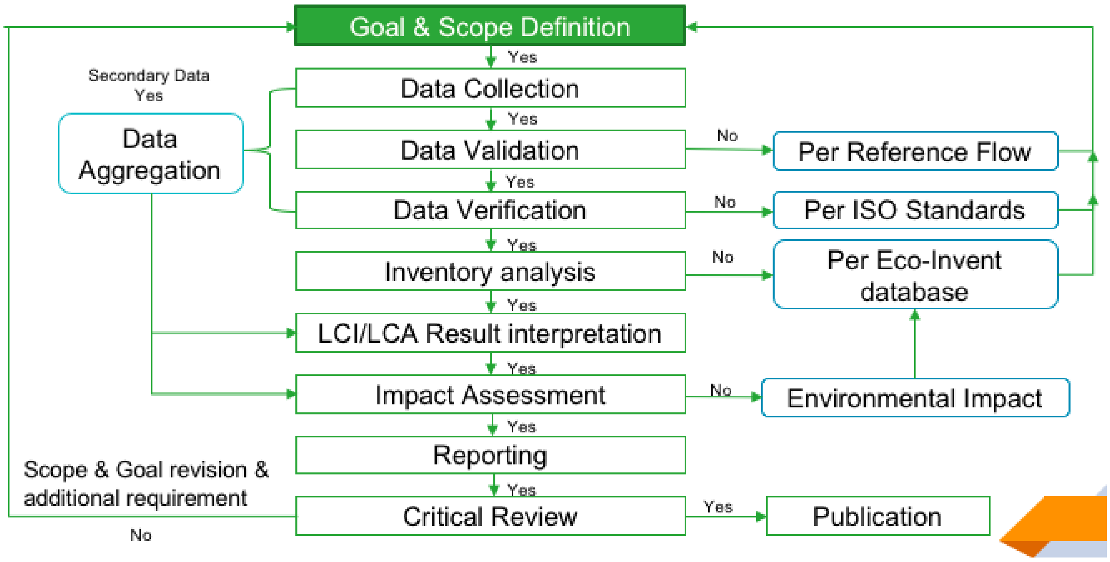

Figure 9: Project LCA Proposed Methodology

a) Solar Farm

Solar Farm is an activity of producing electricity from solar energy harnessing by using photovoltaic modules that covers a large-area of land. The electricity are usually supplied to the grid and had return profits. Solar farm are a growing business that have proven to be profiting from its initial investment after a certain period of time. It's promising market has attracts investor to be involve in the green technology development and growth towards a low-carbon society. Meanwhile, with green technology that are always progressing have produce variation of solar farm with similar intention such as Solar tracker, Solar concentrator, Floating Solar and many others that are yet to be commercialized. These technology has it's pros and cons which are applicable to fulfil certain supply and demand needs.

The balance of system (BOS) for solar farm are as shown in Figure 10 below [19]. The solar farm framework shall include the based LCI phases and implemented to the specific case study.

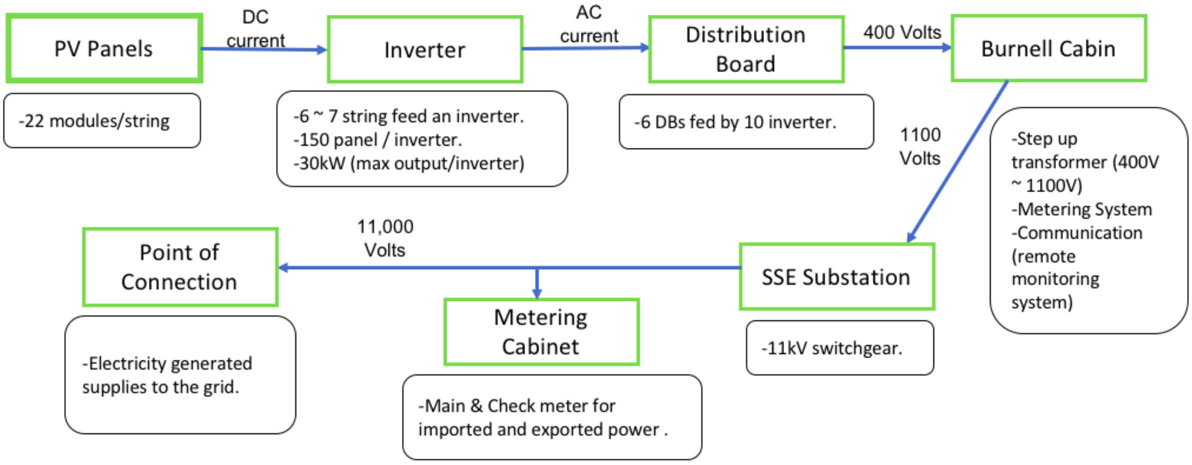

Figure 10: BOS of Solar Farm

b) Solar Rooftop

Solar rooftop which was define differently from Building Integrated Photovoltaic (BIPV) according to the Malaysia policy guideline since the systems are distinguishable and thus the benefits. Solar rooftop is an alternative to Solar Farm. It has the same intention which is to generate electricity but specifically for one building and are in a much smaller scale. The system satisfy the empty-roof-space and put it to function connected to the grid, profiting and saving building consumption.

The system also varies in term of design and technology due to its small scale feature, it can be replace with dye-sensitized solar cell, transparent or flexible which are much modern in design and improved technology to fit in both beauty and green technology for buildings. Many has improvise the system into BIPV so that it can be integrated as façade', windows and any other possible space minimization.

The balance of system (BOS) for solar rooftop are as shown in Figure 11 below. The solar rooftop framework shall include the based LCI phases and implemented to the specific case study.

