

**ECONOMIC EVALUATION OF GRID-TIED PV
TECHNOLOGY USED IN APPAREL
MANUFACTURING INDUSTRY IN SRI LANKA**

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ABSTRACT

Grid-Tied Photovoltaic (PV) technology is a globally accepted renewable technology used for built environment. Application of grid-tied PV system is a promising alternative and it's essential that clients know if the investments in such technologies are actually profitable. In Sri Lanka fewer studies were found on the economic evaluation of grid-tied PV technology. In particular, the economics of generating solar electricity has not been addressed appropriately for Sri Lanka's apparel manufacturing industry. Therefore, aim of this study is to evaluate the economic gain of grid-tied PV technology for apparel manufacturing industry in Sri Lanka to promote its application. The case study approach was adopted as the research strategy and four (04) apparel manufacturing facilities were selected. The data collection was done through semi-structured interviews and documentary reviews, whereas the analysis was conducted through manual content analysis and evaluation of economic indicators. Case study data revealed the key economic benefits of the system such as monthly revenue, low maintenance cost, reduce burden on local utility grid, etc. Key economic challenges were identified as high initial cost, high replacement costs, cost due to conflicts with suppliers, revenue depreciation with system losses and the like. Selecting energy service companies, promote bulk purchase and maintain stocks, enhance national solar energy demand, improve the process of renewable energy loan schemes, etc. are the proposed strategies to overcome those challenges. In addition, three (03) economic indicators were measured, such as levelized cost of electricity, net present value and simple payback period. The levelized cost of electricity resulted in a reasonable range for the cost of producing electricity using a solar PV system, ranging between Rs. 10 and Rs. 12 per kilowatt hour (kWh) and simple payback period and net present value showed a favorable condition, implying system's profitability for apparel manufacturing industry in Sri Lanka.

Key Words: Apparel Manufacturing Industry, Economic Evaluation, Grid-Tied PV Technology, Sri Lanka

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ABBREVIATIONS

Abbreviation	Description
AC	Alternative Current
BIPV	Building Integrated Photovoltaic
CEB	Ceylon Electricity Board
DC	Direct Current
EIA	Energy Information Administration
EU	European Union
FIT	Feed-In Tariff
GHG	Greenhouse Gas
IRR	Internal Rate of Return
LCOE	Levelized Cost of Electricity
MOPRE	Ministry of Power and Renewable Energy
NPV	Net Present Value
PV	Photovoltaic
SLSEA	Sri Lanka Sustainable Energy Authority
SPBP	Simple Payback Period

1 Introduction

1.1 Background

Energy consumption is rapidly growing causing energy supply difficulties and extreme environmental impacts (Pérez-Lombard, Ortiz & Pout, 2008). According to the Global Energy and CO₂ Status Report (2019), energy demand of the developing countries will rise at an annual rate of 3.2% and this rate will be exceeded by 2020 in developed countries. Moreover, in order to meet the rising demand on electricity, the usage of coal and gas power plants was increased by 2.5%, reflecting energy related carbon emissions as 13Gt in 2018. Khan et al. (2020) supports the above argument by recognizing energy consumption as a primary driver of global carbon emissions. Thus, the world is alarmed by the ever-increasing energy-related carbon emission, which has drawn both practitioners and academics' attention (Zhang & Cheng, 2009).

Carbon dioxide emission, releases large quantities of toxic gases, which have major impact on climate changes and global temperature (Zeren & Akkuş, 2020). Consequently, carbon emissions reduction strategies have been implemented internationally to address the global warming issue (Jung, An, Dodbiba, & Fujita, 2012). Renukappa et al. (2013) highlighted that even organizations are implementing carbon reduction strategies with the increasing concern on carbon emission and climate changes. There are four (04) ways to implement energy related carbon reduction strategies in organizational buildings (Chel & Kaushik, 2018). They are passive building design, low embodied energy material for construction, energy efficient domestic appliance and adopting building integrated renewable energy technologies. Sustainability measures including energy-efficient HVAC systems in buildings, energy-efficient lighting systems in buildings, the introduction of renewable energy systems for generating electricity at building will significantly reduce carbon emissions (Abdallah, El-Rayes, & Clevenger, 2015). He et al. (2010) have explained that China has implemented many strategies to reduce carbon dioxide, including energy conservation, re-adjustment of the economic system, the establishment of laws, regulations and institutions and the development of renewable energy technologies.

Among these sustainability measures, renewable energy technologies have been recognized as a potential approach to substantially reduce carbon emissions (Charters, 2001; Jarke & Perino, 2017; Vourdoubas, 2018)

Aliprandi et al. (2016) have stated that electricity produced by fossil fuels raises atmospheric carbon dioxide levels and, as a result, countries are focusing on replacing fossil fuel with renewable energy technologies. Renewable energy technologies allow its customers to reduce their electricity costs and their effect on the environment, compared to conventional centralized electricity generation systems such as coal power plants (McCabe, Pojani, & Van Groenou, 2018). Over the last decade, renewable technologies have evolved exceptionally (Bahaj, 2002). As of 2016, energy generated by renewable energy technologies accounted for approximately 5.4% of total final energy consumption (Global status report, 2018). Amongst renewable energy technologies hydroelectric, solar photovoltaic (PV) and wind turbines have drawn the attention of electricity consumers (Lisserre, Sauter & Hung, 2010).

Solar PV technology has made tremendous progress in the last decade to become one of the most common choices for renewable energy (Lo et al., 2018). Further, according to the authors, total global PV capacity recorded as 6 GW in 2006 and increased to 303 GW by 2016. Wang et al. (2017) explained, solar PV is an alternative source of energy that can reduce greenhouse gas emissions along with air pollution. Furthermore, photovoltaic is one of the innovative solar energy technologies available in today's market that can turn sunlight into electricity. Solar PV system either supplies electricity in its stand-alone mode or supports utility grid in its grid-tied mode (Mahela & Shaik, 2017). PV applications in grid-tied configuration have evolved rapidly with the advancement of PV technologies (Libo, Zhengming & Jianzheng, 2007). About 90% of PV systems around the world are actually utilized as grid-tied systems (Sampaio & González, 2017). Solar grid-tied PV system allows solar power generated from photovoltaic to penetrate the already existing public utility grid (Nwaigwe, Mutabilwa & Dintwa, 2019). According to Parida et al. (2011), the range of grid-tied PV technologies varies from small-scale systems (mainly roof-mounted and building-integrated PV systems in kW) for residential and large-scale systems (megawatt) for solar power plants. In recent years, the population of grid-based photovoltaic systems

has increased, along with many environmental, social and economic benefits (Mahela & Shaik, 2017).

Solar PV technology is a renewable way to produce energy and has many environmental benefits, such as lowering air and water emissions while reducing demand for traditional resources (Grover, 2007). Almaktar (2013) stated that PV technology accounts zero noise and air pollution during operation itself. Furthermore, the use of grid-tied PV systems enables cities to embrace aesthetic and greener principles. The social benefits of grid-tied PV technology are increasing national energy independence, diversification and energy stability, encouraging electricity market deregulation and accelerating rural electrification in developing countries (Tsoutsos, Frantzeskaki & Gekas, 2005). Considering the economic aspects, grid-tied PV decreases the need for electricity from the grid, which relieves the pressure on the local power grid (Almaktar, 2013). Under economic advantages, solar photovoltaic systems are comparatively costly to install in buildings and thus provide many financial opportunities in countries such as the United States, including net metering scheme, cash rebates, tax credits, solar aside and solar renewable energy credits, which serve as key drivers to fuel demand for photovoltaics (Burns & Kang, 2012).

Given the huge potential and benefits of using solar PV technology, there are many challenges to be addressed at both global and local contexts (Shukla, Sudhakar, Baredar & Mamat, 2018). The underlying challenges are the main explanation for weak photovoltaic use compared to traditional energy sources (Isamotu, 2019). According to Azadian and Radzi (2013), there is a significant increase in the inclination towards solar systems all over the world but issues need to be solved to continue this trend. Thus, authors have conducted a study to identify challenges regarding solar PV under the categories of institutional challenges, public acceptance, economic challenges and technical challenges. Karakaya and Sriwannawit (2015) have conducted a similar study on challenges under four categories: policy, management, economic, and sociotechnical. However, Branker et al. (2011) highlighted that economic and/or financial challenge as the principal obstacle for application of solar PV system.

In order to use the PV systems for an entity, the financial benefits need to be determined (Phipps & Sivadas, 2017). Moreover, the authors conducted a study at Otago Polytechnic on economic evaluation of a grid-connected PV system. Bernal-Agustín and Dufo-López (2006) have carried out economic and environmental research on solar photovoltaic installations linked to the Spanish electric grid. To determine the use of integrated PV system for buildings, Oliver and Jackson (2001) applied economic and energy research. An economic study of small-scale, residential PV systems linked to grids in Western Romania is proposed (De Sabata et al., 2014). By taking into account so many investigations, it can be concluded that energy could be supplied with the support of PV technologies in many locations around the world. The benefits of the PV system is assessed by the customers from a purely economic perspective (Zeraatpisheh, Arababadi, & Saffari Pour, 2018). Furthermore, customers should know if investments in such technologies are actually making a profit.

1.2 Problem Statement

Through background search, it was identified that there is a global interest on eliminating negative environmental impacts due to energy consumption. In order to obtain carbon emission free environment, consumers are moving towards energy systems with renewable energy sources. Sri Lanka is blessed with geo-climatic settings and several types of renewable energy resources. Some of them are used extensively and developed to supply the current energy requirements of the country. One of the key renewable energy sources is solar energy, which can be integrated to buildings via technologies. Among these technologies, grid-tied PV technology has been drawing the interest of different sectors in Sri Lanka to gain benefits of solar energy.

In past few years, the number of apparel manufacturing buildings in Sri Lanka has been increased causing high-energy consumption trends (Jayatilake & Withanaarachchi, 2016). Large quantities of both electricity and fuels are used by apparel manufacturing industry, raising environmental concerns (Munasinghe, Jayasinghe, Ralapanawe & Gajanayake, 2016). Even in Bangladesh, garment industries indicate high electricity consumption and therefore as a solution, they have implemented solar mini grid systems on the rooftops (NurAlam, Karim, & Slam, 2015). Additionally, in India, consumption of solar energy can gain huge economic

benefits for apparel manufacturing industry (Gupta, 1989). Apparel industry in Sri Lanka has a high demand for energy compared to many apparel competitors in the world. Leading companies have shown an interest in capitalizing energy efficient technologies for the factories operated by them (Pathirana & Yarime, 2018). Hence, it is vital to regulate the cost of power consumption to make the industry more profitable. Further, apparel manufacturing industry in Sri Lanka creates many environmental impacts and seeking to adopt renewable energy solutions to generate both environmental and economic benefits (Hemachandra, 2014).

Nevertheless, fewer studies ((Muthukumarana et al., 2018) were found on the use of grid-tied PV technology in apparel manufacturing industry. Moreover, few studies (Jayawardena, et al., 2019 & Wijesuriy et al., 2017) have been focused on economic aspects of grid-tied PV to generate electricity in Sri Lanka. Mainly, the economic aspects such as economic benefits, challenges, strategies and economic gain of using solar energy to produce electricity have not been considered significantly for apparel manufacturing industry. As a result, this study intends to carry out an economic evaluation of grid-tied PV for apparel manufacturing industry in Sri Lanka to cater the growing demand for electricity.

1.3 Aim and Objectives

The aim of this research is to conduct an economic evaluation of grid-tied PV technology in apparel manufacturing industry in Sri Lanka.

This aim was achieved through the following objectives;

- i. Critically review the concept and applications of grid-tied PV system in global context
- ii. Examine the economic benefits and challenges of grid-tied PV system for apparel manufacturing industry in Sri Lanka.
- iii. Propose strategies to overcome the economic challenges of the grid-tied PV system for apparel manufacturing industry in Sri Lanka.
- iv. Assess the economic gain of grid-tied PV for apparel manufacturing industry in Sri Lanka.

1.4 Research Methodology

This study adopts a mixed research approach to achieve the aim of this study, to achieve economic evaluation of grid-tied PV technology in apparel manufacturing industry in Sri Lanka. A comprehensive literature review was executed to review the concept “Grid Tied PV technology” and its application in global and local context. Further, the existing benefits, challenges and strategies of grid-tied PV system and economic parameters to evaluate grid-tied PV technology in industry reviewed through the literature. Research strategy of this learning is case study, which was selected based on the criteria of apparel manufacturing factories with grid-tied PV technology. Both qualitative and quantitative data was collected from the selected case studies. Moreover, the primary data collection techniques of this study were document reviews and semi structured reviews. Content analysis and evaluation of economic indicators were used to analyze qualitative and quantitative data respectively. Finally, expert interviews were conducted to validate the research outcomes.

1.5 Scope and Limitation

The scope of this work and the limitations encountered during the study are as bellow.

Scope

This study was conducted to apparel manufacturing industry in Sri Lanka based on the high energy demand and cost control need. As a leading subdivision of industrial sector, the operation of apparel manufacturing industry has caused high energy consumption in Sri Lanka (Muthukumarana, Karunathilake, Punchihewa, Manthilake & Hewage, 2018). Further to author, large manufacturing companies identified this issue in the early stages and took proactive actions by implementing solar PV technology for power generations.

Amongst renewable energy sources, solar PV technologies have clear environmental benefits, which influenced energy consumers to adopt solar PV systems to address shortfalls of the conventional energy system. Even though, there are potential demand and continuous technical advancements of the system, economic challenge is the primary obstacle of solar PV applications. Consequently, the scope of this study address the economic benefits, challenges and strategies of grid-tied PV technology for apparel manufacturing industry in Sri Lanka.

Limitations

As a result of time constraints, the data collection and analysis were limited to four (04) case studies. Due to the absence of estimates in the selected cases, key inputs such as maintenance costs and discount factors were calculated based on the industrial practices when measuring the economic indicators.

1.6 Chapter Breakdown

- Chapter 01: Introduction

Introduction chapter comprises of background of the research, problem statement, aim and objectives of the study, scopes and limitations, methodology of the research and structure of the dissertation.

- Chapter 02: Literature Review

Chapter two discusses theoretical contribution on reviewing the concept and application of grid-tied PV technology for global and local context. Subsequently, existing economic benefits, challenges and strategies connected to grid-tied PV system are discussed. Finally, existing economic analysis methods are discussed under literature review.

- Chapter 03: Research Methodology

Chapter three explains about the methodology of the research, including design of the research, data collection and the techniques of data analysis.

- Chapter 04: Data Analysis and Findings

This section presents data collected through case studies and key research findings. Collected qualitative and quantitative data was analyzed using content analysis and evaluation of economic indicators respectively.

- Chapter 05: Conclusions and Recommendations

Final chapter concludes the research by highlighting the economic benefits, challenges and strategies of grid-tied PV system for apparel manufacturing industry in Sri Lanka. Moreover, this chapter concludes the economic gain of grid-tied PV for apparel manufacturing industry in Sri Lanka purely on economic perspectives. Finally, recommendations of this study were presented through this chapter.

1.7 Chapter Summary

The background study of the research, problem statement, aim and objectives of the study and scope and limitations of the research are elaborated in this chapter. Moreover, the methodology of the research that was used to achieve the aim and objectives of the study is discussed briefly. In conclusion, the chapter breakdown of this study is portrayed by displaying the contribution of each chapter in accomplishing the objectives of the study.

2 Literature Review

2.1 Introduction

This chapter covers the first objective of the research. Accordingly, literature review chapter mainly focuses to display the information regarding concept and application of grid-tied PV system in local and global context. Moreover, this chapter presents literature findings on global energy consumption and available renewable energy technologies. Finally, chapter two presents economic benefits, challenges and strategies of grid-tied PV system along with the indicators for economic gain calculation of renewable energy technologies.

2.2 Global Energy Consumption

Energy plays an important role in the economic and social development of a country and at the same time it improves the quality of life (Wang, Zhang, & Li, 2014). According to Yoon et al. (2010), the energy requirement of the world will be multiplied by the year 2050, due to the expansion of economy and global population. Rapidly growing energy consumption has raised concern over energy supply difficulties and extreme environmental impacts (Pérez-Lombard, Ortiz & Pout, 2008). Energy consumption in the developing countries will expand at a yearly rate of 3.2% and this rate will be exceeded in the developed countries by 2020 (Global Energy & CO₂ Status Report, 2019). Moreover, compared to 2010, consumption of energy in the year 2018 has multiplied the average growth rate. Further to Global Energy & CO₂ Status Report (2019), the changes in the world economy and increasing cooling and heating requirements are identified as the major causes of increasing energy demand. And the continuous rise of global primary energy demand is indicated in Figure 2.1.

According to Figure 2.1, year 2018 displays the highest primary energy demand compared to the last seven years indicating total energy consumption of 328Mtoe (Gas: 143Mtoe, Renewables: 81Mtoe, Oil: 54Mtoe, Coal: 27Mtoe, Nuclear: 23Mtoe). Further, Figure 2.1 displays sources of total primary energy demand in 2018, which includes gas, renewables, oil, coal and nuclear. Moreover, as per Figure 2.1 in 2018,

gas, oil and coal facilitate the majority of total energy demand compared to renewable energy sources.

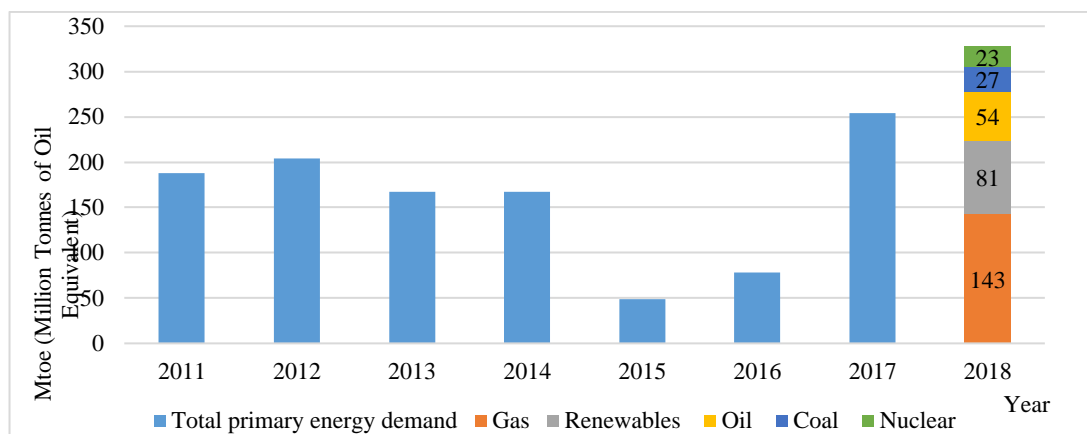


Figure 2.1: Annual Change in Global Primary Energy Demand 2011 – 2018

Source: Global Energy & CO2 Status Report, (2019)

The most flexible form of energy is electricity and it constitutes one of the major infra-structural inputs of social and economic development (Ghosh, 2002). According to author, increasing electricity demand in power sector, responsible nearly for half of the growth in energy consumption. A vital role will be played by the power sector in transforming into a low carbon energy system, since it is responsible for the largest source of carbon emissions in the energy system (BP Statistical Review of World Energy, 2019). Therefore, authors elaborated that it is important to control consumption of power sector to reduce the carbon emission of next 20 years. Table 2.1 indicates the electricity generation by sources for the 2018.

Table 2.1: Global Electricity Generation by Source

Electricity Generation (TWh)	Growth Rate (%)		Shares (%)	
	2018	2017-2018	2000	2018
Total Generation	26, 672	4.0%	100%	100%
Coal	10 116	2.6%	39%	38%
Oil	903	-3.9%	8%	3%
Gas	6 091	4.0%	18%	23%

Electricity Generation (TWh)	Growth Rate (%)		Shares (%)	
	2018	2017-2018	2000	2018
Nuclear	2 724	3.3%	17%	10%
Hydro	4 239	3.1%	17%	16%
Biomass and waste	669	7.4%	1%	3%
Wind	1 217	12.2%	0%	5%
Solar Photovoltaic	570	31.2%	0%	2%
Other Renewable	144	4.2%	0%	1%

Source: Global Energy & CO₂ Status Report, (2019)

According to Table 2.1, in 2000 coal is the highest electricity generating source, which indicates as 39% and gas graded as the second highest electricity generating source with 18%. Further to Table 2.1, in 2000 there is a zero electricity generation via renewable energy sources. Moreover, Table 2.1 displays electricity generation in 2018, where coal and gas still dominate the electricity generation with a percentage of 38% and 23%, respectively. Furthermore, compared to 2000, the renewable base electricity such as solar PV, biomass and wind energy consumption in 2018 has increased by 2%, 3% and 5% respectively. However, according to Table 2.1, coal based electricity production lead the energy supply from a larger percentage in 2018 compared to renewable energy sources. According to Global Energy & CO₂ Status Report (2019), the usage of coal power plants and gas power plants has risen to compensate the high demand of electricity, causing a boost in CO₂ emission. Furthermore, carbon emission from electricity generation increased by 2.5%, indicating energy related carbon emission as 13Gt in 2018.

Considering local context, by the year of 2020, it is expected to increase the primary energy demand by which cannot be met by the conventional resources alone and as a result there is a national consideration on non-conventional renewable energy sources for electricity generation (National Energy Policy & Strategies of Sri Lanka, 2008).

Figure 2.2 displays electricity coverage as at 30th September 2015 which is produced by National Energy Policy & Strategies of Sri Lanka (2008). Although, Figure 2.2 presents that majority of the country receive electricity coverage up to 91% to 99% and there are districts which receive electricity coverage less than 80%.

According to National Energy Policy and Strategies of Sri Lanka (2008), energy and power sector has a greater impact on economy due to imported fossil fuels in Sri Lanka. The targets of energy sector in Sri Lanka will be to increase the contribution of electricity from the renewable resources by 50% to 60% in 2020 and to obtain the total need of electricity from the renewable resources by 2030 (Sri Lanka Energy sector development plan for a knowledge-based economy, 2015). Figure 2.3 shows the expected energy mix in 2030 in Sri Lanka compared to the primary energy supply in 2013.