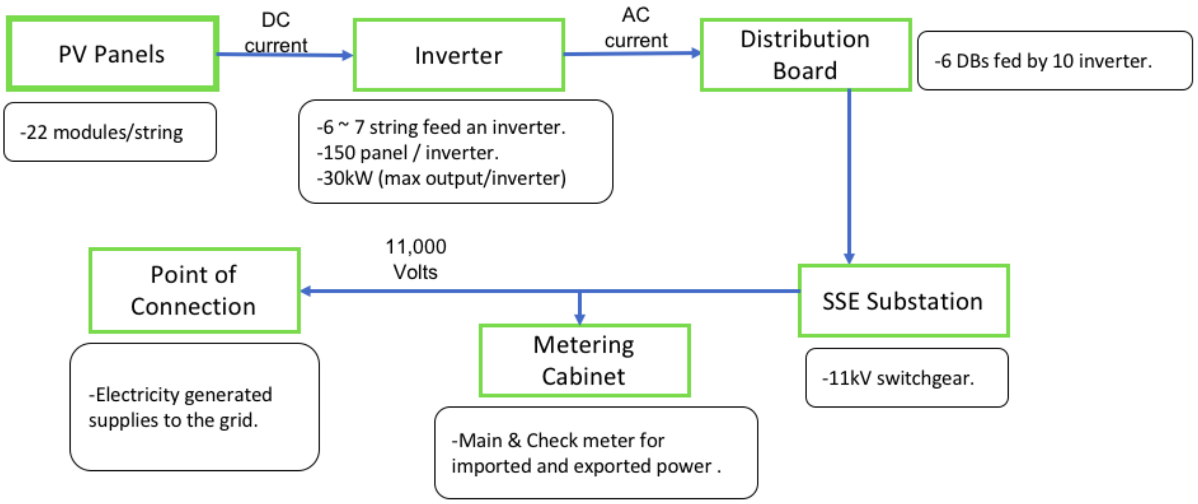

Figure 11: BOS of Solar Rooftop

c) Stand-alone Solar

Stand-alone Solar or Solar for rural for electricity are a much personal scale of technology. It generates and supply electricity solely for a single household especially in a rural area without being connected to the grid. The system work similarly to that of the BIPV but it doesn't generate profit. The system satisfy the demand of electricity in rural residential such as islands, deep forestry and other area with no source of electricity. 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.

A stand-alone or off-grid system is not connected to the electrical grid. 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. In non-portable applications where weight is not an issue, such as in buildings, lead acid batteries are most commonly used for their low cost and tolerance for abuse.

The balance of system (BOS) for stand-alone solar are as shown in Figure 12 below. The stand-alone solar framework shall include the based LCI phases and implemented to the specific case study.

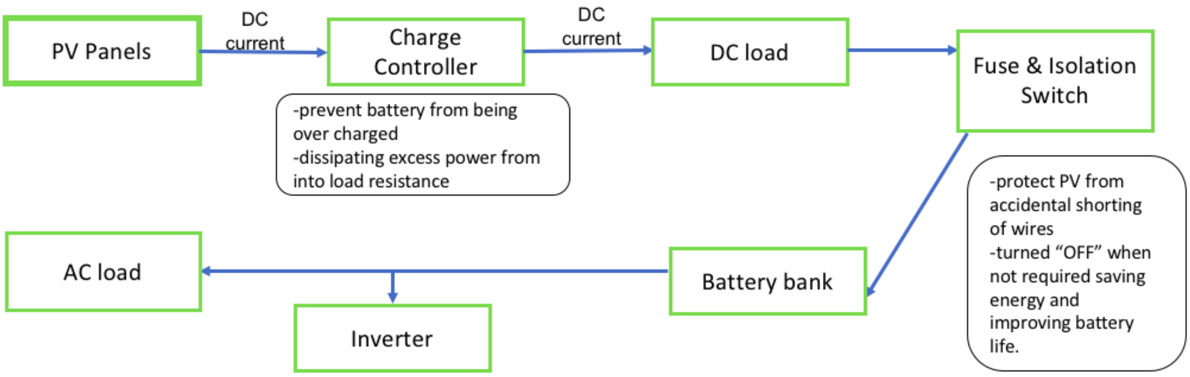

Figure 12: BOS of Stand-alone Solar

2.4 System Boundary

The study has such overall boundaries to keep on tract of the objectives, it covers eco-sphere (environment) affect but not techno-sphere (Human) affect and Social. It only accounts for impacts related to normal operation of processes and products, assuming there is no spill, accident and natural disaster throughout the whole process. It does not take accounts of health impact that products may directly exert on humans, workplace-exposure and indoor emissions. The study estimates through average of the three case studies for maintenance and replacement [20]

The project case study timeline are shown in Figure 13. The system boundary for all case studies is Cradle-to-Grave which include manufacturing, transport, construction, operation & maintenance and dismantling & disposal.

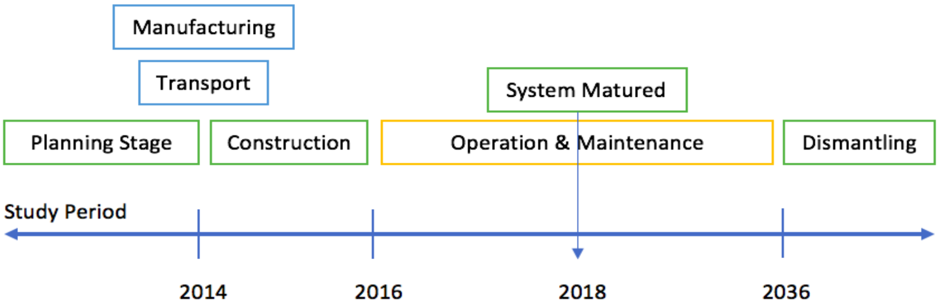

Figure 13: Project Case Study Timeline

The system boundaries as shown in Figure 14 is the source of data and are separated into two which is the primary data that are acquired from the site visit and first hand observation. The other is the secondary data that will be acquired from the SIMAPro software databases which is an internationally approved databases.

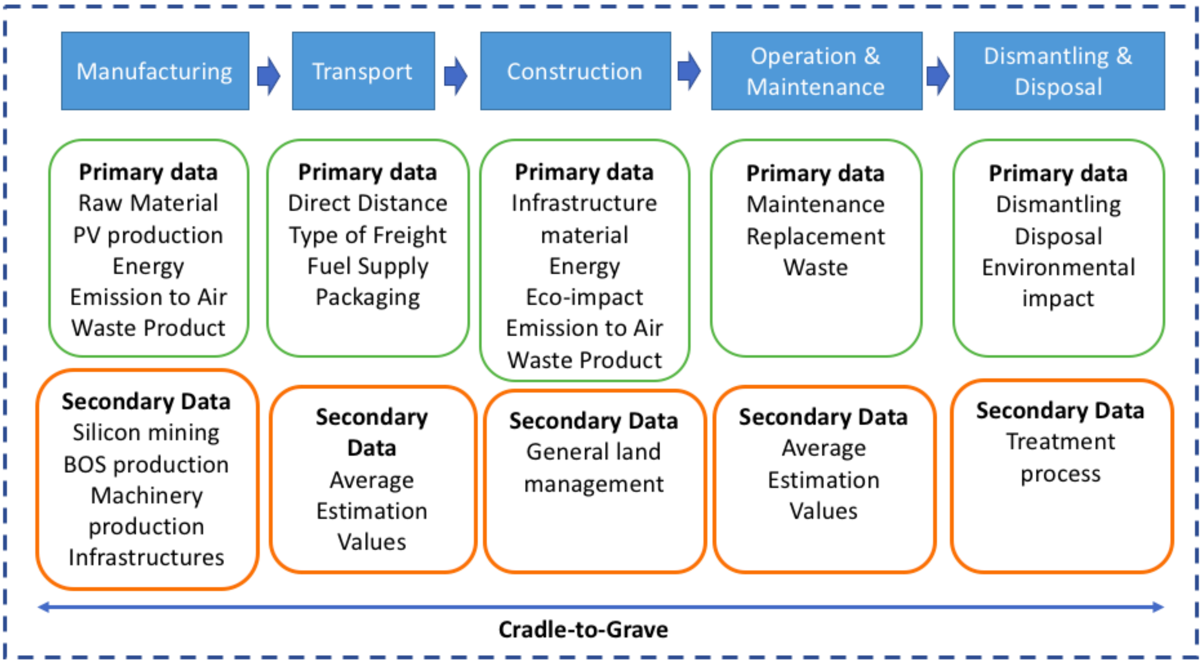

Figure 14: System Boundary for LCA

Manufacturing phase of photovoltaic shall involve production process, the use of chemicals, machinery, raw materials, energy consumption, solid waste and emission. 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.

On the other hand, transportation takes in direct distance which means without considering other factors that are excluded in the overall boundaries. The type of transportation and fuel consumption for direct transfer will be accounted in terms of fuel efficiency and carbon emission. Packaging of product only include the ones that are being transferred for waste. 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.

Moreover, the construction phase shall account the infrastructure material (metal works, balance of system), energy consumption from machinery and eco-impact from land clearing. 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. Assumption of land management will only be accounted in LCCA analysis, and not for LCA.

Furthermore, operation, maintenance and replacement phase will take an assumption of average function number of failure per 1kWp over 25 years of life span forecasted from 2 years of operational time span. The dismantling and disposal phase will include the disposal treatment process until it is inert and left in the landfill.

2.5. Limitation and Problems

LCA is tool to solve unnecessary subjective assumptions in decision makings such as which product is eco-friendly and which is harmful. LCA provides scientific basis that cover the whole product life cycle and forecast reliable comparison between green products [20].

Making comparison between two product life cycle has become the most beneficial studies for both end users and manufacturers. A simple LCA study may end with a midpoint result and an endpoint result, which are to be define its benefits. Others still go further to arrive at a single score by trying to add the aggregated figures for the product or process being evaluated. It is doubtful whether such simplification will be of general benefit.

Reliable methods for aggregating figures generated by LCA, and using them to compare the life cycle impacts of different products, do not yet exist. However, a great deal of work is currently being conducted on this aspect of LCAs to arrive at a standardized method of interpreting the collected data [21].

LCA studies may have few contradiction in its results since comparisons are rarely easy because of the different assumptions that are used, for example in the case of food packaging, about the size and form of container, the production and distribution system used, and the forms and type of energy assumed.

To compare two items which are identically sized, identically distributed, and recycled at the same rate is relatively simple, but even that requires assumptions to be made. For example, whether deliveries were made in a 9-tonne truck, or a larger one, whether it used diesel or petrol, and ran on congested city center roads where fuel efficiencies are lower, or on economy roads or motorways where fuel efficiencies might be better [22].

Comparisons of products which are dissimilar in most respects can only be made by making even more judgements and assumptions.

Preserving the confidentiality of commercially-sensitive raw data without reducing the credibility of LCAs is also a major problem. Another is the understandable reluctance of companies to publish information which may indicate that their own product is somehow inferior to that of a competitor. It is not surprising that many of the studies which are published, and not simply used internally, endorse the views of their sponsors [23].

3.0 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 previous study [24], 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 RM 1 this year will not be the same as the value of RM 1 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. This is because this analysis tells the whole story of a project. Besides that, through it's we can identify the alternative solution that is available throughout the project 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 15 below.