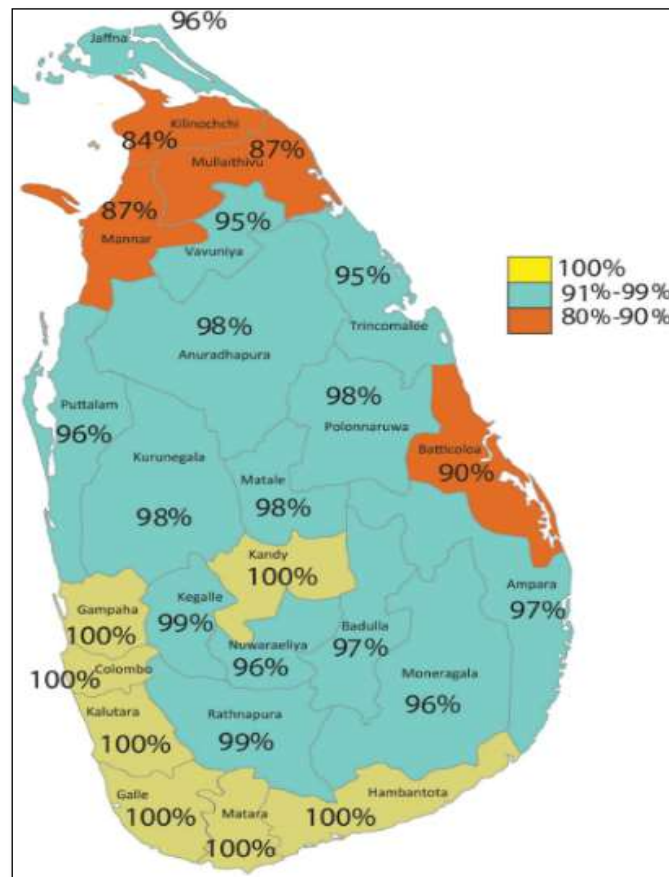


Figure 2.2: Electricity Coverage of Sri Lanka

Source: National Energy Policy & Strategies of Sri Lanka, (2008)

According to Figure 2.3, in Sri Lanka it is expected to reduce petroleum and coal based energy consumption to 1%, while increasing the renewable energy supply up to 34% by 2030. Accordingly, it can be mentioned that, in both global and local contexts, there is an increasing demand for energy which requires prompt solutions.

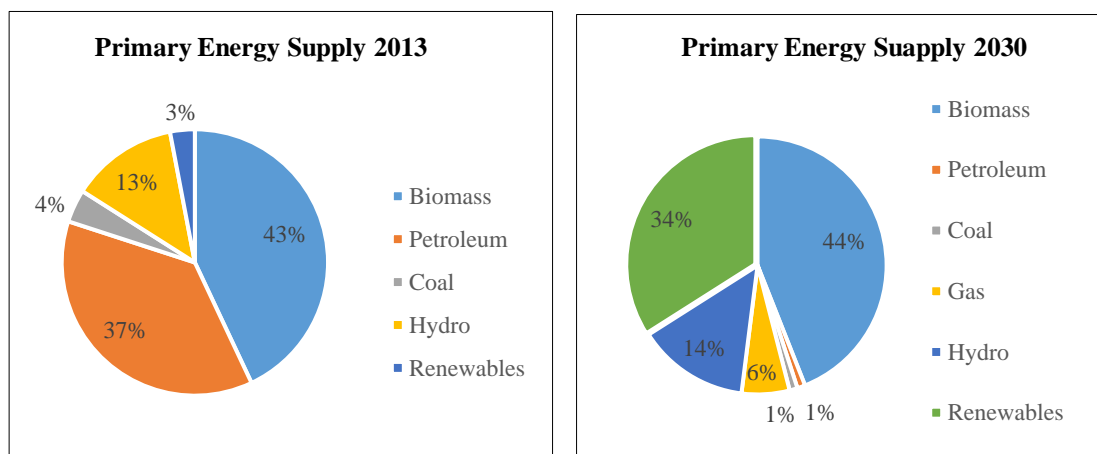


Figure 2.3: Primary Energy Supply in Sri Lanka

Source: Sri Lanka energy sector development plan for a knowledge-based economy, (2015)

2.3 Energy Consumption by Sectors

Various research classified energy use into various sectors. Cuce et al. (2015) describes sectoral energy under four (04) categories including domestic, industry, transport and services sector. Pérez-Lombard et al., (2008) divided the final energy consumption into three (03) main sectors: industry, transport and ‘other’. According to authors other sector represents agriculture, services and residential. U.S. Energy Information Administration (2016) explained that generally consumption of energy categorized under three (03) main sectors including transportation, industrial and building. Expressing similar view, IEA (2018) identifies transportation, industrial and buildings as the three (03) major sectors of energy consumption. According to Sustainable Energy Authority in Sri Lanka (2017), local sectoral energy consumption has been categorized into three (03) sectors; industrial, transportation and building (household and commercial). Accordingly, in this study the sectoral energy consumption is categorized and described under transportation, building and industrial sector as below.

2.3.1 Transportation Sector

Transportation sector increases at an average rate of 1.4% annually (U.S. Energy Information Administration, 2016). Transportation sectors throughout the world are powered by fossil fuels (Hossain, 2019). Petroleum products, biofuels, natural gas and electricity are the major types of energy used for transportation in the United States. In 2018 petroleum products accounted for about 92% of the total energy use of the transportation sector in the United States (U.S. Energy Information Administration, 2016). According to Saboori et al. (2014), the transport sector is a major growing contributor to Greenhouse Gas (GHG) emissions. Further to authors, it contributes towards a significant portion of the global CO₂ emissions. China has become the second largest oil consumer in the world since 2003 and has been an oil importer (Zhang, Li, Zhou, & Mu, 2011). Further to author, a major share of energy consumption in China, especially the petroleum products are used in the transportation sector. Timilsina and Shrestha (2009) mentioned that, the transport sector accounts for a substantial share of total national CO₂ emissions in most of the Asian countries. Therefore, transport sector emissions contributes largely towards the climate change in Asia, which needs to be addressed promptly.

2.3.2 Building Sector

Buildings sector consists of commercial and residential end users and they account for 20% of the total energy consumption of the world (U.S. Energy Information Administration, 2016). According to Energy Information Administration (2016), the average growth in commercial energy consumption is 1.6% per year from 2012 to 2040. The residential sector has a variety of buildings, which consume different types of energy appliances such as computers, television sets, refrigerators, etc. The commercial sector facilities are hotels, office buildings, stores, shopping complex, etc. and in these amenities, energy is primarily used for lighting, heating and cooling and energy using appliances, etc.

Omer (2007) explains in his study that by designing buildings which are more economical in using the energy for heating, lighting, cooling, ventilation and hot water supply is one method of reducing building energy consumption. Building energy has become one of the major sources of carbon emission, which increases the

environmental pollution by releasing large amount of carbon dioxide into atmosphere (González & García Navarro, 2006).

2.3.3 Industrial Sector

Over half of the global energy is used by industrial production and it is expected to grow by 1.5% per annum globally through 2035 (Jordan, 2014). As per U.S. Energy Information Administration (2016), the industrial sector is accountable for the largest portion of energy consumption and it is expected to be responsible for more than half of the total energy use in 2040. Compared to other sectors, the energy intensity and energy usage in the industrial sector is on par with the global primary energy usage (Martínez, Ebenhack, & Wagner, 2019). Figure 2.4 illustrates the projected sector energy consumption in 2020.

According to Figure 2.4, industrial sector consumes highest energy (51.7%) compared to other sectors. As stated by U.S. Energy Information Administration (2016), the energy consumption of industrial sector in the world is projected to increase by an average of 1.2% per year. Therefore, it is evident that energy use in industrial sector is growing along with the expansion in the sector.

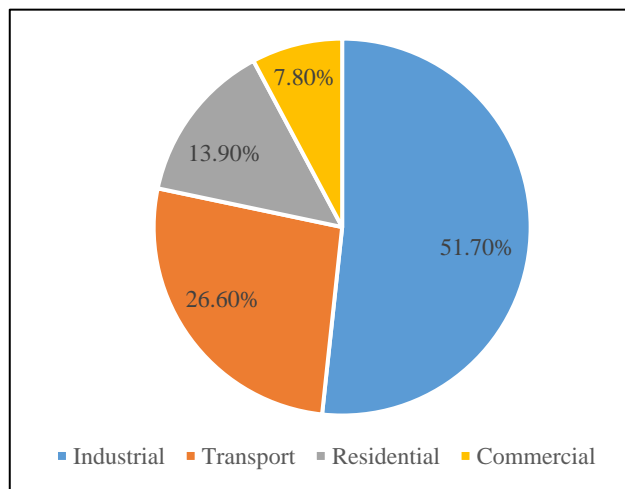


Figure 2.4: Sector Energy Consumption in the Year 2016

Source: U.S. Energy Information Administration, (2016)

2.4 Sources of Energy

Conventional energy sources are coal, oil, petroleum, betumes, natural gas, etc. (Bilgen, 2014). Further to author, renewable energy sources are solar, wind, hydro,

marine, biomass, etc. There are six (06) primary energy sources and their usage can be explained as 44% from petroleum, 26% from natural gas, 25% from coal, 2.5% from hydro power, 2.4% from nuclear power, and 0.2% from non-hydro renewable energy sources (Chow, 2003). Figure 2.5 indicates world electricity generation by energy source, from 2012 to 2040 (trillion Kilowatt-hours). Nonrenewable energy has been used for centuries and it has sustained severe impact on natural environment (Lisserre, Sauter, & Hung, 2010). Further to authors, the extraction of energy from nuclear processes grew in popularity in the second half of the 20th century. Figure 2.5 illustrates world electricity generation (energy unit: trillion kilowatt-hours) by energy sources from 2012 to 2040.

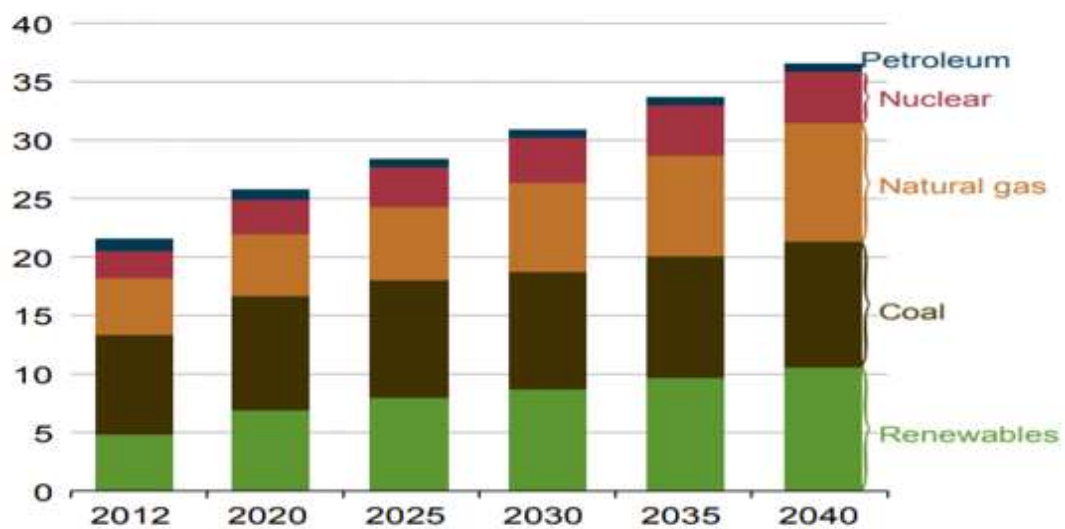


Figure 2.5: World Electricity Generation by Energy Source

Source: U.S. Energy Information Administration, (2016)

According to the graphical presentation of Figure 2.5, petroleum, nuclear, coal, natural gas and renewable based energy are the major sources contribute to the energy mix since 2012. Fossil fuels are the primary source, which cater the present energy requirements of the world (Mohan, 2018). According to author, there will be a worldwide scarcity of fossil fuels in the coming years and the current consumption of fossil fuels has generated drawbacks to the environment and global warming. Hence, as per Mohan (2018) the need for an alternative and/ or renewable energy is crucial. Also Patade, Meher, Grover, Gupta, & Nasim, (2018), stated the use of fossil fuels lead to emit poisonous gases such as carbon dioxide, sulfur dioxide, and nitrogen

oxides etc., which negatively impact on the surrounding environment. Therefore, energy consumers are driven to use renewable energy sources over conventional energy sources.

2.5 Renewable Energy Sources and Technologies

Ecological effects, fossil fuels depletion, and energy supply difficulties are the drawbacks of high energy demand and rapid economic development (Ghenai & Bettayeb, 2019). Further to authors, these energy related issues of the world can be solved by improving alternative renewable energy sources. The quota of renewable energy sources in global electricity is estimated to increase from 14.9% in 2005 to 34.3% in 2020 (European Renewable Energy Council, 2011). And as per the Rafiee et al. (2019), there are modern technologies that convert abundant renewable energy to usable energy power, which can replace the conventional energy sources. Solar Energy, Wind Energy, Biomass Energy, Geothermal Energy and Tidal power can be identified as main renewable sources, which contribute to electricity generation (Alrikabi, 2014). Electricity produced through fossil fuels increases the carbon dioxide level of the atmosphere and as a result, countries are focusing to replace fossil fuel with renewable energy technologies (Aliprandi et al., 2016). According to Chien & Hu (2007), high cost of producing electricity is the key challenge of renewable energy systems. However, according to authors, the cost gap has significantly reduced over the past few years, ensuring stable financial grounds.

Global warming and carbon emission have become a critical factor and as a result companies and organizations are adopting carbon reduction projects in order to identify organization's contribution to global warming and climate changes (Matthews et al. 2008). Buildings adopt sustainability measures, such as energy efficient appliances, HVAC and lighting systems to minimize the energy related carbon emission (Abdallah et al., 2015). Authors further explained that the buildings also utilize renewable energy technologies within organization to reduce conventional energy consumption and carbon emission. Therefore, amongst sustainability measures, organizations are motivated to use renewable energy sources as a carbon reduction mechanism for buildings.

Building integrated wind turbines use wind as a source to produce electricity via wind turbines, which are usually installed around the building (Sari & Kusumaningrum, 2014). Further to author, this technology has become a remarkable technology for green buildings and the power generation of the system is almost equivalent to the power generated by conventional energy sources. Geothermal heat pumps use shallow ground as a heat source or sink to provide efficient heating and cooling at moderate temperature (Tester et al., 2015). Moreover, typical applications of this system are residential and commercial space and water heating. According to Chew and Doshi (2011), biomass is a biological material extracted from plant or animals waste (Chew & Doshi, 2011). Further to author, Brazil has reduced country's carbon emission by 83 million tons by adopting biofuel in its motor vehicles and domestic purposes. Amongst renewable energy sources, solar energy technologies have clear environmental benefits compared to traditional energy sources, thereby leading to sustainable energy generation (Tsoutsos, Frantzeskaki & Gekas, 2005). Consequently, energy users are influenced to adopt solar PV systems to address shortfalls of the conventional energy system (Boontome et al., 2017). Singh, (2013) also stated that solar energy is a widespread abundant and pollution free renewable energy source, which has capability of electricity generation through solar photovoltaic (PV) system.

2.6 PV System as Renewable Energy Technology

Solar photovoltaic (PV) is one of the first clean energy technologies, which has been implemented globally (Chaurey2010). According to Desai (2007), generating electricity by photovoltaic arrays are gaining widespread attention and identified as reliable technology for coming years. Expressing a similar view, Zhang et al. (2013) stated that solar photovoltaic (PV) uses silicon-based material to directly converts sun light into electricity power and has recognized as a primary solar power generating system (Zhang & He, 2013). Poponi (2003) explained that solar photovoltaic technology directly convert abundant solar into usable power without interfering heat engine.

Power generation, water pumping, solar PV home systems, communications and satellites, vehicle charging and solar power plants are some of the applications of solar photovoltaic system (Goetzberger & Hebling, 2000). Moreover, with such a plethora

of functions, there is a boost for the demand of solar photovoltaic system. According to Zhang and He (2013), the demand for the solar PV market has increased significantly with an increasing capacity of 4GW in 2004 to 70GW in 2011. Further to authors, it was the fastest of all renewable technologies from 2006 to 2011, with an annual growth rate of over 58%. Figure 2.6 indicates the global solar PV power generation in the sustainable development scenario from 2000 to year 2030. According to Figure 2.6, there is continuous growth in solar PV power generation in globally and expected to achieve PV power generation of 3268 TWh by 2030. Multiple components like cells, electrical and mechanical connections, mounting options, means of regulating and/or modifying the electrical outputs are some remarkable features of solar PV power generation (Parida, Iniyani & Goic, 2011).

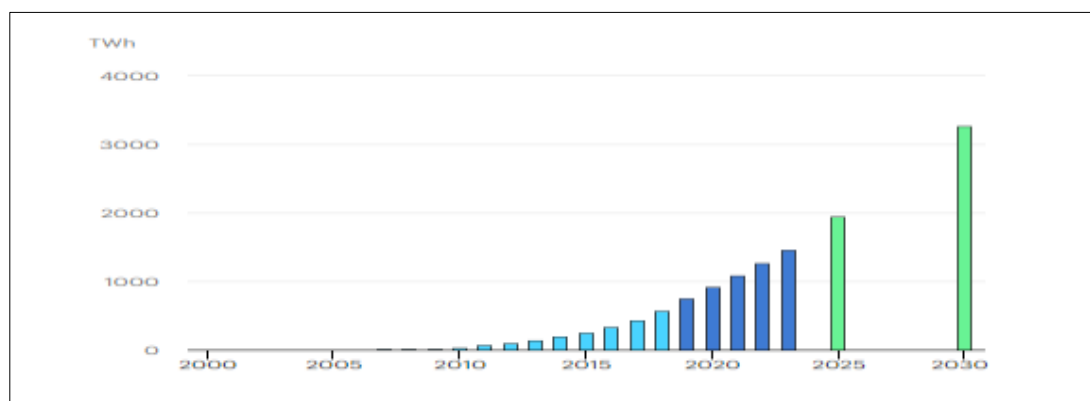


Figure 2.6: Solar PV Power Generation in the Sustainable Development Scenario

Source: International Energy Agency (IEA), (2019)

2.6.1 Types of photovoltaic cells

Different materials and manufacturing ways are incorporated in PV cells manufacturing process (Jestin, 2012). Moreover, other than these differences, the overall performance is the same, that is harvesting solar energy and converting it to useful energy. According to Jestin (2012), monocrystalline silicon, polycrystalline silicon, and thin film are the three (03) main types of PV cell technologies in the global market. Also El Chaar et al., (2011) subdivided PV technology into four categories including crystalline, thin film, compound semiconductor and nanotechnology. Thus, in this study types of PV cells are described under three (03) main categories of monocrystalline silicon, polycrystalline silicon, and Amorphous.

- **Monocrystalline Silicon Cell**

Monocrystalline silicon cells are the cells usually refer to as silicon cells (Bayod-Rújula, 2019). According to the author, pure semiconducting material is necessary to produce a monocrystalline silicon cell (c-Si). Zhao et al., (1998) stated that in the production process of Monocrystalline, a high level of efficiency is guaranteed. Although, manufacturing of Monocrystalline silicon cells is difficult, it offers high efficiency rates such as 13% to 19% (Plante, 2014). Monocrystalline PV cells are more efficient (at least 6%) and more expensive, when compared to polycrystalline PV cells (Husain, Hasan, Shafie, Hamidon & Pandey, 2018).

- **Polycrystalline**

The polycrystalline cells (mc-Si) are more cost effective but there are some defects in the crystals, due to the inefficient production process (Mohammad Bagher, 2015). Further to authors, Polycrystalline silicon is also called polysilicon or poly-Si. And it is a high purity, polycrystalline form of silicon, used as a raw material for the solar photovoltaic industry.

- **Amorphous**

Compared to Monocrystalline and Polycrystalline Cells, these cell type has amorphous silicon cells, which composed of silicon atoms in a thin homogenous layer (Kalogirou, 2009). Moreover, the light absorption of amorphous silicon is more efficient than crystalline silicon, which leads to thinner cells. This is known as a thin film PV technology. The ability to deposit amorphous silicon on wide range of substrates, both rigid and flexible is an added advantage of this technology (Kalogirou, 2009).

2.6.2 Solar PV system configurations

Solar power electricity generated either using photovoltaic or concentrated solar power (Singh, 2013). Photovoltaic system directly converts solar radiation to electricity (Ahmadi et al. 2018). Moreover in concentrated solar power system, solar power is converted to heat and then to electrical energy. Categories of photovoltaic solar systems can be identified as stand-alone PV system, grid-tied PV system and hybrid solar power system (Bimenyimana et al. 2018). Solar PV system configurations can

be of four (04) types including stand-alone solar PV systems without storage battery and storage battery, hybrid systems, building integrated solar PV system and grid interactive solar PV system (Shankarappa, 2017). And each type of solar PV systems are discussed below in briefly.

- **Stand-alone solar PV systems without storage battery and storage battery**

Stand-alone photovoltaic systems are operated independently from the local utility grid, and it is designed and sized to cater certain DC and/or AC electrical loads (Bhatia, 2014). Stand-alone photovoltaic technologies are usually a utility power substitute and they are especially used in places where main local utility grid is not connected (Chaar, 2007). According to Fara & Craciunescu (2017), stand-alone photovoltaic power system consists of a complete set of interconnected components for converting solar irradiance directly into electricity. Further to authors, this system consists of PV generator, charging controller, storage battery, solar inverter and the load of the system. Stand-alone PV systems use wide range of applications in remote and isolated places to meet the ongoing electricity demand (Semaoui, Arab, Bacha & Azoui, 2013). Moreover, to ensure a stable energy supply there should be a compatibility between the size of stand-alone solar PV system and the electricity consumption in isolated sites. However, a storage battery is required to balance the energy of the stand-alone PV system, since the PV cell cannot store energy by itself (Wang et al., 2011).

- **Hybrid systems**

A hybrid renewable energy system consists of more than one energy source, among which one at least is a renewable energy source (Bachev et al., 2018). Kartite et Al., (2019) explained two different technologies that are joined together to create hybrid renewable energy system: one or more conventional energy sources, and at least one renewable energy source. Khare, Nema & Baredar (2016) also stated, the important characteristics of hybrid energy systems are combining two or more renewable power technologies to obtain operating characteristics and efficiencies higher than a single power source. In remote and rural areas, Hybrid systems are used in standalone mode. In this mode, traditional energy resources and battery storages can be used as the back-

up resources due to the uncertain nature of the renewable energy sources (Bahramara, Moghaddam & Haghifam, 2016).