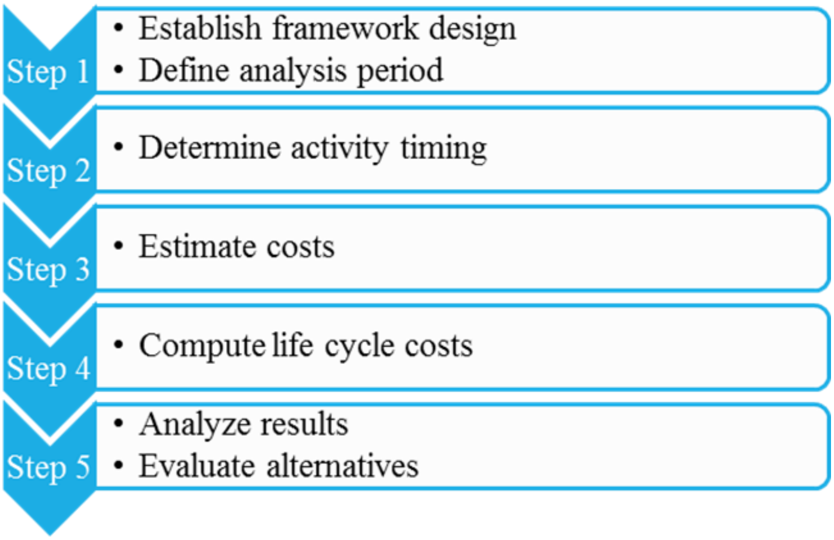

Figure 15: LCCA general framework

LCCA framework comprises of five basic steps [25]. 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 16 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.

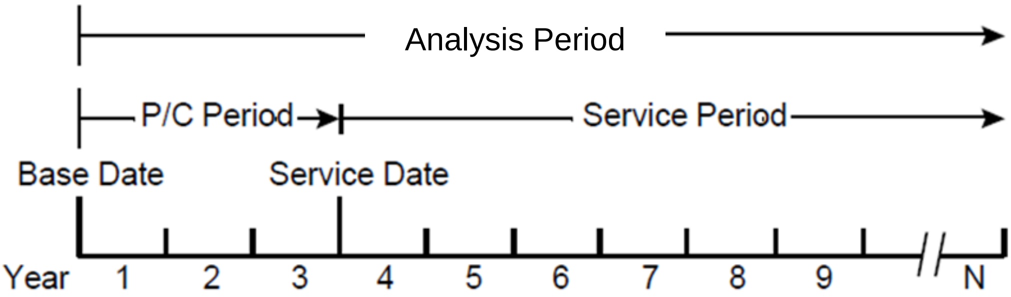

Figure 16: Example of analysis period.

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 so on.

Step 4: Compute life cycle costs.

Once, all data is 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 the last step is to analyse all the results. Through this, where 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, through this alternative which will bring more processes that are most viable and cost-effective for a project.

3.1 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, waste values, finance charges, and other non-financial benefits [26]. Equation 3.1 shows how to calculate the cost of life cycle.

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

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 waste 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.

3.2 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 [27]. 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.

3.3 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 [28].

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

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 [28]:

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

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 [28].

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

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 [28].

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

Where $\overline{\text{CF}}$ is the average cash flow of the project while $PVIFA_{IRR,n}$ 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 [28].

$$PB = (n-1) + \left[\frac{\left(C_I - \text{aliran tunai terkumpul sebelum } n\right)}{\text{aliran tunai semasa } n}\right]$$

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.

3.4 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 is illustrated in Figure 17 below.

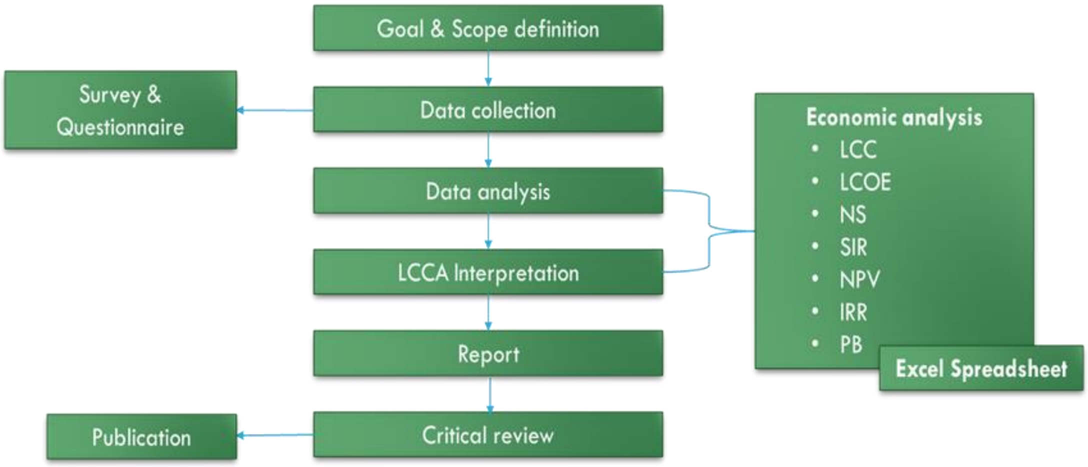

Figure 17: Project LCCA Proposed Methodology

The methodology of LCCA is quite straight forward compared to LCA. 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.

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.

3.5 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 18 below shows the boundary system for this project.