- **Building Integrated solar PV system**

BIPVs are defined as PV modules, that can be incorporated to the building envelope (into the roof or facade) by replacing traditional building materials (tiles e.g.) (Henemann, 2008). Therefore, BIPVs can be considered as a significant part of the energy system of the building and also it has an impact on the functionality of the building. The BIPV is installed considering the architecture of the building and local weather conditions (Biyik et al., 2017). Therefore, the BIPV system can have an impact on the structure and the functionality of the building. BIPV technology improve the functionally of the building by transforming the building into an energy producer (Prasad & Snow, 2014). In this advancement, to get a better performance construction technology should be merged with BIPV technology (Pagliaro, Ciriminna & Palmisano, 2010). And as a result, the PV modules function as a construction element, while serving in building exteriors.

- **Grid –Tied PV System**

Madeti (2017) defines grid-tied solar PV technology as a power generating PV system, which integrates the local utility grid. Grid-tied solar PV system ensures maximum use of energy from the utility grid and solar power system itself (Karki, Adhikary & Sherpa, 2012). Solar grid-tied PV system is widely practiced in many countries globally; as demand for alternative renewable energy against fossil fuels is growing (Nwaigwe, Mutabilwa & Dintwa, 2019). This is a significant technology as it integrates PV systems into local grid and optimizes the energy balance of buildings, improving the infrastructure of the system (Orioli & Di Gangi, 2013). Further to author, it lowers the functional costs and adds value towards customers as well as utilities. Further to author, implementation and operation cost of grid-tied PV is low compared to building integrated and hybrid solar PV systems. Moreover, reliability of grid-tied PV system is high compared to stand alone PV system (Gunerhan et al. 2008).

Taking these advantages into account, this study focuses on grid-tied PV technology. The following sections of this study explain a broad overview of grid-tied PV system,

covering areas such as overview of grid-tied PV technology, benefits, challenges and strategies of implementing the system.

2.7 Overview of Grid-Tied PV Technology

Wang et al. (2017) explained, solar is an alternative energy source capable of reducing GHG emissions and air pollution. Furthermore, photovoltaic is an advanced solar energy system available in the current market, which is capable of converting sunlight into electricity power. Off-grid domestic solar PV system, off-grid non-domestic solar PV systems, grid-tied distributed solar PV systems and grid-tied centralized solar PV systems are the are four (04) main applications of solar PV system (Zahedi, 2006). Mahela and Shaik (2017) described that compared to other PV power systems the population of grid-tied PV system have been increasing in the market as an alternative power source for fossil fuels.

Solar grid-tied PV system allows solar power generated from photovoltaic to penetrate the already existing public utility grid (Nwaigwe, Mutabilwa & Dintwa, 2019). According to Karki et al. (2012), there are two main categories of grid tied PV system and illustrated in Figure 2.7 and Figure 2.8. Accordingly, Figure 2.7 displays the grid-connected solar PV system without batteries and Figure 2.8 displays the solar grid-connected PV system with battery storage.

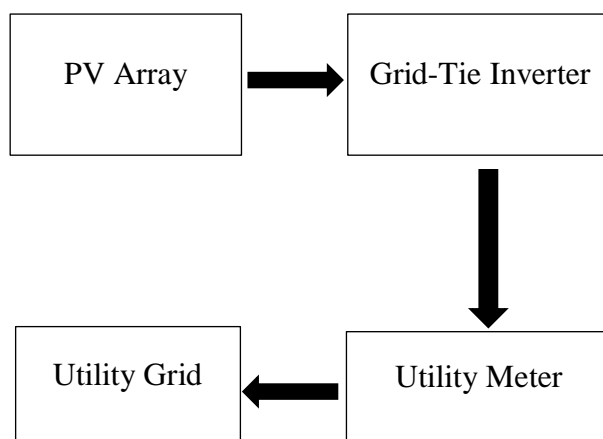


Figure 2.7: Block Diagram of Grid-Tied PV System without Batteries

Source: Karki et al., (2012)

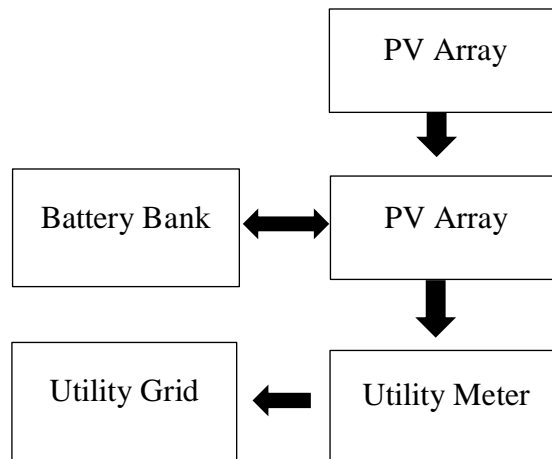


Figure 2.8: Block Diagram of Grid-Tied PV System with Batteries

Source: Karki et al., (2012)

Grid connected PV system range from various sizes such as small capacity systems (commonly, roof-mounted and BIPV, in kW) for residential purposes and large scale systems (in megawatt size) for solar power stations (Parida et al. 2011). Generally, grid-tied PV system includes PV modules, solar inverters and local grid system. (Adaramola, 2014). Furthermore, major components of a grid-tied solar PV system are presented in Figure 2.9. As stated by Tomar and Tiwari (2017), grid-tied PV system's performance depends on inclination of PV array, efficiency of inverter, load profile and climate condition.

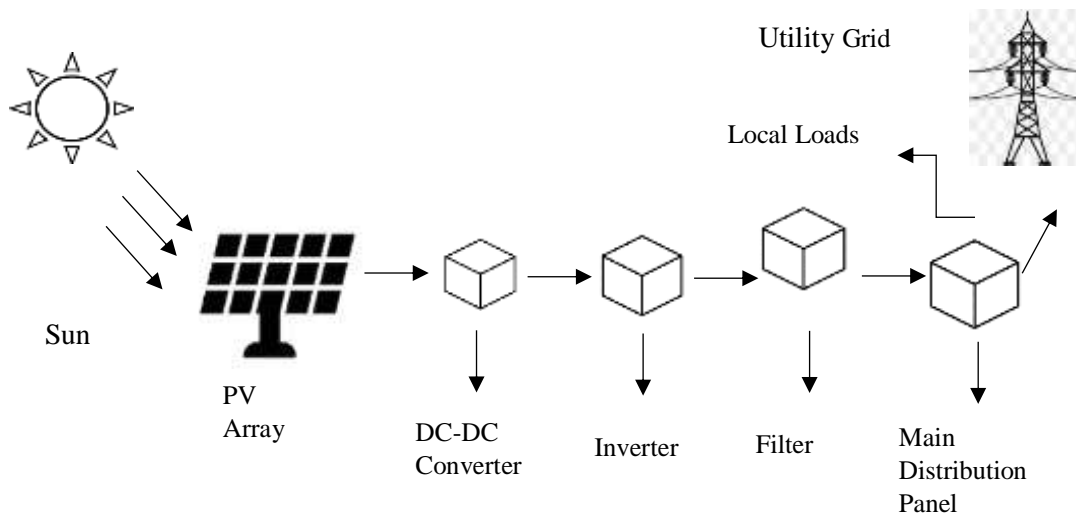


Figure 2.9: Grid-Tied Solar PV System

Source: Adaramola, (2014)

According to authors, the successful performance of grid-tied solar PV system ensures several benefits such as demand shifting from peak to off peak hours, minimizing peak load demand, reliable power supply, high utilization rate and tradeoff between tariff structure and achievement of sustained sellback price. Demand of solar photovoltaic is increasing with the improvements of its applications (Parida et al. 2011). Further to authors, different applications of solar PV includes water pumping, power source for remote building, solar home system, satellites, communications and megawatt scale power plant. The last decades, there has been a significant progress in application of grid-connected solar PV system (Kouro et al. 2015).

2.7.1 Mounting Options of Grid-Tied PV System

Roof mounted, ground mounted and building integrated PV systems are the major mounting options of grid-tied solar PV system. And each category is described in the subsequent section.

- **Roof Mount**

Madessa (2015), describes commercial and residential buildings as the ultimate locations to utilize solar PV system. Further to author, generally buildings have flat roof arrangement, which enable possibilities for applying solar PV system in both design and retrofitting phase of a building. As pointed out by Ceron et al (2013), approximately 50% of BIPV systems are utilized on the building roofs. Moreover, the performance of the solar system could be affected by a several factors, such as availability of solar radiation, the tilt and azimuth of the solar PV modules, the distance between the solar PV module rows, the surface temperature of the PV module, etc.

- **Ground Mounted**

Utility scale photovoltaic (PV) power stations are installed in large open fields (Jubayer & Hangan, 2016). Further to authors, the ground-mounted solar PV modules are designed to generate and supply solar power electricity to the commercial power grid.

- **Building Integrated PV System**

Even the installation of an integrated PV system has been described as a primary form of solar PV system configuration, it is also a modern approach to mounting solar PV systems to building facades (Biyik et al., 2017). Moreover, this system allows user to combine power generation with the function of the facility. According to Bakos and Tsagas (2003), many countries are driven to install building integrated PV system for buildings facades since it is a multi-tasking solar application.

2.7.2 Benefits of Grid-Tied PV Technology

Benefits of grid-tied PV technology are described under three (03) main categories as below, including environmental, social and economic benefits.

2.7.2.1 Environmental Benefits

Solar PV technology is a sustainable way of generating electricity and it contains several environmental benefits such as minimizing air and water pollutions while reducing demand for conventional resources (Gunerhan et al. 2008). Furthermore, grid-Tied PV technology perform as a renewable and clean energy source, which are essential components to deliver environmental benefits. Almaktar et al. (2013) stated that PV technology accounts zero noise, air and water pollution during operation itself. Furthermore, application of grid-tied PV system enables cities to support aesthetic and greener concepts. According to Tsoutsos et al. (2005), the major environmental benefits of grid-tied PV technology is reduction of environmental greenhouse gases emission and prevention of toxic gas emissions.

2.7.2.2 Social Benefits

Social benefits of grid-tied PV technology includes increase of national energy independency, energy supply security and diversification, assist the deregulation of energy markets and improvements to the rural electrification in developing countries (Tsoutsos et al. 2005). Furthermore, another significant social benefit include creating job opportunities with the expansion of solar technology market. In particular, solar PV technologies make it possible for rural areas with local grid connectivity issues to have access to power generation (Pontoriero, Blasco & Hoese, 1998). Further to authors, community-based solar initiatives can have positive social impacts, from

decreased heating bills for low-income individuals, decreased dependency on public utilities, an improved environment from reduced pollution, and job creation.

2.7.2.3 Economic Benefits

Grid-tied PV system reduces the electricity supply demand from grid, which ease the burden on local power grid (Almaktar et al. 2013). Furthermore, grid-tied PV technology has very low maintenance requirement and low maintenance cost during its life span. Grid-tied PV system can support the economy of the country and creating job opportunities (Pillai et al. 2014). Moreover, solar industry create business opportunities for installers of PV power systems, manufacturers, product distributors, engineering and architectural companies. Under economic benefits, solar PV system is comparatively costly to install in buildings therefore in countries like United States provide several financial incentives including tax credits, cash repayments, net metering scheme, solar set aside and solar renewable energy credits, which performs as key drivers to enhance the PV demand (Burns & Kang, 2012). Comparatively grid-tied PV systems are beneficial than separate PV power plant because of zero requirements of additional land, less expenses on supporting structures and there is an indirect energy conservation impact due to the participation of consumer in their own electricity supply (Polo & Haas, 2012).

2.7.3 Economic Challenges of Grid-Tied PV System

Even though, PV system is competitive in the renewable energy world, the adoption of grid-tied solar PV systems remain very low compared to traditional energy sources (Karakaya & Sriwannawit, 2015). Shukla et al. (2018) stated that adoption of solar PV systems are often constrained by several challenges, which need to be overcome both at the national and regional level. Expressing similar view, Zhang et al. (2012) stated that the application of solar energy is limited in practice due to various challenges. Previous studies has identified various sociotechnical challenges under different categories with related to PV technology (Lo et al., 2018). Further to author the challenges of PV system has recognized under five categories; technical and environmental, economic and financial, market, policy and regulatory and social.

Table 2.2: Economic Challenges of Solar PV System

Identified Major Economic Challenges of Solar PV	Source of Reference
Developing countries identifies high initial cost of the system and lack financing options as key challenges	Timilsina, Kurdgelashvili and Narbel, (2012)
Financial institutions recognize solar energy investment as high risk, when assessing the creditworthiness, due to lack of awareness of the system	
Cost of balance of the system is not falling proportional to the decline in solar PV module price	
Long payback period	Lo et al. (2018)
High Maintenance cost	
Low electricity cost of conventional energy sources	
High upfront cost	
Low cost effectiveness	
High cost of solar PV modules	
Low cost of competing energy sources	Karakaya et al. (2015)
Banks are not willing to invest in short and long term solar PV investments	
High lifetime cost, high up-front price, and inflexibility of payment	
lack of suitable financing mechanism	
Inadequate government subsidy	
Initial Cost	Alam Hossain
Payback period	Mondal & Sadrul
Bias against distributed technology platforms among traditional energy agencies and utilities	Islam, (2011)

Amongst challenges of solar PV system, economic challenges are the major concern of energy consumers (Karakaya & Sriwannawit, 2015). Expressing similar view, Timilsina (2012), stated that economic challenges as the major constraint of solar PV

implementation and future growth. Therefore, it is vital to recognize and address the prevailing economic challenges in the energy market. Table 2.2 indicates, economic challenges identified in the previous studies. According to Table 2.2, the major economic challenges of solar PV system are initial system cost, financing difficulties, long payback period, maintenance cost and lack of subsidies

2.7.4 Economic Strategies for implementing Grid-Tied PV System

Cucchiella et al. (2016) explained that without government incentives the life cycle cost of grid-tied PV system would exceed the saving from the renewable energy system. According to Polo and Haas (2012), worldwide programs are conducted to promote the application of grid-tied PV system and few of them can be listed as follows.

- ‘Japanese Residential PV System Dissemination Programme’ since 1994
- Introducing favorable feed-in tariffs for PV users in Germany with the amendment of ‘Renewable Energy Act’ in 2004
- In 2008, PV usage in Spain increase with the favorable feed-in tariffs for PV users

Promotion strategies of grid-tied PV system includes rate based and enhanced feed in tariff incentives, green pricing models, soft loans, NGO marketing and public building program (Palo & Haas, 2012). Studies in Europe countries showed that National Government and European community has introduced many financial strategies to promote the use of PV systems, which guarantee the competitiveness of solar PV in the worldwide market (Campoccia et al. 2007). As per the authors, the most popular strategies of Europe are feed in tariff, capital subsidies, net metering which allows a significant reduction of costs related to PV system. Campoccia et al. (2007) stated the financial strategies for PV systems introduced in twenty seven European countries and presented in Table 2.3.

Table 2.3: Financial Strategies Available for Grid-Tied PV System in European Countries

EU Country	Feed-in tariffs	Net meterin	Capital subsidie	EU Country	Feed-in tariffs	Net Meterin	Capital Subsidie
Austria	✓		✓	Latvia	✓		
Belgium	✓	✓	✓	Lithuania			
Bulgaria				Luxembourg	✓		✓
Cyprus	✓		✓	Malta			
Czech Republic	✓	✓	✓	Netherlands	✓		✓
Denmark		✓		Poland			✓
Estonia	✓			Portugal	✓		✓
Finland			✓	Romania			
Finance	✓		✓	Slovak Republic	✓		
Germany	✓		✓	Slovenia	✓		
Greece	✓		✓	Spain	✓		✓
Hungary	✓			Sweden	✓		✓
Ireland			✓	United Kingdom			✓
Italy	✓	✓	✓				

Source: Campoccia et al. (2007)

According to Table 2.3, the major strategies used for EU countries are feed-in tariffs, net metering and capital subsidies. Government support for both producers and investors are the key reasons for successful solar market in several countries

(Adaramola, 2015). Further to author, commonly used government support schemes are feed-in tariff, net metering and support during initial investment.

A Feed in Tariff (FiT) arrangement includes a premium price to the producer of the renewable electricity and grid operators are liable to purchase the generated solar electricity output (Poullikkas, 2013). Moreover, FiT system popular for employing large scale of wind, biomass and solar energy, especially in Germany, Denmark and Spain. Further the FiT scheme ensures long term financial aid for the users, which reduces the investment risk. Net metering identifies as an electricity policy, where utility operators can reduce solar users electricity use by considering the self-generated renewable energy systems. Many states are using net metering to reduce the electricity use by the solar photovoltaic (PV) system (Darghouth et al. 2011). Moreover, in net metering the utility bill savings decides purely on the relevant electricity rate structure and the characteristics of the customer and the solar PV system. Therefore, the savings generated by net metering can vary from each customer.

California residential has accepted solar PV system as a good investment in terms of financial perspective since there are several factors enhance the financial viability of solar PV in buildings such as incentives from government, net metering scheme on annual basis, time of use billing, high rates of electricity, gradually reducing system costs and high taxes (Black, 2004). Collaboration of Sri Lanka Sustainable Energy Authority (SLSEA), Ceylon Electricity Board (CEB), and Lanka Electricity Company (Private) Limited (LECO) have launched a community-based power generation project under the title of Energy Battle in order to promote the installation of solar panels for domestic puposes, religious places, hotel facilities, commercial buildings and industries (Ministry of Power and Energy, 2016). Furthermore, this project operates under the expectation of adding 200MW of solar electricity to the grid by 2020, which indicates the local attention on solar. According to sustainable energy authority in Sri Lanka, solar market operates three solar PV schemes as net plus, net accounting and net metering.

2.8 Economic Gain of Grid-Tied PV Technology and Calculation Methods

The economic grounds of solar PV system depends on the costs and rewards of the system (Aqeeq et al. 2018). Even though, there are continuous technical advancements of the system, economic challenge is the primary obstacle of solar PV applications (Fthenakis, Mason, & Zweibel, 2009). Based on the source of information, solar PV system might have already achieved grid parity or (Branker, Pathak, & Pearce, 2011), at the other extreme is far from parity with local grid electricity (Yang, 2010). Therefore, these different perspectives hesitate new customers from entering and investing in solar PV market (Swift, 2013). Further to author, the key reasons for contrasting views are avoiding important factors impacting on the cost of the system, continuous change in the factors that impacting on the system's costs and returns based on the location (such as government and utility incentives, solar insolation, local cost of electricity) and continuously declining of solar PV cost.

Regardless of provided incentives and demand for sustainable energy systems, solar PV yet to be identified as a key contributor of global energy mix (Webpage footer for REN21, 2019). The application of solar system for power generation significantly depends on country's political decisions, primarily due to the cost of producing solar electricity is higher than the electricity cost by conventional energy sources (De Sabata et al., 2014). It is considered solar PV has reached to a turning point, if solar PV achieves grid parity in a context where the cost of producing traditional energy sources are rising while solar PV cost is declining (Poponi, Byrne, & Hegedus, 2006). Grid parity is the unit cost (kWh) of producing solar electricity being comparable to the prices offered by the traditional energy sources on the local grid. PV to the lifetime generation cost of the electricity from PV being comparable with the electricity prices for conventional sources on the grid (Sarasa-Maestro, Dufo-López, & Bernal-Agustín, 2013). Therefore, it is important to calculate economics of solar PV, in order recognize its compatibility with the grid supply. The literature on economics of solar PV applications is extensive. Table 2.4 indicates research conducted in order to evaluate economic of grid-tied PV system. And Table 2.4 display source, studied area, software used and economic indicators used for the identified research.

Table 2.4: Studies Conducted on Economics of Grid-Tied PV System

Studied area	Software used	Economic indicators / Economic evaluation tools	Source of reference
The costs and benefits of large-scale solar photovoltaic power production in Abu Dhabi, United Arab Emirates	RETScreen	Net Present Value (NPV), Simple Payback Period (SPBP), and Internal Rate of Return (IRR) of the project, Energy production cost, Benefit cost ratio, Years to Positive Cash flow	Harder and Gibson, (2011)
Economic performance and policies for grid-connected residential solar photovoltaic systems in Brazil	-	Levelized Cost of Electricity electricity costs (LCOE), and Net Present Value (NPV)	Mitscher and R��ther, (2012)
The cost benefit analysis of implementing photovoltaic solar system in the state of Kuwait	-	LCOE and, cost benefit analysis	Ramadhan and Naseeb, (2011)
A review of solar photovoltaic LCOE	-	LCOE	Branker, Pathak, and Pearce, (2011)
Economic Evaluation of a Grid-Connected PV System at Otago Polytechnic	-	LCOE, SPBP and NPV	Phipps and Sivadas, (2017)

Studied area	Software used	Economic indicators / Economic evaluation tools	Source of reference
Economic and environmental analysis of grid connected photovoltaic systems in Spain	-	NPV and SPBP	Bernal-Agustín and (Dufo-López, (2006)
Potential and viability of grid-connected solar PV system in Bangladesh	RETScreen	IRR, benefit-cost ratio, cost of energy production and SPBP	Alam Hossain Mondal and Sadrul (2011)
Viability study of grid-connected solar PV system in Ethiopia	RETScreen , HOMER	NPV, IRR, benefit-cost ratio, SPBP and production cost.	Kebede, (2015)
Economics of a Small-Scale, Grid-Connected PV System in Western Romania: an LCOE Analysis	-	LCOE	De Sabata et al., (2014)

According to Table 2.4, several economic indicators has been used to calculate the economics of grid-tied PV system. Further, identified economic indicators can be summarized as Levelized Cost of Electricity (LCOE), Net Present Value (NPV), Simple Payback Period (SPBP) and Benefit-Cost Ratio (BCR). Each type of main economic indicators is briefly discussed below.