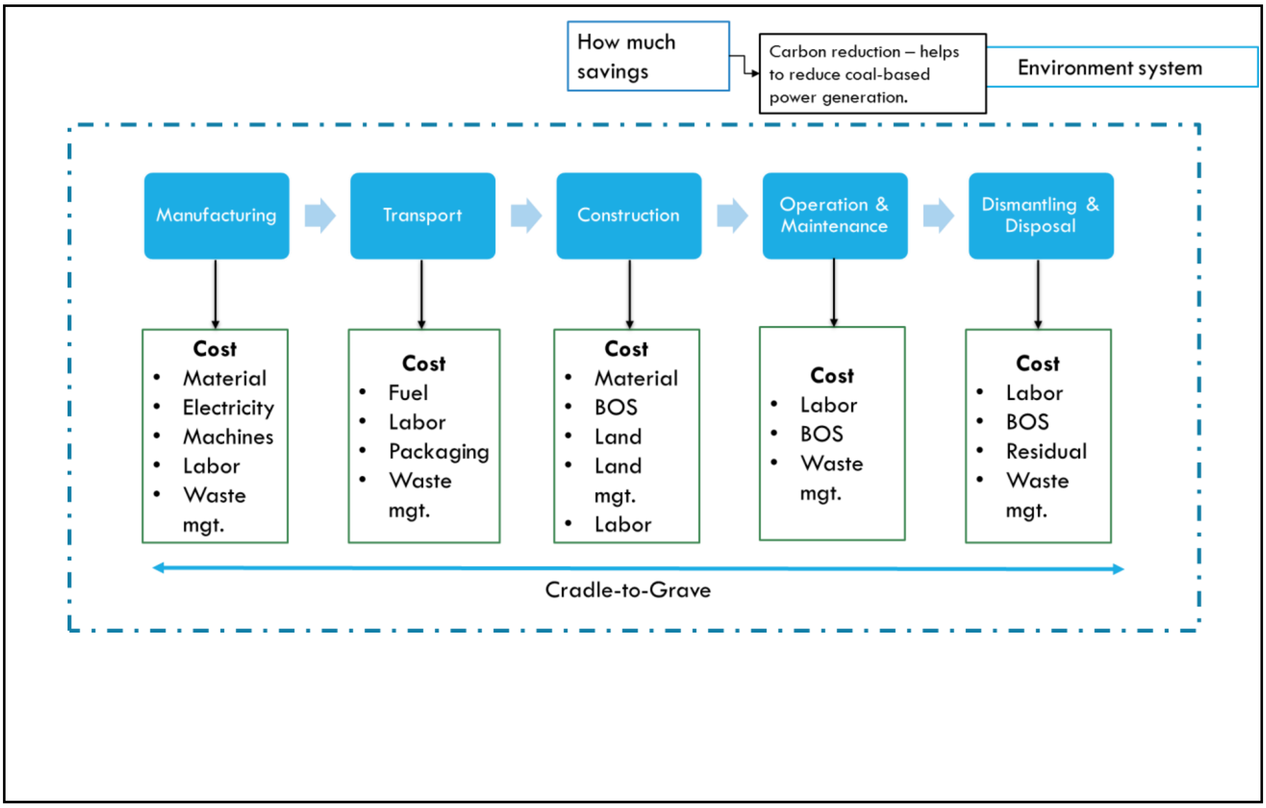

Figure 18: System boundary for LCCA

Everything that involves the cost of 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 19 shows the manufacturing process steps and item involved in manufacturing phase.

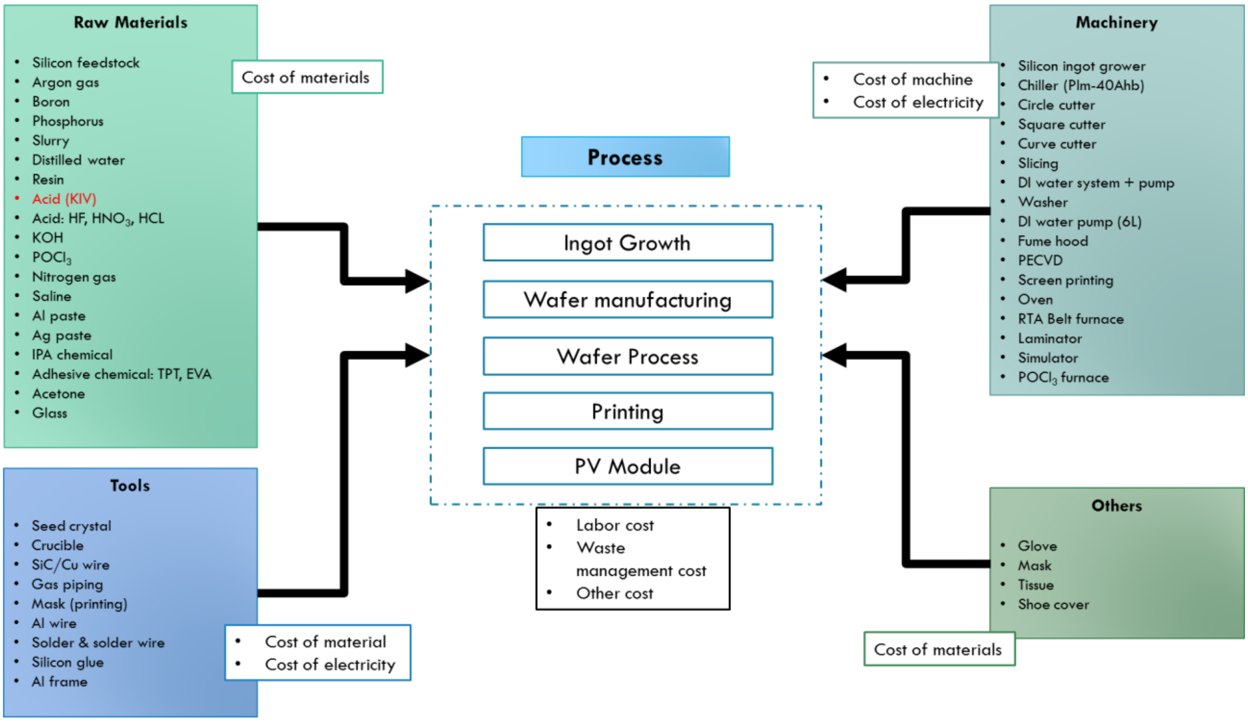

Figure 19: Manufacturing process and item involved.

Besides that, transportation phase only take into account the fuel cost, labour 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 20 shows items that involve is transportation phase.