- **Levelized Cost of Electricity (LCOE)**

The cost of electricity is measured by LCOE and generally used to compare the generating costs of electricity from different energy sources (Adaramola, Paul & Oyedepo, 2011). Further to author the consumers, however, understand this approach easily, because their electricity bill is generally stated in cost per kWh. Using the LCOE method for assessing unit energy costs involves three (03) basic steps: (i) estimating the total electricity produced by the photovoltaic system over its life span; (ii) measuring the investment cost along with project operating and maintenance costs; and (iii) dividing the whole life-cycle costs by the system's energy output (Adaramola, 2015). Branker, Pathak and Pearce (2011) examined the appropriate methodology for calculating the LCOE for PV systems (Branker, Pathak & Pearce, 2011). The reviewed LCOE is indicated in formula (1).

$$LCOE = \frac{\sum_{t=0}^T \frac{(It + Ot + Mt + Ft)}{(1+r)^t}}{\sum_{t=0}^T St \frac{(1-d)^t}{(1+r)^t}} \quad (1)$$

Where: T = Life of the project (years); t =Year t; It = Initial investment, cost of the system including construction, installation, etc.(Rs); Mt = Maintenance costs for t; Ot = Operation costs for t (Rs); Ft = Interest expenditures for t (Rs); r = Discount rate for t (%); St =Yearly rated energy output for t (kWh/year); d = Degradation rate (%)

- **Net Present Value (NPV)**

NPV is a comprehensive and generally recognized financial project success indicator. It is the difference in cash inflows and outflows current value (Guedes Junior & Guedes, 2017). The NPV expresses itself monetarily and is useful in expressing both absolute and relative attractiveness of the project (Jung & Tyner, 2014). According to Phipps & Sivadas, (2017), the net present value formula (2) can be displayed as bellow

$$NPV = \sum_{i=1}^N \frac{income - cost_i}{(1+r)^i} - I + \frac{R}{(1+r)^N} \quad (2)$$

Where: I = initial investment; r = discount rate; i = year; N = number of years; R = scrap value

- **Simple Payback Period (SPB)**

Simple payback period measures the expected number of years to recover the initial investment of the system (Almaktar, Abdul Rahman & Hassan, 2016). According to Brigham et al. (2005) if all aspects remain constant, a project with a shorter payback period is considered to be a better project because investors can recover the capital invested in a shorter time period. In addition, shorter payback period means greater liquidity for the project.

- **Benefit-Cost Ratio**

The benefit cost ration compares the benefits and costs of a selected project (Harder & Gibson, 2011). Further to author, benefits are calculated by excluding social and environmental benefits. Alam et al. (2011) explains this as a ratio, which indicates net benefits to against the costs of the proposed project.

Net Present Value (NPV), Simple Payback Period (SPBP) and Levelized Cost of Electricity (LCOE) are well known indicators, typically used in the PV context (Cucchiella, D'Adamo & Gastaldi, 2017). LCOE and software based calculations are the most commonly used methodologies used to determine the cost of electricity (Ross, Anthony, CA & Harber, 2016). According to Ramadhan and Naseeb (2011), LCOE is used to compare unit cost between different projects with various capacities, investments and lifetime. However, only consider cost of producing, while revenues of the system are avoided (Mitscher & Rüther, 2012). The simple payback period method has an advantage of easy to calculate and it indicates project's feasibility (Phipps & Sivadas, 2017). Therefore, both SPBP and LCOE illustrates efficiency of electricity generation, however does not provide understanding on the economic performance of a power generated in a project. Financial performance of a PV system can be assessed by NPV, since it compute the sum of the present worth of annual net cash flows (revenues-expenses) generated by the project (Mitscher & Rüther, 2012). Therefore, in this study the LCOE, NPV and SPBP were selected as economic indicators to evaluate the economic performance of grid-tied PV system.

2.9 Operation of Apparel Manufacturing Industry

The apparel manufacturing sector is an extensive energy user, and impacts on surrounding environment and health of peoples (Claudio, 2007). According to Conca (2015), it is identified that the garment manufacturing industry is accountable for 10% of the global greenhouse gas emissions, which is recorded as the second highest industrial carbon emitter after the oil sector. In apparel manufacturing industry, electricity usage is continuously growing, as a result of existing and new machines and equipment and an inefficient usage of industrial equipment (Ozturk, 2005). Moreover, apparel industry encompasses a great number of plants, which consume a significant amount of energy. As an example, the apparel sector responsible for about 4% of the primary energy usage in China's manufacturing, while this portion is less than 2% in the United States of America (Ozturk, 2005).

In Sri Lanka's industrial structure, apparel sector occupies a prominent position (Embuldeniya, 2015). According to Wijayasiri et al. (2009), the apparel manufacturing trade is a key driver in the economy of Sri Lanka, which boost foreign earnings, local industrial production and employment generation of the apparel market. Expressing similar view, Dheerasinghe (2009) elaborated apparel manufacturing industry as Sri Lanka's biggest gross export earner (since 1986) and account for more than fifty two percent of total export earnings of the country. However, as a leading subdivision of industrial sector, the operation of apparel manufacturing industry has caused high energy consumption in Sri Lanka (Muthukumarana, Karunathilake, Punchihewa, Manthilake & Hewage, 2018). Accordingly, to address the high energy trend, the leading apparel industries in Sri Lanka are motivated to invest in energy efficient technologies in their plants (Pathirana & Yarime, 2018). Further to author, few leading apparel companies recognized this matter in the initial stage and undertake necessary actions by developing green plants and capitalizing in energy efficient technologies. Thus, there is noticeable concern and motivation, especially in the leading Sri Lanka's apparel manufacturers to utilize energy efficient and sustainable technologies for their new and existing factories of the organizations (Sri Lanka Export Development Board, 2016).

2.9.1 Application of Grid-Tied PV for Apparel Manufacturing Industry

The apparel manufacturing sector in particular is an extensive energy user, and seek application of renewable energy as a solution (Claudio, 2007). Bangladesh garments industries indicate high electricity consumption and therefore as a solution they has implemented solar mini grid system at garments rooftop (NurAlam, Karim, & slam, 2015). MAS Holdings (Pvt.) Ltd., a leading apparel solution provider in Sri Lanka has launched a project under the title of “Photon”, which involves fixing of twenty four roof-mounted grid-tied PV system in a total area of 2,000,000 sqft (from Kilinochchi to Koggala) (MAS Holdings, 2020). According to Wright (2020), Hidaramani Group, a Sri Lanka’s apparel provider has launched the initial stage of a continuing rooftop solar installation project. Further to author, this is part of “Suryadhanavi project” and present capacity includes 21,000 solar PV modules generating 7.7MW. Batticaloa factory operated under Brandix apparel solutions, has installed 1.65 MW rooftop solar plant and energy yield of the system is 2,975 MWh, which exceeds the annual energy requirement of the premises (Lugoda, 2019).

2.9.2 Economic Gain of Grid-Tied PV for Apparel Manufacturing Industry

Solar photovoltaic grid-tied PV system is one of the emerging ways of reducing energy cost of industrial sector (Patrick Gregory, Michael Tan, Eugene A., Carl Michael F. & Joey Duran, 2019). Study conducted in India has identified that use of solar energy can herald enormous economic benefits for apparel industry (Gupta, 1989). Another research was conducted to determine the economic feasibility of a 2.5 MW size solar photovoltaic energy power plant, in order to cater the energy demand of the apparel zone, Jaipur considering on-site and off-site options (Chandel, Agrawal, Mathur, & Mathur, 2014). Moreover, authors evaluated the financial performance of the system using three (03) indicators; internal rate of return (IRR), net present value (NPV) and simple payback period. Taking into account aforementioned investigations, it can be concluded that solar photovoltaic systems have been evaluated under economic aspects for apparel sector around the world. According to Zeraatpisheh et al. (2018) it is essential that customers assess the PV system from a purely economic perspective. Moreover, learning the economic feasibility of solar PV system critical for both national policy makers and investors in solar systems.

2.10 Exploration of Research Gap

Aim of this study is to conduct an economic evaluation of grid-tied PV system for apparel manufacturing industry in Sri Lanka. Accordingly, Figure 2.10 demonstrates the mapping of literature findings leading to research gap of the study. Further to Figure 2.10, under solar energy there are three primary configurations of solar PV system such as grid-tied PV system, stand-alone PV system and hybrid solar power system. And as shown in Figure 2.10, grid-tied PV system can be categorized into two types including grid-tied PV system with battery and without battery. In order to achieve the ultimate aim of the study, economic benefits, challenges, strategies and economic indicators were explored to assess the economic evaluation of the system.

2.11 Chapter Summary

This chapter provides overall understanding about concept and applications of grid-tied PV system. By reviewing the concept and application it was identified that there are several categories of solar PV. Major categories of grid-tied PV system includes grid-tied PV with battery and System without battery storage. Consequently, economic benefits, challenges and strategies of grid-tied PV system were identified. Ease the burden on local grid, reduce electricity bill, low maintenance cost, zero requirement of additional lands and support the country's economy are the identified benefits of grid-tied PV system. Key economic challenges of the system are high initial cost, financial difficulties, low cost effectiveness and lack of government subsidies. Thus, chapter identify Net Metering, Feed-in tariff and capital subsidies as key economic strategies of grid-tied PV system. Subsequently, economic indicators were identified through literature review chapter. Finally, a literature mapping was developed by highlighting the research gap of the study.

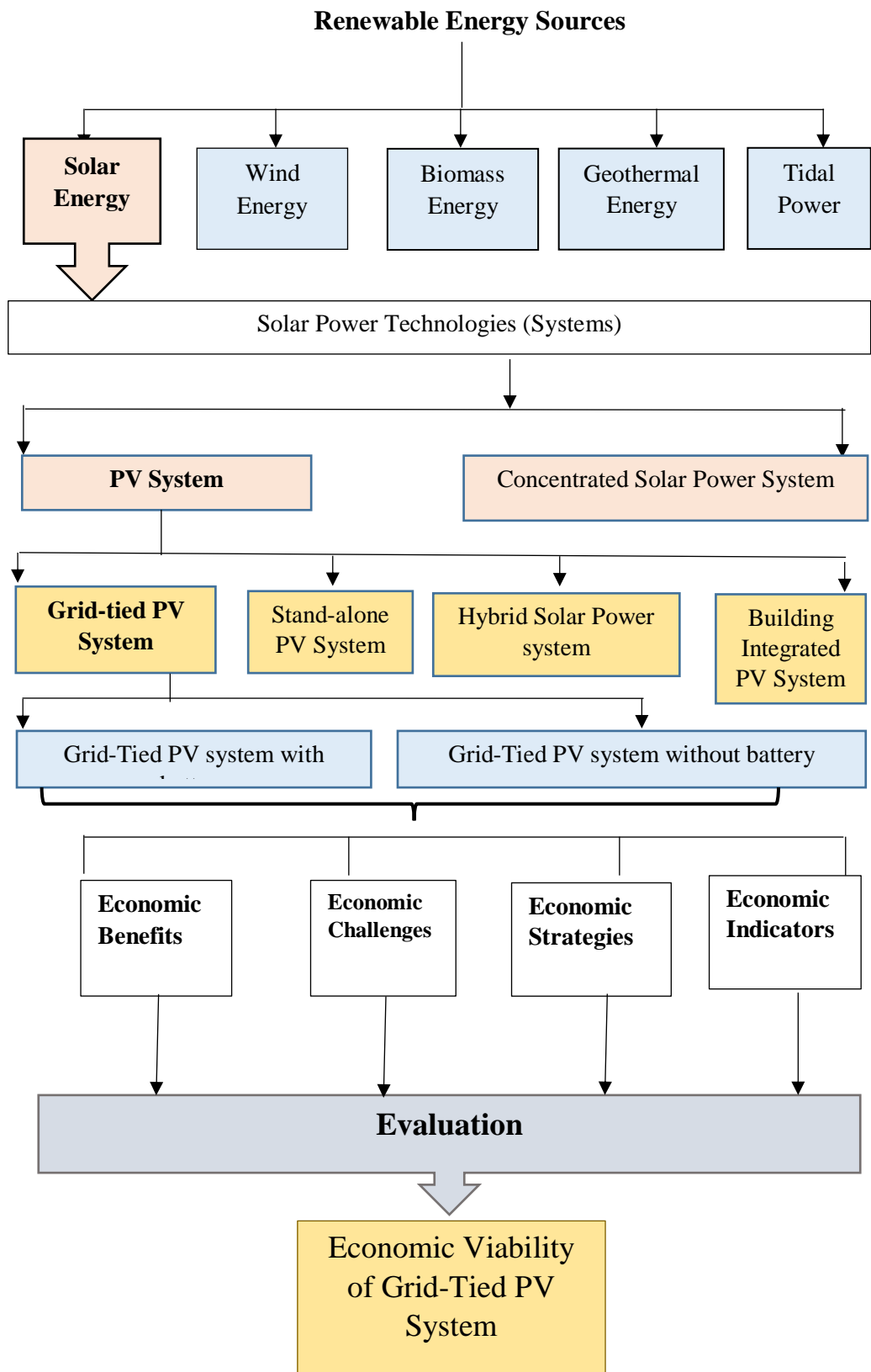


Figure 2.10: Literature Mapping

3 Research Methodology

3.1 Introduction

Research methodology is a scientific approach adopted to guide a research (Mishra & Alok, 2017). Kothari (2004) defines research methodology as a systematic manner in which research problem is solved. This research aims to conduct an economic evaluation of grid-tied PV system for apparel manufacturing industry in Sri Lanka. Accordingly, this chapter elaborates methodology developed to achieve the research aim. Initially, chapter clearly defines the research process. Subsequently, chapter describes the research approach and research strategy of the study. Finally, this chapter provides a detail explanation of data collection and analysis techniques considered in the study.

3.2 Research Process

Research process consists of certain structural process or steps to carry out research effectively (Bist, 2015). Moreover, research usually begins with its problem and ends in empirical generalization. All of these above mentioned steps of research process should maintain in the perfect order to reach in formal conclusion. Most research textbooks represent research as a multi-stage process that you must follow in order to undertake and complete the research project (Saunders, Lewis & Thornhill, 2015). Further to authors, the precise number of stages varies, but they usually include formulating and clarifying a topic, reviewing the literature, designing the research, collecting data, analyzing data and writing up. Thus, it is a necessity to guide the research through this each step in order to deliver the final research outcome. Hence, this study adopt a research process to guide the research in order to achieve its ultimate aim.

Accordingly, research process developed to carry out this study is displayed in Figure 3.1 and discussed below. According to Figure 3.1, research process is illustrated under three phases. As shown in Figure 3.1, phase one defines background of the study, research problem and literature findings. Further to Figure 3.1, in phase two research approach, research strategy and data collection were determined and conducted. And

finally, in phase three data analysis and conclusions and recommendations were derived on to the study.

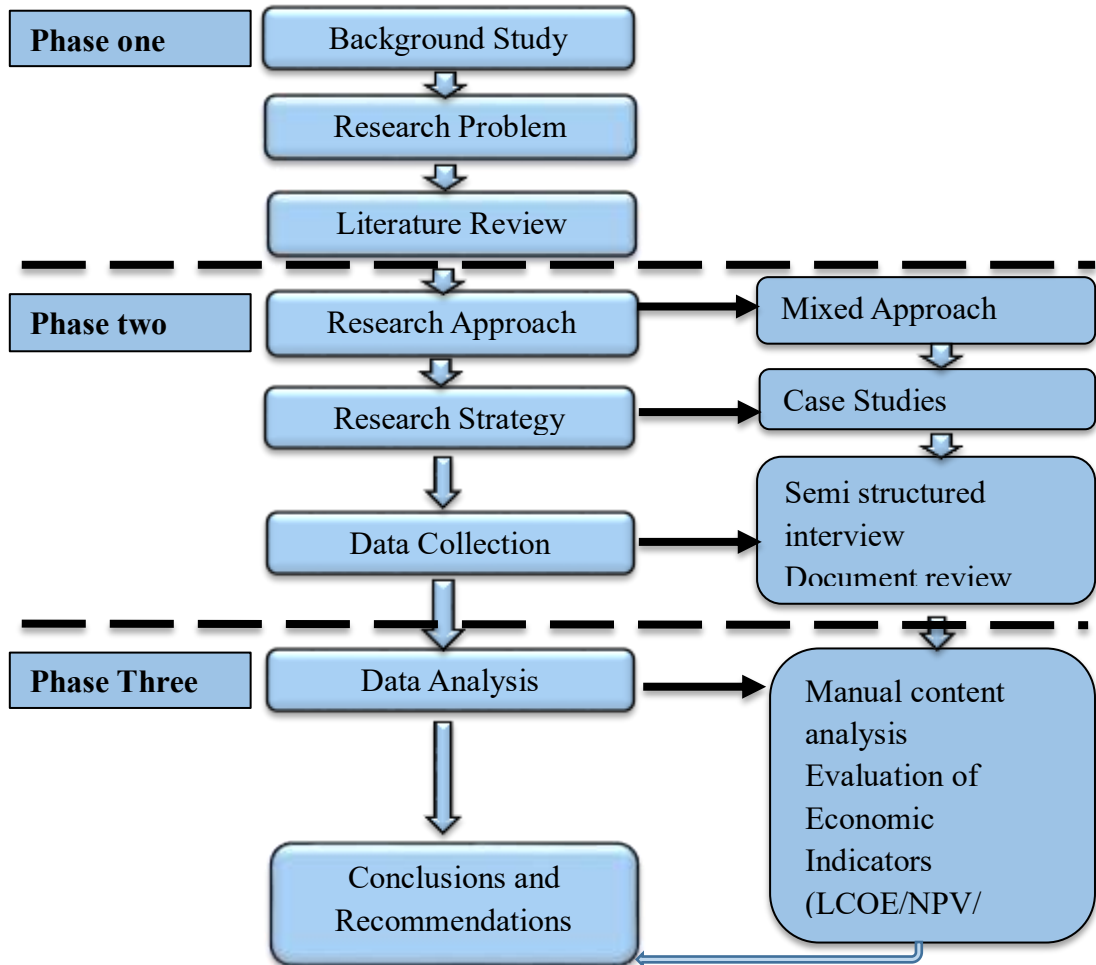


Figure 3.1: Research Process

3.3 Background Study

Initially a background study was carried out, which leads to determine the research problem of this study. Based on the research problem, aim and objectives of the study were developed. Through background study, it was identified that apparel manufacturing industry in Sri Lanka creates many environmental impacts and seeking to adopt renewable energy solutions to generate both environmental and economic benefits. Moreover, amongst available renewable energy solutions grid-tied PV technology has been gain interest of different sectors in Sri Lanka to gain benefits of solar energy. However, background study indicates that only few studies have

examined the economic suitability of grid-tied PV for generating electricity in Sri Lanka. In particular, the economic aspects such as economic benefits, challenges, strategies and economic gain of producing electricity with solar energy has not been addressed appropriately for apparel manufacturing industry. Therefore, this study aim to examine the economic evaluation of grid-tied PV technology in apparel manufacturing industry in Sri Lanka.

3.4 Literature Review

A comprehensive literature review was conducted align with the developed aim and objectives of the study. An in-depth review was carried out on grid-tied PV technology and applications of the system. Moreover, economic benefits, challenges and strategies of grid-tied PV system was identified in literature review. Hence, objective one (01) was achieved and this review provided a base to proceed with the research study.

3.5 Research Approach Adopted in this Study

The three (03) common approaches to conducting research are quantitative, qualitative, and mixed methods (Williams, 2011). Findings of a qualitative research acknowledged as a unique outcome for a certain setting and participants, which limits generalizing the final results to other settings (Jonassen, 2008). “Quantitative research is a method of research that relies on measuring variables using a numerical system, analyzing these measurements using any variety of statistical models, and reporting relationships and associations among the studied variables” (Zedeck, 2014). Bryman (2012) stated that quantitative research provide prominence on numbers and figures in collection and data analysis which reduce the time and effort of researcher on describing the results. In mixed method, researcher incorporate both quantitative and qualitative methods to answer particular research problem (Tariq & Woodman, 2013). This combination can be incorporated at any stage of the study or research process and such combination is important to mixed method research (Glogowska, 2010).

The aim of this research is to conduct an economic evaluation of grid-tied PV system for apparel manufacturing industry in Sri Lanka. In order to achieve the aforementioned aim, economic benefits, economic challenges and economic strategies of grid-tied PV for apparel manufacturing industry in Sri Lanka need to be identified.

Accordingly, it is necessary to understand the reality and different perspectives on economic benefits, challenges and strategies of grid-tied PV system for apparel manufacturing industry in Sri Lanka. Qualitative research tend to focus on every person's view on reality and welcome different perspectives of the participants to the study (Hancock et al., 2007). In qualitative research, participants' response generates a more in-depth understanding of the study (Rubin & Rubin, 2005). Thus, to achieve in-depth understanding of economic benefits, challenges and strategies, opinions and knowledge of professional expertise are required. Accordingly, it is required to include qualitative data collection and analysis methods to investigate economic benefits, challenges and strategies of grid-tied PV system in Sri Lanka.

Subsequently, calculation of economic gain of grid-tied PV for apparel manufacturing industry in Sri Lanka was conducted to achieve the ultimate aim. Thus, quantitative data collection and analysis methods are required to calculate the economic gain of grid-tied PV in Sri Lanka. Accordingly, both qualitative and quantitative research approaches should be incorporated to this study in order to address the research problem. As Creswell et al., (2017) explained main purpose of mixed method is to combine both qualitative and quantitative methods and achieve a better understanding of the research problem. Since this study seeking both quantitative and qualitative methods to address the research problem, it was agreed that mixed approach is best suited to the current study.

3.6 Research Strategy Adopted in this Study

Experiment, survey, case study, action research, grounded theory, ethnography and archival research were identified as main research strategies by Saunders, Lewis and Thornhill (2009). Experimental approach slowly forms laws of nature by testing theories or hypotheses (Bahari, 2010). The survey approach refers to a group of methods that emphasize quantitative analysis, in which data is collected and analyzed for a large number of organizations using statistical techniques (Gable, 1994). Action research or participatory action research is an approach frequently adopted for improving conditions and practices in a range healthcare environments (Kindon, Pain & Kesby, 2009). According to Dunne (2011) grounded theory is a method focused on the generation of theory. Ethnography method involves a direct observation of users

in a natural environment and particularly focus on social interactions (Allard & Anderson, 2005). Archival research is method involving primary sources held in an archives, a special collections library, or other repository (Ventresca & Mohr, 2017). Creswell (2009) explains case studies, in which the researcher explores in depth of a program, an event, an activity, a process, or one or more individuals and further case(s) are bounded by time and activity, and researchers collect detailed information using a variety of data collection procedures over a sustained period. As the study is intended to conduct an in-depth economic evaluation of grid-tied PV technology for apparel manufacturing industry, case study strategy was selected for the study.

Case studies are not necessarily qualitative and can also use an embedded quantitative studies (Gable, 1994). Mixed methods research particularly can be applied for case study research as it allows the researcher to take the rich empirical data produced from case studies where qualitative and quantitative data can be considered to extract meaning from the data sets that might otherwise be hidden (Mills, Durepos, & Wiebe, 2011). Simons (2009) defined case study as “an in-depth exploration from multiple perspectives of the complexity and uniqueness of a particular project, policy, institution, program or system in a real life context”. In order to perform economic evaluation of grid-tied PV for apparel manufacturing industry, an in-depth study of economic benefits, challenges, strategies and economic gain of the system is required. Therefore case study was selected as the research strategy to utilize in progressing with study. When carrying out case studies, it is important to determine the case study design.

3.6.1 Case study design

Case studies can be carried out as single or multiple case studies, in which single case studies are acceptable for rare or unique events and multiple case studies are preferred when similar or contrasting results due to predictable reasons are generated (Yin, 2013). In the current study, a multiple case study approach was selected to carry out the study as the results generated were not unique to a particular case and multiple case studies enhance the reliability of economic evaluation of grid-tied PV for apparel manufacturing industry.

- Selection of Cases

The main criterion considered in selecting cases was apparel manufacturing factories with grid-tied PV technology. According to Yin, (2009), the possible cases under case study could be fall in to two to four or at a maximum ten to fifteen. Accordingly four (04) factories were selected since there are only few apparel manufacturing factories in Sri Lanka that have utilized grid-tied PV system.

- Unit of Analysis and Case Boundary

Unit of analysis of a case study approach may be a project, process, an individual or an organization based on the requirements of a particular research (Yin, 2009). For the purpose of this research, economic gain was selected as unit of analysis under the case boundary of grid-tied PV in apparel manufacturing industry in Sri Lanka and illustrated in Figure 3.2.

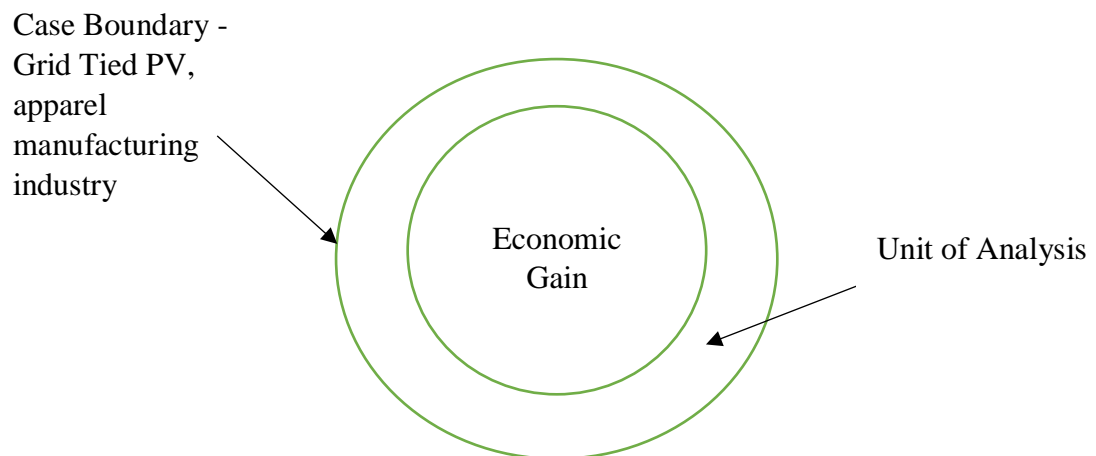


Figure 3.2: Unit of Analysis and Case Boundary

3.6.2 Data Collection Techniques

The primary aim in collecting data is to maximize the amount and accuracy of transfer of meaning from the provider to the researcher (Fellows & Liu, 2015). According to Yin (2016), several data collection techniques can be recognized under case studies approach such as interviews, observation and document review. Data collection of this study was based on document review and semi structured interviews.

3.6.2.1 Document Review

Document review involves the process of systematically evaluating the documents (Bowen, 2009). Accordingly, for this research electricity bill documents, records of solar PV system and power generation record documents of solar panels were reviewed. Additionally, system maintenance records were reviewed. Refer Appendix B to identify the data that were collected from document review.

3.6.2.2 Semi Structured Interviews

Punch (2005) highlighted interview method as one of the most commonly used data collection method when research embodies a qualitative approach. Further to author, semi-structured interview employs a blend of closed- and open-ended questions, often accompanied by follow-up why or how questions, which is suitable for gain insight and information. Accordingly, semi-structured interviews were selected and twelve interviews were conducted to collect data from selected cases. Further, three (03) respondents from each case was selected according to their role performed including one managerial level respondent, one senior electrical technician and one solar system project coordinator from the relevant solar company. In selecting respondents, the data collection of energy consumption and awareness of grid-tied PV technology was considered. The semi-structured data collection instrument is given in Appendix A and B.

3.6.3 Data Analysis Techniques

Wahyuni (2012) stated that content analysis is the common approach used to analyze qualitative data. Gathered qualitative data from case studies were analyzed using manual content analysis. Accordingly, economic benefits, challenges and strategies of case studies were analyzed using manual content analysis. Furthermore, quantitative data was analyzed based on evaluation of economic indicators. Thus, economic calculations were conducted by using Levelized Cost of Electricity (LCOE), Net Present Value (NPV) and Simple Payback Period (SPBP). Excel tool was used to analyze data regarding economic calculations. The equations used for the economic analysis are listed below.

Equation of LCOE

$$\text{LCOE} = \sum_{t=0}^T \frac{(It + Ot + Mt + Ft)}{(1+r)^t} \frac{1}{\sum_{t=0}^T St \frac{(1-d)^t}{(1+r)^t}} \quad (1)$$

Equation of NPV

$$\text{NPV} = \sum_{i=1}^N \frac{\text{income} - \text{cost}_i}{(1+r)^i} - I + \frac{R}{(1+r)^N} \quad (2)$$

Equation of yearly rated energy output

$$\text{Yearly Rated Energy output} = \frac{\text{System size (Watts)} \times \text{Peak Sunshine Hours} \times 365}{1000} \quad (3)$$

Equation of standard rated energy output

$$\text{Standard Rated} = \text{YREO per year per pane} \times \text{Number of Pnels} \quad (4)$$

3.6.4 Validation of Research Findings

The process of taking ideas, feedback and recommendations is considered as expert validation (Dorussen, Lenz, & Blavoukos, 2005). In order to obtain feedback and recommendation on the economic evaluation of grid-tied PV system, three (3) experts were interviewed. The final research findings were presented incorporating the recommendations made by the experts.

3.7 Summary

This chapter provides a detail view on research methodology carried out in this study. The research approach used to carry out the study was mixed approach. Under mixed approach, case study strategy was selected in order to get an in depth understanding on grid-tied PV system in terms of its economic benefits, challenges, strategies and economic gain. Interviews and document review were used in the selected cases in order to gather relevant data. Semi-structured data collection instrument was used to support this task. The collected data was then analyzed using manual content analysis and evaluation of economic indicators.

4 Data Analysis and Discussion

4.1 Introduction

This chapter presents analysis of the collected data. Case studies were used as the main data collection method. Four (04) apparel manufacturing buildings in Sri Lanka were selected for the case studies. Semi structured interviews and documents review were used for the selected cases as the key data collection techniques. Manual content analysis and evaluation of economic indicators were used to evaluate the collected data in order to draw conclusions.

4.2 Procedure adopted in analyzing case study data

The aim of this research is to assess the economic evaluation of grid-tied PV technology in apparel manufacturing industry in Sri Lanka. To achieve ultimate aim, the relevant data was collected and analyzed under case study method. Documents and interviews were used to compile the required data. Subsequently, collected data was analyzed based on manual content analysis and evaluation of economic indicators for the case studies. Case study and Interviewees profiles and documents reviewed are discussed in the following sections.

4.2.1 Case study profile

In the preceding chapter, criteria considered for selecting cases were addressed. Hence, four (04) apparel manufacturing buildings with grid-tied PV technology were selected in order to identify the economic benefits, challenges and strategies and to finally determine the economic gain of grid-tied PV for apparel manufacturing industry in Sri Lanka. The summary of the case study profile is presented in Table 4.1.

Table 4.1 indicates information of the selected plants under the criteria of location of the building, number of floors, number of staff, height of the building, roof area, material of the roof, electricity consuming services and operating hours of the building. Moreover, Table 4.1 illustrates the tariff categories of each selected facility, based on the categorization of Ceylon Electricity Board (CEB), Sri Lanka. As per Table 4.1, Case A, B and D were recognized under I-2 customer category. And Case C identified under I-3 customer category.

Table 4.1: Case Study Profile

Criteria	Case A	Case B	Case C	Case D
Location of the building	Wathupitiwala	Biyagama	Batticaloa	Colombo
Number of floors	01	01	01	03
Number of staff of the building	1500	500	3000	400
Height of the building (m)	3.6	3.6	3.6	6.1
Roof Area (m ²)	6553	6234	11,152	4125
Material used for the roof	Zinc Aluminum Roofing Sheet	Zinc Aluminum Roofing Sheet	Zinc Aluminum Roofing Sheet	Zinc Aluminum Roofing Sheet
Plant Operating Hours	8.00am – 5.30pm	8.00am – 5.30pm	6.00am-10.00 pm	8.00am – 5.30pm
Tariff Category	Customer category I – 2	Customer category I – 2	Customer category I - 3	Customer category I - 2

4.2.2 Profile of Interviewees

Two (02) interview guidelines were developed (Refer to Appendix A and B). The first interview guideline was structured in four (04) sections. Under Section 01, general information of the selected buildings were collected. Section 02 was structured to capture information of the solar PV system of the selected buildings. Under Section 03 and 04, costs and revenues associated with solar PV system of the selected buildings were investigated respectively. Second interview guideline was designed to collect data under three (03) main sections; (i) economic benefits of implementing grid-tied PV system, (ii) economic challenges of implementing grid-tied PV system and (iii)

economic strategies for implementing solar PV system. Three (03) respondents from each case was selected according to their role performed including one managerial level respondent, one senior electrical technician and one solar system project coordinator from the relevant solar company. In selecting respondents, awareness of grid-tied PV technology and access to cost and revenue data of the system were considered. And all the respondents were actively involved in the implementation and operation stages of the grid-tied PV system of each case study. The profile of respondents subjected to interviewing is presented in Table 4.2. The interview guidelines are attached as Appendix A and B for further reference.

Table 4.2: Profile of the Interviewees

Case Study	Respondents	Designation	Experience (years)
Case A	A1	Department head of Engineering Department	15
	A2	Assistant Engineer	5
	A3	Assistant Engineer - Solar Company	4
Case B	B1	Department head of Engineering Department	12
	B2	Assistant Engineer	6
	B3	Assistant Engineer - Solar Company	5
Case C	C1	Department head of Engineering Department	20
	C2	Assistant Engineer	5
	C3	Assistant Engineer - Solar Company	6
Case D	D1	Department head of Engineering Department	13
	D2	Assistant Engineer	5
	D3	Assistant Engineer - Solar Company	4

4.2.3 Documents Reviewed

Several documents have been reviewed to capture data of grid-tied PV systems attached to the selected case studies. Table 4.3 displays the documents reviewed and the respective purposes.

Table 4.3: Documents Reviewed

Documents reviewed	Purpose
Panel Layouts	To identify panel and inverter configurations (kWh)
Records of solar PV system	To identify technical details of grid-tied PV system of the selected facility
Power generation record of solar panels	To identify power generated by solar PV system (kWh)
Maintenance records of solar system	To capture maintenance activities performed on grid-tied PV system
Financial reports	To identify costs associated with implemented grid-tied PV system

4.3 Research Findings

The data collected from documents reviewed and interviews were analyzed in order to derive conclusions for the developed objectives of the study. Findings are presented under four (04) key sections. The key sections are economic evaluation, economic benefits, economic challenges and economic strategies. Economic evaluation of grid-tied

PV system is conducted using three (03) economic indicators. The three (03) key economic indicators are LCOE, NPV and SPP. In this study the method of calculating LCOE of the system is divided into six steps as listed below,

Step 1 – Calculate the initial cost of the system

Step 2 – Calculate the operation and maintenance costs of the system

Step 3 – Calculate the yearly rated energy output per panel

Step 4 – Determine the discount rate and degradation rate of the system

Step 5 – Determine the life of the grid-tied PV system

Step 06 – Substitute the variables into the LCOE formula

For each case study, the LCOE value of the grid-tied PV system is extracted using the above six (06) steps. Subsequently, NPV and SPP of grid-tied PV system is calculated under each case study. Finally identified economic benefits, challenges and strategies of grid-tied PV system based on selected case studies are presented. These sections elaborate identified economic benefits, challenges and proposed strategies of the grid-tied PV system for apparel manufacturing industry in Sri Lanka.

4.4 Economic Evaluation

Economic evaluation for the four (04) case studies are discussed in this section. Under each case study, the system configuration and calculation of key economic indicators such as LCOE, NPV and SPBP are presented.

4.4.1 Case A

Case A is a single-storey facility located at Wathupitiwala, Sri Lanka. This plant has total roof area of 6553m², which is utilized with roof mounted grid-tied PV system. According to the tariff category of Ceylon Electricity Board (CEB), this facility categorized under customer category I -2.

4.4.1.1 Configuration of grid-tied PV system

The capacity of the implemented system in Case A is 1095kWp and Figure 4.4 displays the installed roof mounted grid-tied PV system. Further detail about the grid-tied PV system in Case A is displayed in Table 4.4 under different criteria.



Figure 4.1: Roof-Mounted Grid-Tied PV System at Case A

Table 4.4: Grid-Tied PV System Information of Case A

Criteria	
Capacity of the system	1095kWp
Life span of the system	20 years
Year of installed	2019
PV module capacity	360W 365W
Number of Panels	360W – 1530 panels 365W - 1490 panels
Inverter capacity and number of inverters	60kW – 13 inverters
	50kW – 03 inverters
	20kW – 01 inverter
Solar panel configuration	Series
Type of module	Monocrystalline solar panels
Degradation Rate	0.55%
Tilt and Azimuth	$10^0/135^0$ and $10^0/-45^0$

Moreover, as displayed in Table 4.4, this system comprise of 17 inverters in total. This includes 13 inverters of 60kW, 03 inverters with 50kW and 01 inverter with 20kW capacities as presented in Table 4.4.

4.4.1.2 Economic Indicator 01 - Levelized cost of electricity (LCOE)

This is the first economic indicator used to assess the economic evaluation of grid-tied PV system in Case A. The listed six steps (Refer to Section 4.3) have been performed to extract the key variables of LCOE formula. The LCOE of the grid-tied PV system of Case A was subsequently determined by substituting variables to the formula.

Step 1 – Initial cost of the system

Initial cost of the system includes consultancy fee, panels and inverter cost, structural cost, electricity system cost, installation cost, transportation cost and additional costs of the system. The initial cost of Case A is presented in Table 4.5.

Table 4.5: Initial Cost of PV System in Case A

No.	Component	Quantity	Rate (Rs.)	Amount (Rs.)	
1.0	Consultancy Fee				
1.1	Consultancy Fee			136,828.80	136,828.80
2.0	Solar Panels				
2.1	360W Panels	1,530.00	29,404.80	44,989,344.00	
2.2	365W Panel	1,490.00	29,812.79	44,421,057.10	89,410,401.10
3.0	Solar Inverters				
3.1	STP60	13.00	1,410,512	18,336,656.00	
3.2	Core 1 50	3.00	1,272,677	3,818,031.00	
3.3	STP20	1.00	882,144	882,144.00	
3.4	Inverter Manager	2.00	459,450	918,900.00	
3.5	RainWise weather station	1.00	624,852	624,852.00	24,580,583.00
4.0	Structure				
4.1	Al –framework	3,010.00	3,491.82	10,510,378.20	
4.2	Walkways	3,010.00	3,124.26	9,404,022.60	
4.3	Access Ladder	1.00	91,890	91,890.00	20,006,290.80
5.0	Electrical System				
5.1	DC Cables	27,620.00	183.78	5,076,004.00	
5.2	AC Cables	1.00	1,745,910	1,745,910.00	
5.3	Surge arrestors – AC	1.00	73,512	73,512.00	
5.4	Surge arrestors – DC	27.00	29,404.8	793,929.60	
5.5	Other Electrical Components	1.00	735,120	735,120.00	
5.6	Increase in Panel board cost	1.00	275,670	275,670.00	8,700,145.60

No.	Component	Quantity	Rate (Rs.)	Amount (Rs.)	
6.0	Installation of the Structure and Panels & Electrical	3,010.00	4,962.06	14,935,800.60	14,935,800.60
7.0	Transportation	1.00	367,560	367,560.00	367,560.00
8.0	Skylights Removal	54.00	16,540.20	893,170.80	893,170.80
9.0	Plumbing System	1.00	367,560	367,560.00	367,560.00
TOTAL					159,398,340.70

According to Table 4.5, the initial cost of the grid-tied PV system of Case A indicates as Rs. 159,398,340.70. Considering the total initial cost, solar panels record the highest cost which is Rs. 89,410,401.10. Other cost components of the system includes consultancy fee, inverter costs, structure, electrical components and installation costs.

Step 2 – Calculate the operation and maintenance costs of the system

According to the respondents, industrial practice for estimating operation and maintenance cost is taken as 1% of the initial cost of the system. Accordingly, operation and maintenance cost identified as 1% of the initial cost per year in case A and the calculations are presented below.

Initial Cost of Case A = Rs. 159,398,340.70

Operation and maintenance costs per year = Rs. 159,398,340.70 x 0.01

= Rs. 1,593,983.40

Step 3 – Calculate the yearly rated energy output per panel

Yearly rated energy output per panel is calculated using the systems size in watts as well as the peak sunshine hours. Hence, yearly rated energy output and standard rated energy output are presented in Table 4.6.

Table 4.6: Yearly Rated Energy Output and Standard Rated Energy output of Case A

	Yearly Rated Energy Output (YREO) per panel per year	Standard Rated Energy Output (SREO)
Equation	$= \frac{\text{System size (Watts)} \times \text{Peak Sunshine Hours} \times 365}{1000}$	$= \text{YREO per year per pane} \times \text{Number of Pnels}$
YREO and SREO of 360W panels	$= \frac{(360 \times 4.5 \times 365)}{1000}$ = 591.3kWh	= 591.3 x 1530 = 904,689kWh
YREO and SREO of 365W panels	$= \frac{(365 \times 4.5 \times 365)}{1000}$ = 599.51kWh	= 599.51 x 1490 = 893,269.9kWh
Total SREO of the PV system (360W+ 365W)		1,797,958.9kWh

Firstly, yearly rated energy output per panel was calculated for the two types of panels installed in Case A i.e. 360W and 365W. Subsequently, standard rated energy output was calculated by considering the total number of PV modules of the system. As shown in Table 4.6, standard rated energy output of the system for a year indicates as 1,797,958.9kWh.

Step 4 – Determine the discount rate and degradation rate of the system

The next step of LCOE calculation is to determine the discount and degradation rate. According to the respondents from solar companies, the industrial practice for discount rate in Sri Lanka for solar market is considered as 10%. Therefore, in this study discount rate is considered as 10%. Further, the degradation rate of Case A identified as 0.55% and this is based on the PV modules manual of the solar manufacturer.

Discount Rate = 10%

Degradation Rate = 0.55%

Step 5 – Determine the life of the grid-tied PV system

In step 5, life span of the system was determined. And this data was collected from the respondents from each case study. It was determined that solar system has a 20 years of life span in all four case studies.

Life of the project = 20 years

Step 6 – Substitute the variables into the LCOE formula

This is the final step to determine the LCOE of Case A, which is to substitute variables into the LCOE formula. Table 4.7 indicates the variables of LCOE formula, along with respective values.

Table 4.7: Variables of LCOE Formula in Case A

Variables	Value
Initial Cost	Rs. 159,398,340.70
Operation and Maintenance Cost per year	Rs. 1,593,983.40
Standard rated energy output	1,797,958.9kWh
Discount Rate	10%
Degradation Rate	0.55%
Life of the Project	20 years

These values in Table 4.7 are derived from the previous steps under the subheading of LCOE calculation. Calculation table of LCOE for Case A is presented in Appendix C. Further to Appendix C, the initial cost, maintenance cost and standard rated energy output was calculated for each year and the derived values were substituted to Formula 1.

$$\text{LCOE} = \sum_{t=0}^T \frac{(It + Ot + Mt + Ft)}{(1+r)^t} \div \sum_{t=0}^T St \frac{(1-d)^t}{(1+r)^t} \quad (1)$$

$$= \text{Rs. } 172,968,819.941 / 14,692,349.98 \text{ kWh}$$

$$= \text{Rs. } 11.77/\text{kWh}$$

As per the calculation of the LCOE for Case A, the final value indicates as Rs. 11.77/kWh. Accordingly, considering the life time cost of solar PV system of Case A, the unit cost of generated solar power of the installed system shown as Rs. 11.77 for a kWh.

4.4.1.3 Economic Indicator 02 - Net present value (NPV)

In order to calculate NPV, it is required to identify the produced energy of the solar PV system throughout the life span. The energy production of the solar PV system was determined by the data simulation.

- Simulation and results

The simulation calculates the distributed energy throughout the year. Primary inputs of simulation are number of PV modules orientations and kinds of PV arrays. According to Table 4.4, PV modules of Case A has two different azimuths: 100/1350 and 100/-450. Therefore, two (02) key orientations of solar PV modules have been identified. Under PV array characteristics, eight (08) kinds of arrays has been determined based on PV module capacity and orientation. Accordingly data simulation has been carried out and identified generations are listed in Table 4.8. Simulation reports are attached in the Appendix D. The produced energy and the amount in Rs. is presented in Table 4.8. According to Table 4.8, there is a decrease in energy generation over the life span due to the collection loss and system of loss of the grid-tied PV system.

Table 4.8: Produced Energy of Case A

Year	Units (kWh)	Amount (Rs.)
0		
1	1559000	34,298,000.00
2	1555000	34,210,000.00
3	1547000	34,034,000.00
4	1538000	33,836,000.00
5	1529000	33,638,000.00
6	1520000	33,440,000.00

Year	Units (kWh)	Amount (Rs.)
7	1509000	33,198,000.00
8	1499000	23,234,500.00
9	1487000	23,048,500.00
10	1476000	22,878,000.00
11	1464000	22,692,000.00
12	1452000	22,506,000.00
13	1439000	22,304,500.00
14	1426000	22,103,000.00
15	1414000	21,917,000.00
16	1401000	21,715,500.00
17	1390000	21,545,000.00
18	1380000	21,390,000.00
19	1370000	21,235,000.00
20	1360000	21,080,000.00
Total	29315000 kWh	Rs. 524,303,000.00
Average produced energy per year	1,465,750.00 kWh/ year	Rs. 26,215,150.00/ year

Table 4.9 displays the net present value calculations of Case A. In Table 4.9 the initial cost and maintenance cost were derived from the LCOE calculation. And net earning determined by the produced energy calculated in Table 4.8. As displayed in Table 4.9 net cash flow is determined by deducting initial and maintenance and operation cost by net earnings of the system. Finally, net present value of the system indicates as Rs. 73,490,986.93 as presented in Table 4.9.