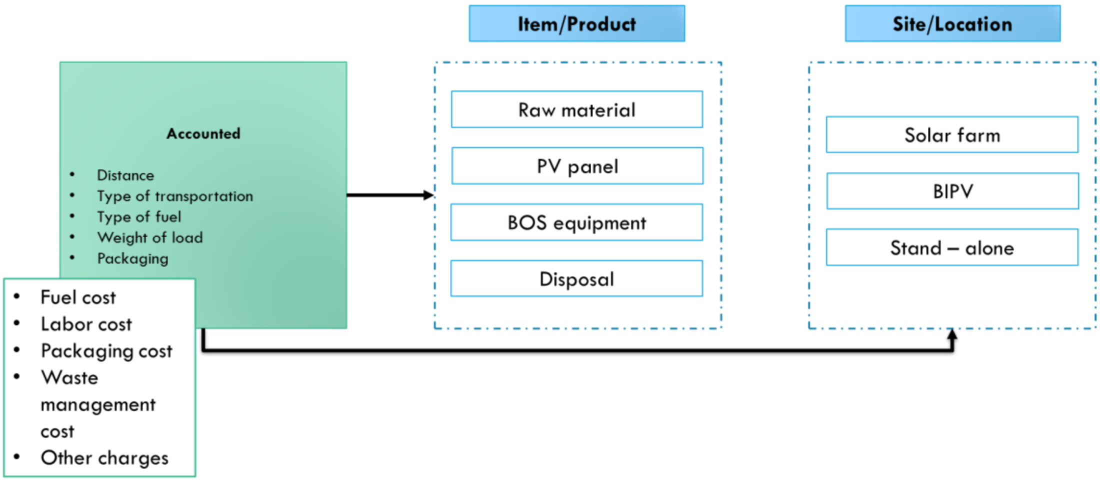

Figure 20: Transportation Process and Item Involved.

While, 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 21 show the process and items that is involved in construction phase.

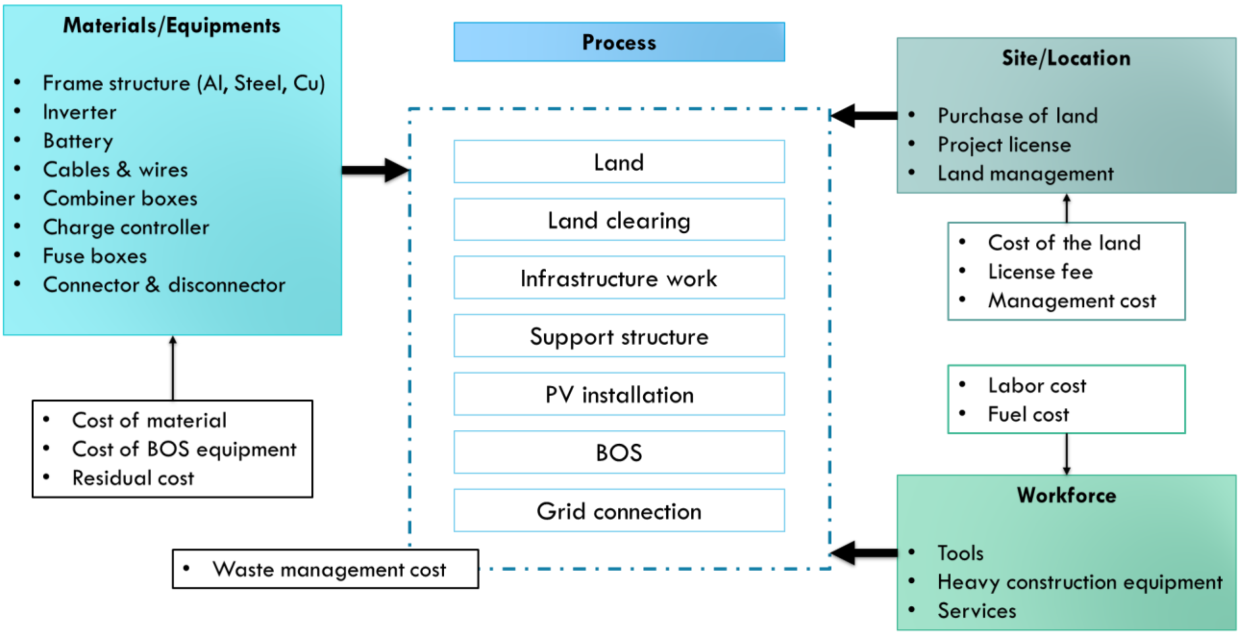

Figure 21: Construction Process and Item Involved.

Furthermore, operation, maintenance and replacement phase will take the labor cost, BOS cost and waste management cost into account. Figure 22 shows the items that is involved in operation, maintenance and replacement phase.

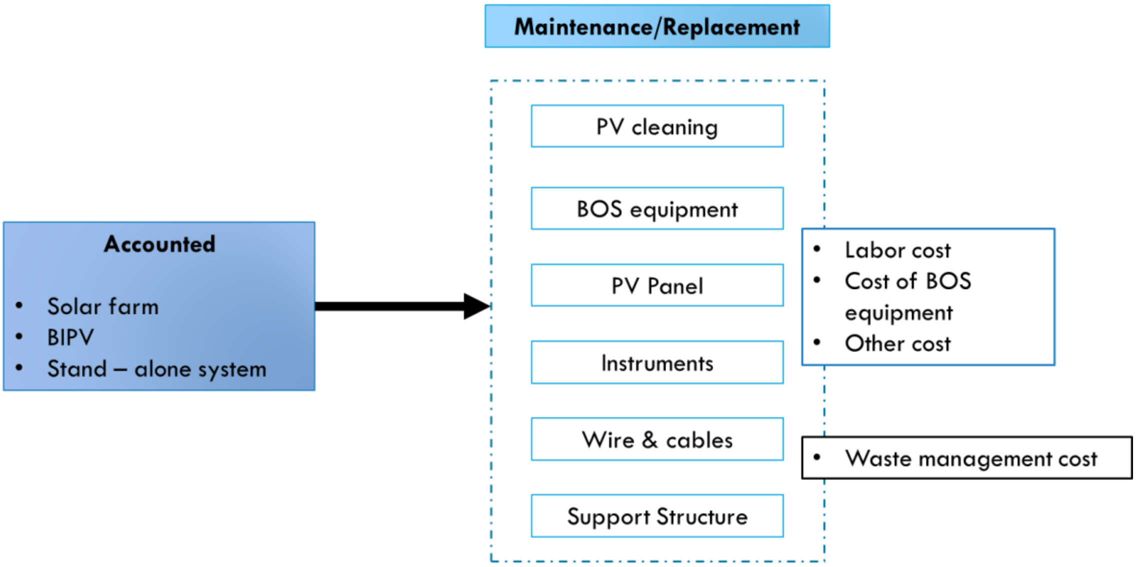

Figure 22: Operation & Maintenance and Item Involved.

Then for dismantling and disposal phase will include the cost for labour, BOS cost, residual cost and waste management cost. Figure 23 show the items that involved in dismantling and disposal phase.

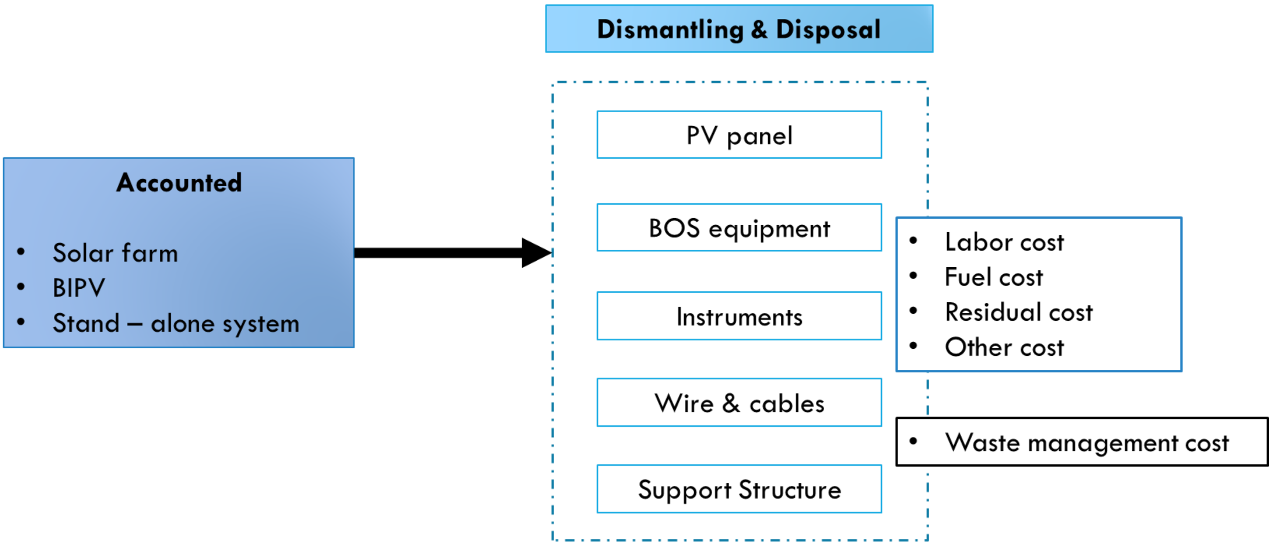

Figure 23: Dismantling & Disposal and Item involved.

4.0 Case Studies

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, Philippines, Thailand, Indonesia and Singapore. The three case studies are:

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 3 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, Thailand and Philippines. 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.

4.1 Solar Farm

a) Malaysia Case Study

Kompleks Hijau Solar Gading Kencana, located in Melaka. The solar farm is deemed to be one of the most resource-efficient in the world, as it produces 1MW per 0.6ha (1.5 acres) against the worldwide norm of 1MW per 2ha (5 acres). This impressive yield emerged from a setback that the actual land area turned out to be smaller than on paper. Aside from generating renewable energy, the solar farm supports Malacca's goal to be a green state. It started feeding solar power into the national grid in mid-December. Under the Feed-in Tariff (FiT) scheme, the company will be paid 80sen per kilowatt hour of electricity [29].

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 24.

Figure 24: Kompleks Hijau Solar

Company : Gading Kencana Sdn Bhd
PV Manufacturer : Yingli Solar, China
No. of Panels : 29,092 units
Type of Panel : Yingli PANDA Monocrystalline-60 Cell Series
Launch : Late 2014
Operated : 4 years
Power Production : 8 MWp = 10,120 MWh

b) Thailand

Kanchanaburi, SSE1 PV power plant is the second large-scale project for Siam Solar Energy 1 Co., Ltd. (SSE), a subsidiary of Thai Solar Energy Company Limited as shown in Figure 25 below. In 2013, Conergy connected to the grid two power plants for SSE with a total installed capacity of 21 MW. These three additional solar parks with an installed capacity of 10.5 megawatts each have followed and are scheduled for commissioning in Q1 of 2014 [30].

Figure 25: SSE1 PV Kanchanaburi

Company : Siam Solar Energy 1 Co., Ltd. (SSE)
PV Manufacturer : Conergy
No. of Panels : 128,200 units
Type of Panel : Conergy 245PX and Conergy 250PX crystalline modules
Launch : January 2014
Operated : 4 years
Power Production : 31.5 MWp = 45,200 MWh

4.2 Solar Rooftop

a) Malaysia

Malaysia Green Technology Corporation, Green Energy Office (GEO) building is the first of its kind in Malaysia. Located on a five-acre land parcel, 40km south of Kuala Lumpur, the GEO building is designed to be exceptionally energy efficient, with a building energy index (BEI) of 30kWh/m2year for conventional office buildings.