Table 4.9: Net Present Value of Case A

yr.	Initial Cost (Rs.)	Maintenance Cost (Rs.)	Net Earnings (Rs.)	Net Cash Flow (Rs.)	Discount Rate (1+r) ^t	Net Present Value (Rs.)
0	159,398,340.70	-	-	(159,398,340.70)	1.000000	(159,398,340.70)
1		1,593,983.40	34,298,000.00	32,704,016.60	1.100000	29,730,924.18
2		1,593,983.40	34,210,000.00	32,616,016.60	1.210000	26,955,385.62
3		1,593,983.40	34,034,000.00	32,440,016.60	1.331000	24,372,664.61
4		1,593,983.40	33,836,000.00	32,242,016.60	1.464100	22,021,731.17
5		1,593,983.40	33,638,000.00	32,044,016.60	1.610510	19,896,813.18
6		1,593,983.40	33,440,000.00	31,846,016.60	1.771561	17,976,246.15
7		1,593,983.40	33,198,000.00	31,604,016.60	1.948717	16,217,857.69
8		1,593,983.40	23,234,500.00	21,640,516.60	2.143589	10,095,460.71
9		1,593,983.40	23,048,500.00	21,454,516.60	2.357948	9,098,809.39
10		1,593,983.40	22,878,000.00	21,284,016.60	2.593742	8,205,909.77
11		1,593,983.40	22,692,000.00	21,098,016.60	2.853117	7,394,726.11
12		1,593,983.40	22,506,000.00	20,912,016.60	3.138428	6,663,212.95
13		1,593,983.40	22,304,500.00	20,710,516.60	3.452271	5,999,098.94
14		1,593,983.40	22,103,000.00	20,509,016.60	3.797498	5,400,665.07
15		1,593,983.40	21,917,000.00	20,323,016.60	4.177248	4,865,168.59
16		1,593,983.40	21,715,500.00	20,121,516.60	4.594973	4,379,028.27
17		1,593,983.40	21,545,000.00	19,951,016.60	5.054470	3,947,202.27
18		1,593,983.40	21,390,000.00	19,796,016.60	5.559917	3,560,487.59
19		1,593,983.40	21,235,000.00	19,641,016.60	6.115909	3,211,463.16
20		1,593,983.40	21,080,000.00	19,486,016.60	6.727500	2,896,472.20
NPV						Rs.73,490,986.93

4.4.1.4 Economic Indicator 03 - Simple payback period

Simple payback of Case A is displayed in Table 4.10. Initial cost and net cash flow of the project were considered to calculate simple payback of the system. According to Table 4.10, simple payback period of Case A indicates as four years and eleven months.

Table 4.10: Simple Payback Period of Case A

Year	Initial Cost (Rs.)	Net Cash Flow (Rs.)	Investment Recovery
0	159,398,340.70	(159,398,340.70)	(159,398,340.70)
1		32,704,016.60	(126,694,324.10)
2		32,616,016.60	(94,078,307.50)
3		32,440,016.60	(61,638,290.90)
4		32,242,016.60	(29,396,274.30)
5		32,044,016.60	2,647,742.30
6		31,846,016.60	34,493,758.90
7		31,604,016.60	66,097,775.50
8		21,640,516.60	87,738,292.10
9		21,454,516.60	109,192,808.70
10		21,284,016.60	130,476,825.30
11		21,098,016.60	151,574,841.90
12		20,912,016.60	172,486,858.50
13		20,710,516.60	193,197,375.10
14		20,509,016.60	213,706,391.70
15		20,323,016.60	234,029,408.30
16		20,121,516.60	254,150,924.90
17		19,951,016.60	274,101,941.50
18		19,796,016.60	293,897,958.10
19		19,641,016.60	313,538,974.70
20		19,486,016.60	333,024,991.30
SPBP			04 years and 11 months

4.4.1.5 Summary of economic evaluation

Table 4.11 displays the summary of economic evaluation of Case A grid-tied PV system. According to Table 4.11, system capacity of Case A is 1095kWp and its initial cost presented as Rs. 159,398,340.70. Considering the SPBP, investment of the system can be recovered within four (04) years and eleven (11) months. As discussed in Table 4.4, the expected life span of the PV system is twenty years (20) and as per the SPBP,

after four years the generated earnings of the system will exceed the initial cost of the system.

Table 4.11: Summary of Economic Evaluation of Case A

Criteria	Value
System Capacity	1095kWp
Initial Cost	Rs. 159,398,340.70
Standard rated energy output per year	Rs. 1,797,958.9kWh
Average produced Energy per year (units)	1,465,750.00kWh
Average produced Energy per year (amount)	Rs. 26,215,150.00
LCOE	Rs. 11.77/kWh
NPV	Rs. 73,490,986.93
SPBP	04 years and 11 months

Further to Table 4.11, the NPV of the system is Rs. 73,490,986.93. A positive NPV value for the system indicates that investment in grid-tied PV system for Case A is generally profitable. According to Table 4.11, the system expect an average energy production of 1,465,750.00kWh per year and this generates an income of Rs. 26,215,150.00 per year for Case A.

LCOE of 1095kWp system shall be at Rs. 11.77/kWh as shown in Table 4.11. The export tariff in Sri Lanka for solar energy is Rs. 22.00/kWh for the first seven (07) years and Rs. 15.5/kWh from year eight up to contract period of 20 years. Considering LCOE of Case A, the unit cost of produced solar energy is 11.77/kWh, which is lesser than the earning received from CEB for a unit ; Rs. 22.00/kWh . Therefore, the Case A grid tied PV system capable of generating a profit of Rs. 10.23/kWh (Rs. 22.00 – 11.77) in first seven years. And after 8th year Case A capable of generating a profit of Rs. 3.73/kWh (Rs. 15.50 – 11.77) up to the contract period of 20 years. Accordingly, the economic analysis of Case A indicates that implemented system is an indeed a gain as a result of low unit cost, quick investment recovery and positive NPV.

4.4.2 Case B

Case B is a single-storey facility located at Biyagama, Sri Lanka. This plant has total roof area of 6234m² which is utilized with roof mounted grid-tied PV system. According to the tariff category of Ceylon Electricity Board (CEB), this facility categorized under customer category I -2.

4.4.2.1 Configuration of grid-tied PV system

The capacity of the implemented system in Case B is 819 kWp and mounted system is displayed in Figure 4.2. Furthermore, detail about the grid-tied PV system in Case B is displayed in Table 4.12.



Figure 4.2: Roof-Mounted Grid-Tied PV System of Case B

Table 4.12: Grid-Tied PV System Information of Case B

Criteria	
Capacity of the system	819 kWp
Life span of the system	20 years
Year of installed	2019
PV module capacity	370W
Number of Panels	2214
Inverter capacity and number of inverters	60kW – 10 Inverters
	50kW – 02 Inverters
Solar panel configuration	Series
Type of module	Monocrystalline solar panels
Degradation Rate	0.55%
Tilt and Azimuth	10 ⁰ /-135 ⁰ and 10 ⁰ /45 ⁰

According to Table 4.12, the Case B has installed grid-tied 819 kWp solar PV system that implemented in 2019 with an expected life span of 20 years. Therefore, the system has 370W Monocrystalline solar panels, which have been connected in series. As per Table 4.12, this system has 10 inverters of 60kW capacity and 02 inverters of 50kW capacity.

4.4.2.2 Economic Indicator 01 - Levelized cost of electricity (LCOE)

Similar to Case A, six steps have been performed to extract the key variables of LCOE formula in Case B. The LCOE of the grid-tied PV system of Case B was subsequently determined by substituting variables to the Formula.

Step 1 – Initial cost of the system

Table 4.13 displays the initial cost of the system implemented in Case B. Accordingly, initial cost of the system calculated as Rs. 119,714,333.23. As per Table 4.13, cost of solar panels record the highest cost, which is 66,912,882.89.

Table 4.13: Initial Cost of PV system in Case B

No	Description	Quantity	Rate	Amount (Rs.)	
1.0	Consultancy Fee				
1.1	Consultancy Fee				102,397.50
2.0	Solar Panels				
2.1	Solar Panels Longi 370W Mono Perc (panels)	2214	30,222.621	66,912,882.89	66,912,882.89
3.0	Solar Inverters				
3.1	STP60	10.00	1,410,511.50	14,105,115.00	
3.2	Core 1 50	2.00	1,272,676.50	2,545,353.00	
3.3	Inverter Manager	1.00	459,450.00	459,450.00	
3.4	RainWise weather station	1.00	624,852.00	624,852.00	17,734,770.00
4.0	Structure				
4.1	Al –framework	2,214.00	3,491.82	7,730,889.48	
4.2	Walkways	2,214.00	3,124.26	6,917,111.64	
4.3	Access Ladder	2.00	91,890.00	183,780.00	14,831,781.12

No	Description	Quantity	Rate	Amount (Rs.)	
5.0	Electrical System				
5.1	DC Cables (m)	25,000.00	183.78	4,594,500.00	
5.2	AC Cables (m)	1.00	2,021,580.00	2,021,580.00	
5.5	Surge arrestors – AC	1.00	73,512.00	73,512.00	
5.6	Surge arrestors –DC	18.00	29,404.80	529,286.40	
5.8	Other Electrical Components	1.00	793,699.88	793,699.88	
5.9	Increase in Panel board cost	1.00	275,670.00	275,670.00	8,288,248.28
6.0	Installation of the Structure and Panels & Electrical	2,214.00	4,962.06	10,986,000.84	10,986,000.84
7.0	Transportation	1.00	367,560.00	367,560.00	367,560.00
8.0	Skylights Removal	13.00	16,540.20	215,022.60	215,022.60
9.0	Plumbing System	1.00	275,670.00	275,670.00	275,670.00
TOTAL				119,714,333.23	

Step 2 – Calculate the operation and maintenance costs of the system

According to the respondents, industrial practice for estimating operation and maintenance cost is taken as 1% of the initial cost of the system. Accordingly, operation and maintenance cost identified as 1% of the initial cost per year in case B and the calculations are presented below.

Initial Cost of the System = Rs. 119,714,333.23

Operation and maintenance costs per year = 119,714,333.23 x 0.01

= Rs. 1,197,143.33

Step 3 – Calculate the yearly rated energy output per panel

Yearly rated energy output per panel is calculated using the systems size in watts as well as the peak sunshine hours. Hence, yearly rated energy output and standard rated energy output are presented in Table 4.14. Firstly, yearly rated energy output per panel was calculated for the 370W panel installed in Case B. Subsequently, standard rated

energy output was calculated by considering the total number of PV modules of the system. As shown in Table 4.14, standard rated energy output of the system for a year indicates as 1,345,503.15kWh.

Table 4.14: Yearly Rated Energy Output and Standard Rated Energy output of Case B

	Yearly Rated Energy Output (YREO) per panel per year	Standard Rated Energy Output (SREO)
Equation	$= \frac{\text{System size (Watts)} \times \text{Peak Sun}}{1000}$	$= \text{YREO per year per pane} \times N$
YREO and SREO of 370W panels	$= \frac{(370 \times 4.5 \times 365)}{1000}$ $= 607.725\text{kWh}$	$= 607.725 \times 2214$ $= 1,345,503.15\text{kWh}$
Total SREO of the PV system		1,345,503.15kWh

Step 4 – Determine the discount rate and degradation rate of the system

The next step of LCOE calculation is to determine the discount and degradation rate. As mentioned in Case A, the respondents from solar companies, the industrial practice for discount rate in Sri Lanka for solar market is considered as 10%. Therefore, in this study discount rate is considered as 10%. Further, the degradation rate of Case B identified as 0.55% and this is based on the PV modules manual of the solar manufacturer.

Discount Rate = 10%

Degradation Rate = 0.55%

Step 5 – Determine the life of the grid-tied PV system

The respondents of Case B mentioned life span of grid-tied PV system as 20 years.

Life of the project = 20 years

Step 6 – Substitute the variables into the LCOE formula

This is the final step to determine the LCOE of Case B, which is to substitute variables into the LCOE formula. Table 4.15 indicates the variables of LCOE formula, along with respective values. These values are derived from the previous steps under the subheading of LCOE calculation.

Table 4.15: Variables of LCOE Formula in Case B

Variables	Value
Initial Cost	Rs. 119,714,333.23
Operation and Maintenance Cost per year	Rs. 1,197,143.33
Standard rated energy output	1,345,503.15kWh
Discount Rate	10%
Degradation Rate	0.55%
Life of the Project	20 years

Calculation table of LCOE for Case B is presented in Appendix C. Further to Appendix C, the initial cost, maintenance cost and standard rated energy output was calculated for each year and the derived values were substituted to Formula 1.

$$LCOE = \sum_{t=0}^T \frac{(It + Ot + Mt + Ft)}{(1+r)^t} \quad (1)$$

$$\frac{\sum_{t=0}^T St \frac{(1-d)^t}{(1+r)^t}}{\sum_{t=0}^T St \frac{(1-d)^t}{(1+r)^t}}$$

= Rs. 129,906,289.25 / 10,995,025.07 kWh

= **Rs. 11.82/ kWh**

As per the calculation of the LCOE for Case B, the final value indicates as Rs. 11.82/ kWh. Accordingly, considering the life time cost of solar PV system of Case B, the unit cost of generated solar power of the installed system shown as Rs. 11.82 for a kWh.

4.4.2.3 Economic Indicator 02 - Net present value (NPV)

In order to calculate NPV, it is required to identify the produced energy of the solar PV system throughout the life span. The energy production of the solar PV system was determined by the data simulation.

- Simulation and results

Table 4.16: Produced Energy of Case B

Year	Units (kWh)	Amount (Rs.)
0	-	-
1	1187000	26,114,000.00
2	1183000	26,026,000.00
3	1177000	25,894,000.00
4	1171000	25,762,000.00
5	1164000	25,608,000.00
6	1156000	25,432,000.00
7	1148000	25,256,000.00
8	1139000	17,654,500.00
9	1130000	17,515,000.00
10	1120000	17,360,000.00
11	1111000	17,220,500.00
12	1101000	17,065,500.00
13	1092000	16,926,000.00
14	1083000	16,786,500.00
15	1074000	16,647,000.00
16	1065000	16,507,500.00
17	1057000	16,383,500.00
18	1050000	16,275,000.00
19	1043000	16,166,500.00
20	1036000	16,058,000.00
Total	22287000 kWh	Rs. 398,657,500.00
Average produced energy per year	1,114,350kWh/ year	Rs. 19,932,875.00 / year

According to Table 4.12, PV modules of Case B has two different azimuths: 100/-1350 and 100/450. Therefore, two (02) key orientations of solar PV modules have been identified. Under PV array characteristics, five (05) kinds of arrays has been determined based on PV module capacity and orientation.

Table 4.17: Net Present Value of Case B

Yr	Initial Cost (Rs.)	Maintenance Cost (Rs.)	Net Earnings (Rs.)	Net Cash Flow (Rs.)	Discount Rate $(1+r)^t$	Net Present Value (Rs.)
0	119,714,333.23	-	-	(119,714,333.23)	1.000000	(119,714,333.23)
1		1,197,143.33	26,114,000.00	24,916,856.67	1.100000	22,651,687.88
2		1,197,143.33	26,026,000.00	24,828,856.67	1.210000	20,519,716.26
3		1,197,143.33	25,894,000.00	24,696,856.67	1.331000	18,555,113.95
4		1,197,143.33	25,762,000.00	24,564,856.67	1.464100	16,778,127.63
5		1,197,143.33	25,608,000.00	24,410,856.67	1.610510	15,157,221.42
6		1,197,143.33	25,432,000.00	24,234,856.67	1.771561	13,679,944.79
7		1,197,143.33	25,256,000.00	24,058,856.67	1.948717	12,345,997.62
8		1,197,143.33	17,654,500.00	16,457,356.67	2.143589	7,677,478.35
9		1,197,143.33	17,515,000.00	16,317,856.67	2.357948	6,920,364.15
10		1,197,143.33	17,360,000.00	16,162,856.67	2.593742	6,231,480.93
11		1,197,143.33	17,220,500.00	16,023,356.67	2.853117	5,616,088.76
12		1,197,143.33	17,065,500.00	15,868,356.67	3.138428	5,056,147.46
13		1,197,143.33	16,926,000.00	15,728,856.67	3.452271	4,556,089.51
14		1,197,143.33	16,786,500.00	15,589,356.67	3.797498	4,105,164.85
15		1,197,143.33	16,647,000.00	15,449,856.67	4.177248	3,698,572.85
16		1,197,143.33	16,507,500.00	15,310,356.67	4.594973	3,331,979.69
17		1,197,143.33	16,383,500.00	15,186,356.67	5.054470	3,004,539.71
18		1,197,143.33	16,275,000.00	15,077,856.67	5.559917	2,711,885.06
19		1,197,143.33	16,166,500.00	14,969,356.67	6.115909	2,447,609.43
20		1,197,143.33	16,058,000.00	14,860,856.67	6.727500	2,208,971.65
NPV						Rs. 57,539,848.71

Accordingly data simulation has been carried out and identified generations are listed in Table 4.16. Simulation reports are attached in the appendix C. The produced energy and the amount in Rs. is presented in Table 4.16. Table 4.17, presents NPV of Case B. In Table 4.17 the initial cost and maintenance cost were derived from the LCOE

calculation. And net earnings determined by the produced energy calculated in Table 4.16. As displayed in Table 4.17 net cash flow is determined by deducting initial and maintenance and operation cost by net earnings of the system. Finally, net present value of the system indicates as Rs. 57,539,848.71

4.4.2.4 Economic Indicator 03 - Simple payback period (SPBP)

Table 4.18: Simple Payback Period of Case B

Year	Initial Cost (Rs)	Net Cash Flow (KW)	Investment Recovery
0	119,714,333.23	(119,714,333.23)	(119,714,333.23)
1		24,916,856.67	(94,797,476.56)
2		24,828,856.67	(69,968,619.89)
3		24,696,856.67	(45,271,763.22)
4		24,564,856.67	(20,706,906.55)
5		24,410,856.67	3,703,950.12
6		24,234,856.67	27,938,806.79
7		24,058,856.67	51,997,663.46
8		16,457,356.67	68,455,020.13
9		16,317,856.67	84,772,876.80
10		16,162,856.67	100,935,733.47
11		16,023,356.67	116,959,090.14
12		15,868,356.67	132,827,446.81
13		15,728,856.67	148,556,303.48
14		15,589,356.67	164,145,660.15
15		15,449,856.67	179,595,516.82
16		15,310,356.67	194,905,873.49
17		15,186,356.67	210,092,230.16
18		15,077,856.67	225,170,086.83
19		14,969,356.67	240,139,443.50
20		14,860,856.67	255,000,300.17
SPBP			04 years and 10 months

Table 4.18 presents the simple payback period of Case B. Net cash flows of the system was used to calculate the SPBP, as shown in Table 4.18. According to the Table 4.18 the investment on grid-tied PV system of Case B can be recovered by 04 years and 10 months.

4.4.2.5 Summary of economic evaluation

Table 4.19 displays the summary of economic evaluation of Case B grid-tied PV system. According to Table 4.19, system capacity of Case B is 819 kWp and its initial cost presented as Rs. 119,714,333.23. Considering the SPBP, investment of the system can be recovered within four (04) years and ten (10) months. As discussed in Table 4.12, the expected life span of the PV system is twenty years (20) and as per the SPBP, after four years the generated earnings of the system will exceed the initial cost of the system. Further to Table 4.19, the NPV of the system is Rs. 57,539,848.71. A positive NPV value for the system indicates that investment in grid-tied PV system for Case B is generally profitable. According to Table 4.19, the system expect an average energy production of 1,114,350kWh per year and this generates an income of Rs. 19,932,875.00 per year for Case B.

Table 4.19: Summary of Economic Evaluation of Case B

Criteria	Value
System Capacity	819 kWp
Initial Cost	Rs. 119,714,333.23
Standard rated energy output per year	1,345,503.15kWh
Average produced Energy per year (units)	1,114,350kWh
Average produced Energy per year (amount)	Rs. 19,932,875.00 / year
LCOE	Rs. 11.82/ kWh
NPV	Rs. 57,539,848.71
SPBP	04 years and 10 months

LCOE of 819 kWp system shall be at Rs. 11.82/kWh as shown in Table 4.19. The export tariff in Sri Lanka for solar energy is Rs. 22.00/kWh for the first seven (07) years and Rs. 15.50/kWh for the remaining period. Considering LCOE of Case B, it is lesser than the earning received from CEB for a unit ; Rs. 22.00/kWh . Therefore, the

Case B grid tied PV system capable of generating a profit of Rs. 10.18/kWh (Rs. 22.00 – 11.82) in first seven years. And after 8th year Case B capable of generating a profit of Rs. 3.68/kWh (Rs. 15.50 – 11.82) up to the contract period of 20 years. Accordingly, the economic analysis of Case B indicates that implemented system is an indeed a gain as a result of low unit cost, quick investment recovery and positive NPV.

4.4.3 Case C

Case C is a single-storey facility located at Batticaloa, Sri Lanka. This plant has total roof area of 11,152m², which is utilized with roof mounted grid-tied PV system. According to the tariff category of Ceylon Electricity Board (CEB), this facility categorized under customer category I -3, as shown in Table 4.1.

4.4.3.1 Configuration of grid-tied PV system

The capacity of the implemented system in Case C is 1648kWp and Figure 4.3 displays the mounted system in Case C. The system was implemented in 2018, which has 4920 panels attached to the grid. Furthermore detail about the grid-tied PV system in Case C is displayed in Table 4.20.