Building Integrated Photovoltaic (BIPV) systems are architecturally and aesthetically incorporated into the GEO building’s design, and form a key feature of the building. The BIPV systems generate electricity for the GEO building’s needs while exporting surplus electricity into the national utility network during the daytime via a net-metering arrangement. The BIPV systems provide up to 50% of the building’s electricity requirements, which amounts to 120,000 kWh/year. There are 6 photovoltaic packages installed (System A: Polycrystalline, System B: Amorphous Silicon, System C: Monocrystalline Glass-Glass, System D: Monocrystalline, Systems E and F: Thin Film CdTe) as shown in Figure 26.

Figure 26: Green Energy Office (GEO) building MGTC

Company	: Malaysia Green Technology Corporation
Manufacturer	: Jinko Solar
No. of Panel	: - units
Type of Panel	: Polycrystalline, Monocrystalline & Amorphous
Launch	: 2007
Operated	: 11 years
Power Production	: 6 KWp

b) Philippines

Located in Quezon City, the 1.5 MW PV project is owned by SM Prime Holdings. Inc. and is managed by SM Malls. The panel are greatly utilizing the space on the rooftop as shown in Figure 27. Our partner, Solar Philippines is responsible for the engineering, procurement and construction of this project [31].

SM City North EDSA is the world’s largest solar-powered mall on the day its rooftop solar power project was switched on, 24th November 2014. The Project utilizes 5,760 pieces of Yingli 255Wp high efficiency multicrystalline modules over the mall’s 12,000 Square meters roof powering 16,000 light fixtures, 59 escalators and 20 Elevators of SM North at the same time. This represents 5 percent of the mall’s average electricity consumption per day, which is an estimate of 2 million pesos in savings per month.

Figure 27: SM City North EDSA

Company : SM Prime Holdings Inc
Manufacturer : Yingli Solar
No. of Panel : 5,760 units
Type of Panel : Multi-Crystalline 255Wp
Launch : November 2014
Operated : 4 years
Power Production : 1.5 MWp = 2,000,000 kWh

c) Thailand

C.R.C Wharf is a reputable wharf operator that deals with stevedoring, harbour and dock services for ships located on the famous Chao Phraya River which flows through Bangkok and then into the Gulf of Thailand. The 1MW rooftop installation as shown in Figure 28, comes under the Thailand's Power Development Plan (PDP) with long- term plans for Thailand's energy conservation and alternative energy development plans [32].

It has an 8,000 square meter rooftop space, 4,000 Yingli multicrystalline 60 cell series panels can generate about 1.4 GWh of electricity per annum which is equivalent to the average annual energy consumption of 580 typical Thailand household. This reduces the carbon dioxide emission by some 9,000 tonnes every year which is equivalent of planting 45,000 trees.

Figure 28: C.R.C Wharf

Company	: CRC Wharf Co Ltd
Manufacturer	: Yingli Solar
No. of Panels	: 4,000 units
Type of Panels	: Yingli Multicrystalline YL250p
Launch	: September 2015
Operated	: 3 years
Power Production	: 1 MWp
Efficiency	: 1 MW per 8,000 Square meter roof

4.3 Stand-alone Solar for Rural Electrification

a) Malaysia

Residential, Bkt Mertajam, Penang. It is a private home which reside 40 units of polycrystalline panels. The system are setup upon the rooftop as illustrated in Figure 29. The system is a stand-alone solar which is not connected to the electricity power grid. The house has installed the panels since October 2014 with total power production of 12 kWp.

Figure 29: Bkt Mertajam, Penang

b) Indonesia

Oksibil Solar Power Plant, Pergunungan Bintan, Papua is located 1,300 meters above the sea level, Oksibil Solar Power Plant is the highest installed solar power plant in South East Asia. Providing the electricity for the newly developed area in Oksibil, Pegunungan Bintang as shown in Figure 30. Installed 1,280 units of Yingli Multicrystalline 235kWp since October 2012. The plant produces 300 kWp [33].

Figure 30: Oksibil Solar Power Plant

5.0 Conclusion

In conclusion, the framework for this study of three types of photovoltaic systems life cycle analysis has been completely outlined according to ISO standards [1] on power production of three types of Photovoltaic System under similar weather condition, with environmental impact according to Environment [4] and Carbon footprint [5] for 25 years of lifetime.

Meanwhile, the reporting shall be within the Midpoint which is the GWP based on IPCC 2006, Carbon emission and carbon emission reduction for each case study forecasted. Damage or Endpoint will not be considered for impact category unless required.

The LCA outcomes hypothesis are that the manufacturing process phase would contributes the largest total emission to air. It is anticipated that dismantling and disposal phase contributes the most to long term waste disposal and largest carbon dioxide emission and energy consumption throughout the transportation.

It is predicted that the GWP from Solar Farm is the largest compared to Solar rooftop and Stand-alone Solar using 1kWp production benchmark. The energy cycle from Solar Rooftop is at par for initial energy used against energy production, with Solar farm would be the reversed, for instance initial energy used is smaller compared to energy production. While, Stand-alone solar being on the extreme end of the spectrum with initial energy used is bigger than the energy production.

While for LCCA, the outcomes is the whole scenario of the solar energy systems (solar farm, BIPV & stand-alone) in terms of cost can be identified. In LCCA, for every processes and phases, the cost is calculated. In addition, the analysis is then strengthen by supplementary measures. Besides that, alternative solution in each processes and phases of the solar energy systems also can be identified through LCCA. This is because each of the cost of materials, equipment, services etc., is calculated. Thus, identifying which component cost more and find alternative which helps to reduce cost. Lastly, enable identification the most viable and cost-effective processes for a project, not only in monetary terms but environmental impact as well.

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