Figure 4.3: Roof-Mounted Grid-Tied PV System at Case C

Table 4.20: Grid-Tied PV System Information of Case C

Criteria	
Capacity of the system	1648kWp
Life span of the system	20 years
Year of installed	2018
PV module capacity	335W
Number of Panels	4920
Inverter capacity and number of inverters	60kW – 25 Inverters
Solar panel configuration	Series
Type of module	Monocrystalline solar panels
Degradation Rate	0.7%
Tilt and azimuth	10 ⁰ /0 ⁰ and 10 ⁰ /180 ⁰

According to Table 4.20, the Case C has installed grid-tied 1648kWp solar PV system, which implemented in 2018 with an expected life span of 20 years. Furthermore, the system has 335W Monocrystalline solar panels, which have been connected in series. There are 25 inverters with 60kW capacity in Case C, as shown in Table 4.20.

4.4.3.2 Economic Indicator 01 - Levelized cost of electricity (LCOE)

The listed six steps have been performed to extract the key variables of LCOE formula. The LCOE of the grid-tied PV system of Case C was subsequently determined by substituting variables to the formula.

Step 1 – Initial cost of the system

Table 4.21 presents total initial cost of Case C. According to Table 4.21 initial cost of Case C is 239,350,664.18. And solar panels records the highest cost, which is Rs. 133,821,244.8, as per Table 4.21.

Table 4.21: Initial Cost of PV System in Case C

No	Description	Quantity	Rate (Rs.)	Amount (Rs.)	
1.0	Consultancy Fee				
1.1	Consultancy Fee				206,250.00
2.0	Solar Panels				
2.1	Longi 335W Mono Perc (panels)	4920	27,199.44	133,821,244.80	133,821,244.8
3.0	Solar Inverters				
3.1	STP60	25.00	1,410,511.50	35,262,787.50	
3.3	Inverter Manager	1.00	459,450.00	459,450.00	
3.4	RainWise weather station	1.00	624,852.00	624,852.00	36,347,089.50
4.0	Structure				
4.1	Al –framework	5,000.00	3,491.82	17,459,100.00	
4.2	Walkways	5,000.00	3,124.26	15,621,300.00	
4.3	Access Ladder	2.00	91,890.00	183,780.00	33,264,180.00
5.0	Electrical System				
5.1	DC Cables (m)	28,000.00	183.78	5,145,840.00	
5.2	AC Cables (m)	1.00	2,021,580.00	2,021,580.00	
5.5	Surge arrestors – AC	28,000.00	183.78	5,145,840.00	
5.6	Surge arrestors –DC	1.00	2,021,580.00	2,021,580.00	
5.8	Other Electrical Components	1.00	793,699.88	793,699.88	
5.9	Increase in Panel board cost	1.00	275,670.00	275,670.00	10,258,369.88
6.0	Installation of the Structure and Panels & Electrical	5,000.00	4,962.06	24,810,300.00	24,810,300.00
7.0	Transportation	1.00	367,560.00	367,560.00	367,560.00
8.0	Plumbing System	1.00	275,670.00	275,670.00	275,670.00
TOTAL					239,350,664.18

Step 2 – Calculate the operation and maintenance costs of the system

According to the respondents of case, industrial practice for estimating operation and

maintenance cost is taken as 1% of the initial cost of the system. Accordingly, operation and maintenance cost identified as 1% of the initial cost per year in case C and the calculations are presented below.

Initial Cost of the System = Rs. 239,350,664.18

Operation and maintenance costs per year = 239,350,664.18 x 0.01

= Rs. 2,393,506.64

Step 3 – Calculate the yearly rated energy output per panel

Yearly rated energy output per panel is calculated using the systems size in watts as well as the peak sunshine hours. Hence, yearly rated energy output and standard rated energy output are presented in Table 4.22. Firstly, yearly rated energy output per panel was calculated for the 335W panel installed in Case C. Subsequently, standard rated energy output was calculated by considering the total number of PV modules of the system. As shown in Table 4.22, standard rated energy output of the system for a year indicates as 2,707,168.5 kWh.

Table 4.22: Yearly Rated Energy Output and Standard Rated Energy output of Case C

	Yearly Rated Energy Output (YREO) per panel per year	Standard Rated Energy Output (SREO)
Equation	$= \frac{\text{System size (Watts)} \times \text{Peak Sun}}{1000}$	$= \text{YREO per year per pane} \times \text{N}$
YREO and SREO of 335W panels	$= \frac{(335 \times 4.5 \times 365)}{1000}$ $= 550.2375\text{kWh}$	$= 550.2375 \times 4920$ $= 2,707,168..5$
Total SREO of the PV system		2,707,168.5kWh

Step 4 – Determine the discount rate and degradation rate of the system

The next step of LCOE calculation is to determine the discount and degradation rate. As mentioned in Case A and B, the respondents from solar companies, the industrial practice for discount rate in Sri Lanka for solar market is considered as 10%. Therefore, in this study discount rate is considered as 10%. Further, the degradation

rate of Case C identified as 0.7% and this is based on the PV modules manual of the solar manufacturer.

Discount Rate = 10%

Degradation Rate = 0.7%

Step 5 – Determine the life of the grid-tied PV system

The respondents of Case C mentioned life span of grid-tied PV system as 20 years.

Life of the project = 20 years

Step 6 – Substitute the variables into the LCOE formula

This is the final step to determine the LCOE of Case C, which is to substitute variables into the LCOE formula. Table 4.23 indicates the variables of LCOE formula, along with respective values. These values are derived from the previous steps under the subheading of LCOE calculation. Calculation table of LCOE for Case C is presented in Appendix C. Further to Appendix C, the initial cost, maintenance cost and standard rated energy output was calculated for each year and the derived values were substituted to Formula 1. As per the calculation of the LCOE for Case C, the final value indicates as Rs. 11.87/ kWh. Accordingly, considering the life time cost of solar PV system of Case C, the unit cost of generated solar power of the installed system shown as Rs. 11.87 for a kWh.

Table 4.23: Variables of LCOE Formula of Case C

Variables	Value
Initial Cost	Rs. 239,350,664.18
Operation and Maintenance Cost per year	Rs. 2,393,506.64
Standard rated energy output	2,707,168.5kWh
Discount Rate	10%
Degradation Rate	0.7%
Life of the Project	20 years

$$LCOE = \sum_{t=0}^T \frac{(It + Ot + Mt + Ft)}{(1+r)^t} \frac{1}{\sum_{t=0}^T St \frac{(1-d)^t}{(1+r)^t}} \quad (1)$$

$$= \text{Rs. } 259,727,935.47 / 21,878,555.70 \text{ kWh}$$

$$= \text{Rs. } 11.87 / \text{kWh}$$

4.4.3.3 Economic Indicator 02 - Net present value (NPV)

In order to calculate NPV, it is required to identify the produced energy of the solar PV system throughout the life span. The energy production of the solar PV system determined by the data simulation.

- Simulation and results

Table 4.24: Produced Energy of Case C

Year	Units (kWh)	Amount (Rs.)
0		
1	2,365,000.00	52,030,000.00
2	2,357,000.00	51,854,000.00
3	2,340,000.00	51,480,000.00
4	2,324,000.00	51,128,000.00
5	2,307,000.00	50,754,000.00
6	2,288,000.00	50,336,000.00
7	2,269,000.00	49,918,000.00
8	2,249,000.00	34,859,500.00
9	2,228,000.00	34,534,000.00
10	2,206,000.00	34,193,000.00
11	2,206,000.00	34,193,000.00
12	2,162,000.00	33,511,000.00
13	2,139,000.00	33,154,500.00
14	2,116,000.00	32,798,000.00
15	2,094,000.00	32,457,000.00
16	2,072,000.00	32,116,000.00

Year	Units (kWh)	Amount (Rs.)
17	2,052,000.00	31,806,000.00
18	2,034,000.00	31,527,000.00
19	2,017,000.00	31,263,500.00
20	1,999,000.00	30,984,500.00
Total	43,824,000.00 kWh	Rs. 784,897,000.00
Average produced energy per year	2,191,200.00 kWh/ year	Rs. 39,244,850.00 / year

According to Table 4.20, PV modules of Case C has two different azimuths: 100/00 and 100/1800. Therefore, two (02) key orientations of solar PV modules have been identified. Under PV array characteristics, two (02) kinds of arrays has been determined based on PV module capacity and orientation. Accordingly data simulation has been carried out and identified generations are listed in Table 4.24. Simulation reports are attached in the appendix C. The produced energy and the amount in Rs. is presented in Table 4.24.

Table 4.25: Net Present Value of Case C

Yr.	Initial Cost (Rs.)	Maintenance Cost (Rs.)	Net Earnings (Rs.)	Net Cash Flow (Rs.)	Discount Rate (1+r) ^t	Net Present Value (Rs.)
0	239,350,664.18	-	-	(239,350,664.18)	1.000000	(239,350,664.18)
1		2,393,506.64	52,030,000.00	49,636,493.36	1.100000	45,124,084.87
2		2,393,506.64	51,854,000.00	49,460,493.36	1.210000	40,876,440.79
3		2,393,506.64	51,480,000.00	49,086,493.36	1.331000	36,879,408.99
4		2,393,506.64	51,128,000.00	48,734,493.36	1.464100	33,286,314.71
5		2,393,506.64	50,754,000.00	48,360,493.36	1.610510	30,028,061.52
6		2,393,506.64	50,336,000.00	47,942,493.36	1.771561	27,062,287.64
7		2,393,506.64	49,918,000.00	47,524,493.36	1.948717	24,387,579.58
8		2,393,506.64	34,859,500.00	32,465,993.36	2.143589	15,145,625.51
9		2,393,506.64	34,534,000.00	32,140,493.36	2.357948	13,630,706.69
10		2,393,506.64	34,193,000.00	31,799,493.36	2.593742	12,260,081.27
11		2,393,506.64	34,193,000.00	31,799,493.36	2.853117	11,145,528.43
12		2,393,506.64	33,511,000.00	31,117,493.36	3.138428	9,914,992.35
13		2,393,506.64	33,154,500.00	30,760,993.36	3.452271	8,910,364.06

Yr.	Initial Cost (Rs.)	Maintenance Cost (Rs.)	Net Earnings (Rs.)	Net Cash Flow (Rs.)	Discount Rate (1+r) ^t	Net Present Value (Rs.)
14		2,393,506.64	32,798,000.00	30,404,493.36	3.797498	8,006,453.37
15		2,393,506.64	32,457,000.00	30,063,493.36	4.177248	7,196,961.29
16		2,393,506.64	32,116,000.00	29,722,493.36	4.594973	6,468,480.54
17		2,393,506.64	31,806,000.00	29,412,493.36	5.054470	5,819,105.01
18		2,017,906.27	31,527,000.00	29,133,493.36	5.559917	5,239,914.86
19		2,017,906.27	31,263,500.00	28,869,993.36	6.115909	4,720,474.61
20		2,017,906.27	30,984,500.00	28,590,993.36	6.727500	4,249,868.98
NPV						Rs. 111,002,070.90

Table 4.25, presents NPV of Case C. In Table 4.25 the initial cost and maintenance cost were derived from the LCOE calculation. And net earnings determined by the produced energy calculated in Table 4.24. As displayed in Table 4.25 net cash flow is determined by deducting initial and maintenance and operation cost by net earnings of the system. Finally, net present value of the system indicates as Rs. 111,002,070.90.

4.4.3.4 Economic Indicator 03 - Simple payback period (SPBP)

SPB of Case C is calculated and presented in Table 4.26. As per the Table 4.26 the SPB of Case C indicates as 04 years and 10 months. In order to calculate SPBP, initial cost and net cash flows of the system was derived as shown in Table 4.26.

Table 4.26: Simple Payback Period of Case C

Year	Initial Cost (Rs)	Net Cash Flow (Rs.)	Investment Recovery
0	239,350,664.18	(239,350,664.18)	(239,350,664.18)
1		49,636,493.36	(189,714,170.82)
2		49,460,493.36	(140,253,677.46)
3		49,086,493.36	(91,167,184.10)
4		48,734,493.36	(42,432,690.74)
5		48,360,493.36	5,927,802.62
6		47,942,493.36	53,870,295.98
7		47,524,493.36	101,394,789.34
8		32,465,993.36	133,860,782.70
9		32,140,493.36	166,001,276.06
10		31,799,493.36	197,800,769.42

Year	Initial Cost (Rs)	Net Cash Flow (Rs.)	Investment Recovery
11		31,799,493.36	229,600,262.78
12		31,117,493.36	260,717,756.14
13		30,760,993.36	291,478,749.50
14		30,404,493.36	321,883,242.86
15		30,063,493.36	351,946,736.22
16		29,722,493.36	381,669,229.58
17		29,412,493.36	411,081,722.94
18		29,133,493.36	440,215,216.30
19		28,869,993.36	469,085,209.66
20		28,590,993.36	497,676,203.02
SPBP			04 years and 10 months

4.4.3.5 Summary of economic evaluation

Table 4.27 displays the summary of economic evaluation of Case C grid-tied PV system. According to Table 4.27, system capacity of Case C is 1648kWp and its initial cost presented as Rs. 239,350,664.18. Considering the SPBP, investment of the system can be recovered within four (04) years and ten (10) months. As discussed in Table 4.20 the expected life span of the PV system is twenty years (20) and as per the SPBP, after fourth year the generated earnings of the system will exceed the initial cost of the system. Further to Table 4.27 the NPV of the system is Rs. 111,002,070.90. A positive NPV value for the system indicates that investment in grid-tied PV system for Case C is generally profitable. According to table 4.27, the system expect an average energy production of 2,191,200.00 kWh per year and this will generate an income of Rs. 39,244,850.00 per year for Case C.

LCOE of 1648kWp system shall be at Rs. 11.87/ kWh as shown in Table 4.27. The export tariff in Sri Lanka for solar energy is Rs. 22.00/kWh for the first seven (07) years and Rs. 15.50/kWh from year eight up to contract period of 20 years. Considering LCOE of Case C, the unit cost of produced solar energy is 11.87/kWh, which is lesser than the earning received from CEB for a unit ; Rs. 22.00/kWh . Therefore, the Case C grid tied PV system capable of generating a profit of Rs. 10.13/kWh (Rs. 22.00 – 11.87) in first seven years. And after 8th year Case C capable

of generating a profit of Rs. 3.63/kWh (Rs.15.50 – 11.87) up to the contract period of 20 years. Accordingly, the economic analysis of Case C indicates that implemented system is an indeed a gain as a result of low unit cost, quick investment recovery and positive NPV.

Table 4.27: Summary of Economic Evaluation of Case C

Criteria	Value
System Capacity	1648kWp
Initial Cost	Rs. 239,350,664.18
Standard rated energy output per year	2,707,168.5 kWh
Average produced Energy per year (units)	2,191,200.00 kWh/ year
Average produced Energy per year (amount)	Rs. 39,244,850.00 / year
LCOE	Rs. 11.87/ kWh
NPV	Rs. 111,002,070.90
SPBP	04 years and 10 months

4.4.4 Case D

Case D is a single-storey facility located at Panadura, Sri Lanka. This plant has roof mounted grid-tied PV system. According to the tariff category of Ceylon Electricity Board (CEB), this facility categorized under customer category I -2.

4.4.4.1 Configuration of grid-tied PV system



Figure 4.4: Roof-Mounted Grid-Tied PV System of Case D

According to Table 4.28, the Case D has installed grid-tied 551kWp solar PV system implemented in 2019 with an expected life span of 20 years. Furthermore, the system has 370W Monocrystalline solar panels which have been connected in series. The system consists of 1488 panels, where each panel has a capacity of 370W.

Table 4.28: Grid-Tied PV System Information of Case D

Criteria	
Capacity of the system	551kWp
Life span of the system	20 years
Year of installed	2019
PV module capacity	370W
Number of Panels	1488
Inverter capacity and number of inverters	27.60kW – 19
Solar panel configuration	Series
Type of module	Monocrystalline solar panels
Degradation Rate	0.7%
Tilt and Azimuth	10 ⁰ /-70 ⁰ and 10 ⁰ /110 ⁰

4.4.4.2 Economic Indicator 01 - Levelized cost of electricity (LCOE)

The listed six steps have been performed to extract the key variables of LCOE formula. The LCOE of the grid-tied PV system of Case D was subsequently determined by substituting variables to the formula.

Step 1 – Initial cost of the system

The initial cost of Case D is presented in Table 4.29. According to Table 4.29, initial cost of the system displayed as Rs. 69,088,000.00. And solar panels indicate the highest cost, which is Rs. 50,592,000.00. As per Table 4.29, other cost components of the system are solar inverters, power optimizer, structure and electrical system. Under electrical system both AC and DC cables were used. Power optimizers recorded as second highest cost component with a total cost of 7,986,000.00. Furthermore, Case D has implemented seven hundred and twenty six power optimizers to maximize the power generation of the system.

Table 4.29: Initial Cost of PV System in Case D

Item	Description	Qty.	Rate (Rs.)	Amount (Rs.)	
1.0	Solar Panels				
1.1	Solar Panels 370W (JAM72S10- 400/MR)	1488	34,000.00	37,752,000.00	50,592,000.00
2.0	Solar Inverters				
2.1	27.6kW Solar Edge Inverter	19	390,000.00	7,410,000	7,410,000.00
3.0	Power Optimizers	726.00	11,000.00	7,986,000.00	7,986,000.00
4.0	Structure			2,000,000.00	2,000,000.00
5.0	Electrical System				
5.1	DC Cables			850,000.00	
5.2	AC Cables			250,000.00	1,100,000.00
	TOTAL				69,088,000.00

Step 2 – Calculate the operation and maintenance costs of the system

According to the respondents, industrial practice for estimating operation and maintenance cost is taken as 1% of the initial cost of the system. Accordingly, operation and maintenance cost identified as 1% of the initial cost per year in case D and the calculations are presented below.

Initial Cost of the System = Rs. 69,088,000.00

Operation and maintenance costs per year = 69,088,000.00 x 0.01

= Rs. 690,880.00

Step 3 – Calculate the yearly rated energy output per panel

Yearly rated energy output per panel is calculated using the systems size in watts as well as the peak sunshine hours. Hence, yearly rated energy output and standard rated

energy output are presented in Table 4.30. Firstly, yearly rated energy output per panel was calculated for the 370W panel installed in Case D. Subsequently, standard rated energy output was calculated by considering the total number of PV modules of the system. As shown in Table 4.30, standard rated energy output of the system for a year indicates as 904,294.8kWh.

Table 4.30: Yearly Rated Energy Output and Standard Rated Energy output of Case D

	Yearly Rated Energy Output (YREO) per panel per year	Standard Rated Energy Output (SREO)
Equation	$= \frac{\text{System size (Watts)} \times \text{Peak Suns}}{1000}$	$= YREO \text{ per year per pane} \times N$
YREO and SREO of 370W panels	$= \frac{(370 \times 4.5 \times 365)}{1000}$ = 607.725kWh	= 607.725 x 1488 = 904,294.8kWh
Total SREO of the PV system		904,294.8kWh

Step 4 – Determine the discount rate and degradation rate of the system

The next step of LCOE calculation is to determine the discount and degradation rate. As mentioned in Case A, B and C, the respondents from solar companies, the industrial practice for discount rate in Sri Lanka for solar market is considered as 10%. Therefore, in this study discount rate is considered as 10%. Further, the degradation rate of Case D identified as 0.7% and this is based on the PV modules manual of the solar manufacturer.

Discount Rate = 10%

Degradation Rate = 0.7%

Step 5 – Determine the life of the grid-tied PV system

The respondents of Case D mentioned life span of grid-tied PV system as 20 years.

Life of the project = 20 years

Step 6 – Substitute the variables into the LCOE formula

This is the final step to determine the LCOE of Case D, which is to substitute variables into the LCOE formula. Table 4.31 indicates the variables of LCOE formula, along with respective values. These values are derived from the previous steps under the subheading of LCOE calculation. Calculation table of LCOE for Case D is presented in Appendix C. Further to Appendix C, the initial cost, maintenance cost and standard rated energy output was calculated for each year and the derived values were substituted to Formula 1. As per the calculation of the LCOE for Case D, the final value indicates as Rs. 10.26/ kWh. Accordingly, considering the life time cost of solar PV system of Case D, the unit cost of generated solar power of the installed system shown as Rs. 10.26 for a kWh.

Table 4.31: Variables of LCOE Formula of Case D

Variables	Value
Initial Cost	Rs. 69,088,000.00
Operation and Maintenance Cost per year	Rs. 690,880.00
Standard rated energy output	904,294.8kWh
Discount Rate	10%
Degradation Rate	0.7%
Life of the Project	20 years

$$LCOE = \sum_{t=0}^T \frac{(It + Ot + Mt + Ft)}{(1+r)^t} \frac{1}{\sum_{t=0}^T St \frac{(1-d)^t}{(1+r)^t}} \quad (1)$$

$$= \text{Rs. } 74,969,850.90 / 7,308,249.98$$

$$= \text{Rs. } 10.26/ \text{ kWh}$$

4.4.4.3 Economic Indicator 02: Net present value (NPV)

In order to calculate NPV, it is required to identify the produced energy of the solar PV system throughout the life span. The energy production of the solar PV system determined by the data simulation.

- Simulation and results

Table 4.32: Produced Energy of Case D

Year	Units (kWh)	Amount (Rs.)
0	-	-
1	780600	17,173,200.00
2	777500	17,105,000.00
3	777500	17,105,000.00
4	766800	16,869,600.00
5	766800	16,869,600.00
6	761400	16,750,800.00
7	756000	16,632,000.00
8	750700	11,635,850.00
9	745300	11,552,150.00
10	740000	11,470,000.00
11	734600	11,386,300.00
12	729200	11,302,600.00
13	718500	11,136,750.00
14	718500	11,136,750.00
15	713100	11,053,050.00
16	707800	10,970,900.00
17	702400	10,887,200.00
18	697000	10,803,500.00
19	691600	10,719,800.00
20	686300	10,637,650.00
Total	14,721,600kWh	Rs. 263,197,700.00
Average produced energy per year	736,080kWh/ year	Rs. 13,159,885.00 / year

According to Table 4.28, PV modules of Case D has two different azimuths: 100/-700 and 100/1100. Therefore, two (02) key orientations of solar PV modules have been identified. Under PV array characteristics, two (02) kinds of arrays has been determined based on PV module capacity and orientation. Accordingly data simulation has been carried out and identified generations are listed in Table 4.32. Simulation reports are attached in the Appendix D. The produced energy and the amount in Rs. is presented in Table 4.32.

Table 4.33, presents NPV of Case D. In Table 4.33 the initial cost and maintenance cost were derived from the LCOE calculation. And net earnings determined by the produced energy calculated in Table 4.32. As displayed in Table 4.33 net cash flow is determined by deducting initial and maintenance and operation cost by net earnings of the system. Finally, net present value of the system indicates as Rs. 48,581,907.04.

Table 4.33: Net Present Value of Case D

Year	Initial Cost (Rs.)	Maintenance Cost (Rs.)	Net Earnings (Rs.)	Net Cash Flow (Rs.)	Discount Rate (1+r) ^t	Net Present Value
0	69,088,000.00	-	-	(69,088,000.00)	1.000000	(69,088,000.)
1		690,880.00	17,173,200.00	16,482,320.00	1.100000	14,983,927.27
2		690,880.00	17,105,000.00	16,414,120.00	1.210000	13,565,388.43
3		690,880.00	17,105,000.00	16,414,120.00	1.331000	12,332,171.30
4		690,880.00	16,869,600.00	16,178,720.00	1.464100	11,050,283.45
5		690,880.00	16,869,600.00	16,178,720.00	1.610510	10,045,712.23
6		690,880.00	16,750,800.00	16,059,920.00	1.771561	9,065,406.16
7		690,880.00	16,632,000.00	15,941,120.00	1.948717	8,180,315.14
8		690,880.00	11,635,850.00	10,944,970.00	2.143589	5,105,909.28
9		690,880.00	11,552,150.00	10,861,270.00	2.357948	4,606,238.74
10		690,880.00	11,470,000.00	10,779,120.00	2.593742	4,155,817.38
11		690,880.00	11,386,300.00	10,695,420.00	2.853117	3,748,679.46
12		690,880.00	11,302,600.00	10,611,720.00	3.138428	3,381,221.02

Year	Initial Cost (Rs.)	Maintenance Cost (Rs.)	Net Earnings (Rs.)	Net Cash Flow (Rs.)	Discount Rate (1+r) ^t	Net Present Value
13		690,880.00	11,136,750.00	10,445,870.00	3.452271	3,025,796.45
14		690,880.00	11,136,750.00	10,445,870.00	3.797498	2,750,724.05
15		690,880.00	11,053,050.00	10,362,170.00	4.177248	2,480,621.11
16		690,880.00	10,970,900.00	10,280,020.00	4.594973	2,237,231.87
17		690,880.00	10,887,200.00	10,196,320.00	5.054470	2,017,287.55
18		690,880.00	10,803,500.00	10,112,620.00	5.559917	1,818,843.60
19		690,880.00	10,719,800.00	10,028,920.00	6.115909	1,639,808.56
20		690,880.00	10,637,650.00	9,946,770.00	6.727500	1,478,523.98
NPV					Rs.48,581,907.04	

4.4.4.4 Economic Indicator 03: Simple payback period (SPBP)

SPBP of Case D is calculated and presented in Table 4.34. As per the Table 4.34 the SPBP of Case D indicates as 04 years and 3 months.

Table 4.34: Simple Payback Period of Case D

Year	Initial Cost (Rs)	Net Cash Flow (KW)	Investment Recovery
0	69,088,000.00		(69,088,000.00)
1		16,482,320.00	(52,605,680.00)
2		16,414,120.00	(36,191,560.00)
3		16,414,120.00	(19,777,440.00)
4		16,178,720.00	(3,598,720.00)
5		16,178,720.00	12,580,000.00
6		16,059,920.00	28,639,920.00
7		15,941,120.00	44,581,040.00
8		10,944,970.00	55,526,010.00
9		10,861,270.00	66,387,280.00
10		10,779,120.00	77,166,400.00

Year	Initial Cost (Rs)	Net Cash Flow (KW)	Investment Recovery
11		10,695,420.00	87,861,820.00
12		10,611,720.00	98,473,540.00
13		10,445,870.00	108,919,410.00
14		10,445,870.00	119,365,280.00
15		10,362,170.00	129,727,450.00
16		10,280,020.00	140,007,470.00
17		10,196,320.00	150,203,790.00
18		10,112,620.00	160,316,410.00
19		10,028,920.00	170,345,330.00
20		9,946,770.00	180,292,100.00
Simple payback period			04 years and 03 months

4.4.4.5 Summary of economic evaluation

Table 4.35 displays the summary of economic evaluation of Case D grid-tied PV system. According to Table 4.35, system capacity of Case D is 551kWp and its initial cost presented as Rs. 69,088,000.00. Considering the SPBP, investment of the system can be recovered within four (04) years and three (03) months. As discussed in Table 4.28 the expected life span of the PV system is twenty years (20) and as per the SPBP, after four year the generated earnings of the system will exceed the initial cost of the system. Further to Table 4.35 the NPV of the system is Rs. 48,581,907.04. A positive NPV value for the system indicates that investment in grid-tied PV system for Case D is generally profitable. According to table 4.35, the system expect an average energy production of 736,080kWh per year and this will generate an income of Rs. 13,159,885.00 per year for Case D.

LCOE of 551kWp system shall be at Rs. 10.26/ kWh as shown in Table 4.35. The export tariff in Sri Lanka for solar energy is Rs. 22.00/kWh for the first seven (07) years and Rs. 15.5/kWh from year eight up to contract period of 20 years. Considering LCOE of Case D, the unit cost of produced solar energy is 10.26/kWh, which is lesser

than the earning received from CEB for a unit ; Rs. 22.00/kWh . Therefore, the Case D grid tied PV system capable of generating a profit of Rs. 11.74/kWh (22 – 10.26) in first seven years. And after 8th year Case D capable of generating a profit of Rs. 5.24/kWh (15.5 – 10.26) up to the contract period of 20 years. Accordingly, the economic analysis of Case D indicates that implemented system is an indeed a gain as a result of low unit cost, quick investment recovery and positive NPV.

Table 4.35: Summary of Economic Evaluation of Case D

Criteria	Value
System Capacity	551kWp
Initial Cost	Rs. 69,088,000.00
Standard rated energy output per year	904,294.8kWh
Average produced Energy per year (units)	736,080kWh/ year
Average produced Energy per year (amount)	Rs. 13,159,885.00 / year
LCOE	Rs. 10.26/ kWh
NPV	Rs. 48,581,907.04
SPBP	04 years and 03 months

4.5 Summary of the Economic Evaluation

In this study three (03) economic indicators were analyzed including LCOE, NPV and SPBP. Table 4.36 indicates the summary of the research findings under each economic indicator.

Table 4.36: Summary of Economic Evaluation

Economic Indicators	Case A	Case B	Case C	Case D
LCOE	Rs. 11.77/kWh	Rs. 11.82/ kWh	Rs. 11.87/ kWh	Rs. 10.26/ kWh
NPV	Rs.73,490,986.93	Rs. 57,539,848.71	Rs. 111,002,070.90	Rs. 48,581,907.04
SPBP	04 years and 11 months	04 years and 10 months	04 years and 10 months	04 years and 03 months

LCOE of all four cases guarantee a profitable outcome from grid-tied PV system. Table 4.37 indicates the profit generated by the four case studies by adopting grid-tied PV system. This profit is calculated by deducting LCOE value from solar power purchasing rates of CEB in Sri Lanka. The export tariff in Sri Lanka for solar energy is Rs. 22.00/kWh for the first seven (07) years and Rs. 15.5/kWh from year eight up to contract period of 20 years. Accordingly, the profit per kWh was shown for both first seven years and remaining contract period, as illustrated in Table 5.2.

Table 4.37: Profit Generated per kWh by Using Grid-Tied PV System

Profit per kWh	Case A	Case B	Case C	Case D
0 -7 year	Rs.10.23/kWh	Rs. 10.18/kWh	Rs. 10.13/kWh	Rs.11.74/kWh
8 -20 year	Rs.3.73/kWh	Rs. 3.68/kWh	Rs.3.63/kWh	Rs.5.24/kWh

Hence, the analysis reveals that, grid-tied PV systems of selected apparel buildings have achieved a LCOE which is lower than the purchase price of CEB. This guarantees a positive net earning throughout the contracted period. Continuous flow of the earnings ensures investment recovery for all (04) cases which is indicated through SPBP. Thus, NPV of the systems of selected cases indicates as a positive value, ensuring profitability of the investment.

4.6 Economic Benefits of Grid-Tied PV Technology

Opinions of the interviewees in case studies about the benefits of the grid-tied PV technology for apparel industry in Sri Lanka were gathered through the section V of the semi-structured interview in Appendix A. All respondents agreed that application of grid-tied PV system does not have any impact on organization's monthly electricity bill. Since, the selected case studies are operate under Net Plus scheme, the solar power generated is sold to the grid as per the contract. Therefore, there is a zero reduction in monthly electricity bill. However, under net plus scheme a payment is provided for the generated solar power, which is an income to the respective organizations. Respondent A1 emphasized the importance of the income as, *“Our Company produces monthly*

income without extra effort because of the implemented solar system and our top management is extremely pleased and encourages the current system to be strengthened". Expressing similar view, respondent C1 defined the system as "Business profit generating technology". Accordingly, it is evident that even there is no change in monthly electricity bill, the implemented systems enable to generate a monthly revenue to the facility.

Considering the pattern of solar power generation, respondent B2 mentioned, "*Over the life span the generation of solar power gradually decrease due to solar modules degradation*". However, C3 declared, "*Even there is reduction in power generation, it is not recorded as a significant reduction compared to the previous months. Therefore, the system ensure gradual reduction over the life span, which indicates less impact on our monthly cash inflows*". B1 also expressed similar views stating that there are slight variations in power generation due to solar hours and degradation rate. But these facts do not significantly change the solar power generation and system's cash inflows. Respondents of Case D mentioned, "*We are experiencing both incensements and reductions in power generation, however these are minor changes to overall power generation pattern*". The conducted simulation study indicates, there is a gradual reduction in expected solar power generation over the system's contracted period. Nevertheless, simulation results shows these changes are minor variations over the system's life span. Accordingly, it is visible that even there is variation in power generation, this has less impact on economic benefit of the system.

Respondents (A2, B2,C2 and D2) agreed that maintenance requirement of grid-tied PV system is comparatively low compared to other renewable energy systems. Particularly in Case study A, the first two years of maintenance activities are performed without a charge by the solar company. Therefore, it is an additional economic benefit achieved by the client under the category of maintenance. Reduction in maintenance cost create less impact on operation cost of the organization. Moreover, respondents of Case D elaborated that whole life maintenance cost of solar PV system is significantly low compared to other renewable technologies such as wind and hydroelectricity. Supporting the above statement department heads of engineering

(A1, B1, C1 and D1) claimed that low maintenance cost as a key aspect for maximizing the income from solar PV system.

The unit cost of grid-tied PV system is a key fact to decide the profitability of the system. Interviewee A1 mentioned *“Even the initial cost of the system is high, it is expected that operating cost of the system low. Therefore, we expect the unit cost of solar PV to be substantially low, taking into account the cost of the life cycle”*. Respondent D1 mentioned that the unit cost of solar PV is lower than the system’s revenue. C1 supported the above statement as *“CEB purchase a unit produce from solar PV system at a rate of Rs. 22.00 for the first seven years and from eighth year to the twentieth year will purchased at a rate of Rs. 15.50. And our expected unit cost of solar PV system is lower than the solar energy purchased rate”*. Interviewees from Cases B and D stated that, given the low operating cost of the system, the unit cost of the grid-tied PV system is expected to be low. The findings under section 4.4 indicates unit cost of grid-tied PV range from Rs. 10.00 -12.00, which is clearly lower than the rate paid by the CEB, Sri Lanka. Accordingly, it can be stated that the unit cost of solar energy is significantly low in Sri Lanka, which ensures system’s profit.

Under economic benefits, D3 highlighted that usage of grid-tied PV system has led to reduction in air conditioning load. Further, compared to other renewable technologies the roof-mounted grid-tied PV system has a zero expenditures on land requirements. C2 expressed *“Use of solar energy has attracted new and existing customers to the organization. Therefore the use of solar energy has improved the direct income of our organization”*. This has been experienced by all the Case studies, indicating customer attraction and interest on investing for sustainable organizations.

Respondents expressed similar views on the support of grid-tied PV system for economy of the country. B2 explained *“In Sri Lanka power generation is significantly rely on conventional energy sources. Therefore, changing power sources in organizations will positively impact on reducing the national cost on conventional energy sources”*. Expressing similar view, A1 stated that organizations consumes significant portion of countries electricity. Therefore, the organizations contribution on renewable energy consumption can significantly reduce the national cost on

traditional energy sources. D1 pointed out “*By using solar energy, we can reduce the burden on local electricity grid and it will reduce local expenditures on coal based power plants in the long run*”. C1 emphasized that creating solar market in Sri Lanka will enhance the local job opportunities, which will boost the local economy.

Table 4.38: Summary of Economic Benefits across Cases

Economic Benefits	Case			
	A	B	C	D
Economic Benefits in Organization Level				
System ensure a monthly revenue to the organization	x	x	x	x
Gradual reduction of solar power generation in system’s life span, which ensure minimum impact on monthly income of solar power.			x	x
Low maintenance cost, which minimize the operation cost of the system	x	x	x	x
Maximize the income of solar power because of the low unit cost of solar power generation.	x	x	x	x
Reduce the air conditioning load of the building, which minimize the operation cost of the facility.				x
Zero cost in purchasing land when implementing roof-mounted grid-tied PV technology.				x
Use of renewable energy technologies in apparel sector attracts new and existing customers, which enhance the direct income of the organization.			x	
Economic Benefits in National Level				
Reduce national costs in conventional energy sources and reduce the burden on national grid	x	x	x	x
Creating job opportunities with the expansion of solar energy market	x	x	x	x

Therefore, as per the respondents it is evident that there are several economic benefits generated by implementing grid-tied PV system. A summary of economic benefits of selected cases are displayed in Table 4.38, under organizational and national level.

According to Table 4.38, several benefits such as monthly revenue, low maintenance cost, low unit cost and national level economic benefits were experienced and identified by all the cases. Nevertheless, several benefits were identified in one or more cases during system's operation. As an example, the gradual reduction in solar power has a minimum impact on monthly revenue was highlighted by the responses of Case C and D. And reducing air conditioning load of the building and zero land requirement were emphasized in Case D. Hence, it is evident that the introduction of solar PV in the selected case studies has gain economic benefits in both organizational and national level.

4.7 Economic Challenges of Grid-Tied PV Technology

The respondents (A1, B1, C1 and D1) agreed that initial cost as key challenge for implementing grid-tied PV system. In Case D, the expansion of the grid-tied PV system has been restricted due to the high initial cost of the system. The respondents of Case D expressed that initial cost as a key economic challenge to improve solar system capacity. Similarly, B2 mentioned *“High initial cost was key economic challenge faced during implementation stage. Even the top management highlighted the burden on high initial cost in the planning stage of the project”*. Whereas, Department head of Case C (C1) highlighted *“Since our plant is located in Batticaloa, the transportation cost was significantly high, which highly impact on our initial cost. One Assistant engineer of Case D (D3) explained “Even solar market in Sri Lanka is expanding, there is no significant drop in solar system prices. The primary reason for price variation is that import cost and add on taxes on solar components”*. Expressing similar view B3 explained *“In Sri Lanka we do not perform bulk ordering for solar components, the systems parts are imported only if there is a customer requirement. Therefore, these purchase patterns results in a high purchasing cost, which increase the client's initial cost”*.

Respondents from Case C highlighted that there are lack of financing support for renewable energy in Sri Lanka. According to respondent A1 *“There is no proper loan scheme for Sri Lanka's renewable users. Therefore, the organizations invest organization's capital to implement solar system. The project acceptance and execution is difficult due to financing difficulties”*. On the other hand, D2 mentioned

that lack of subsidies at the initial stage as a key economic challenge for solar implementation. B1 stated that since government provide high purchase rate for solar power, there is a lack of subsidies currently provided at the initial stage for solar users. A1 and D1 emphasized that high initial cost can be overcome, if the subsidies and more financing schemes are introduced. Therefore, it is clear that high initial cost of solar system is key economic challenge for new users to enter the solar market. Further existing customers limit system expansions to control the initial cost. Moreover, the client's pressure on initial cost is increasing with the economic challenges such as financing difficulties and lack of government subsidies.

In the implementation stage respondents agreed to have several economic challenges. A1 mentioned "*we have faced several delays from solar company. These delays have caused to increase the indirect costs of the system*". Expressing similar view explained by C2 as, "*The solar company had several delays in the implementation stage, causing delays in operation of the system. And it has created an additional cost to the organization*". D1 highlighted that in the implementation, stage there were conflicts over responsibilities of solar company, which had created an additional cost to the organization. Therefore, lack of commitment of solar companies has identified as the key economic challenge during the implementation stage.

The key economic challenge during operation stage is identified as replacement cost of the system. Interviewee C1 explained it as "*In Sri Lanka we do not keep stocks for spare parts. Therefore, in case of replacement the component should be import from the supplier. This process burdens the client with high courier cost and taxes*". Expressing similar view respondents of Case A and D explained that inverters, solar modules and batteries are expensive to import. Therefore in case of a replacement the company must bear the import cost.

Further economic challenges were highlighted by the interviewees. D2 and B2 mentioned that zero reduction in electricity bill as an economic challenge. Even there is a cash inflow, the lack visible reduction in monthly electricity bill identified as a challenge. C2 emphasize on gradual reduction in solar power generation. C3 explained it as "*The gradual reduction in solar power generation will gradually impact on*

revenue of the solar PV system". A1 mentioned that there are several losses attached to solar PV system, such as cable losses, degradation rates, sunshine hours and system losses. Further to respondent these challenges create additional cost burden on client. Similarly, B2 explained "*The system losses and environmental conditions reduce the power generation of the system, which impact on the system's revenue*". Therefore losses attached to PV system eventually act as an economic challenge to the organization.

Accordingly, several economic challenges have been identified by the respondents under initial, implementation and operation stages of the system. Table 4.39, displays a summary of the economic challenges of cases. As per Table 4.39, high initial cost and lack of financial support were identified by all four cases. Nevertheless, several challenges were expressed in one or more cases. As an example high replacement cost was identified in the selected cases except Case B. And zero reduction in monthly electricity bill was highlighted in Case B and D. Accordingly, economic challenges have been recognized by implementing grid-tied PV system.

Table 4.39: Summary of Economic Challenges across Cases

Economic Challenges	Case			
	A	B	C	D
High initial cost	x	x	x	x
Lack of financial support at the initial stage of solar projects	x	x	x	x
Additional costs in implementation stage due to conflicts with solar companies	x		x	x
High replacement costs	x		x	x
Zero reduction in monthly electricity bill		x		x
Gradual reduction in solar power generation over the life span of the system			x	
Solar income reduction due to system losses	x	x		

4.8 Proposed Strategies to Overcome Economic Challenges of the System

High initial cost of the system is a primary economic challenge encountered by the solar PV users. According to respondents, there are three (03) primary solar PV schemes in Sri Lanka to sell generated solar units in order to recover the system's initial cost. The three (03) schemes are Net accounting, Net metering and Net plus. The four (04) selected case studies are operating under net plus scheme and respondents agreed this as the key strategy to overcome the high initial cost of the system. As defined by respondent A1, net plus strategy enable user to pay for the consumed energy according to the existing tariff rates. Moreover, Ceylon Electricity Board (CEB) will pay for the generated units from the implemented solar PV system. Respondent C1 explained that in net plus scheme there is no connection between consumed energy and the on-site generated energy of the facility. Further to respondents of Case A, B, C and D, CEB will perform a payment for the total electricity generated from the implemented solar PV system in relevant facilities.

According to department heads of each facility (A1, B1, C1 and D1), it is a unique feature to adopt net plus scheme compared to remaining two strategies: net accounting and net metering. Further to respondents, the key reason for aforementioned statement is that net plus strategy confirm comparatively high profit for apparel industry in Sri Lanka. Respondent C2 mentioned that selling a generated unit from solar PV system is economical for an industrial building rather than consuming it. As explained by assistant engineers of A, B and C, currently CEB purchase a unit produce from solar PV system at a rate of Rs. 22.00 for the first seven years and from eighth year to the twentieth year will purchase at a rate of Rs. 15.50. Moreover, currently CEB tariff rates for industrial buildings under customer category I2, includes Rs. 22.00 for peak time, Rs. 11.00 for day time and Rs. 6.85 for off-peak. And charges for customer category I3 are Rs. 23.50 for peak time, Rs. 10.25 for day time and Rs. 5.90 for off-peak. Considering mentioned above tariff rates respondents (A2, B2 and C3) explained that it is economical to pay for the total consumed electricity while selling the generated electricity at a rate of Rs 22.00 for the first seven years and Rs 15.50 for the remaining years. In addition, in the data analysis of this study it was identified that LCOE of grid-tied systems of all four (04) cases ranges from Rs. 10.00 to 12.00. Therefore, it is an

indeed a profit for the selected cases to sell a generated unit for CEB at a rate of Rs. 22.00 and Rs 15.50. Respondents also mentioned that (A1, B1, C1 and D1) net plus strategy enable them to recover the initial cost of the solar PV system in the long run. Therefore, as per the respondents, the key economic strategy adopted by case studies to overcome the high initial cost was to adopt Net Plus scheme. All respondents agreed that they are expecting to recover system's initial cost and generate profit through Net Plus scheme. Therefore, interviewees highlighted the net plus scheme as an economic solution to overcome the high initial cost of solar PV system in Sri Lanka.

Supplier conflicts is another economic challenge that has led to additional cost attached to the system. Respondent A1 suggested to select solar companies registered as energy service companies under sustainable energy authority in Sri Lanka to overcome conflicts with suppliers. Expressing similar view C1 mentioned that clients encounters financial difficulties over the delays and conflicts by the suppliers. Therefore, it is acceptable to select a company registered as Energy Service Company to overcome such difficulties in the implementation and operation stage. High replacement cost is another economic challenge encountered by the solar PV users. B2 suggested to promote bulk purchase of solar modules and inverters to reduce the high replacement cost of solar PV in Sri Lanka. Commenting to the above suggestion A1 explained "*It is advisable to promote bulk purchase and maintain stocks in Sri Lanka to avoid high components cost within Sri Lanka.*" According to D2, it is mandatory to enhance the solar PV demand in Sri Lanka to overcome the high initial and replacement cost.

Accordingly, this study identifies several suggested strategies to overcome the economic constraints of grid-tied PV system in Sri Lanka. The respondents of case studies indicated Net Plus scheme as the primary solution to enhance the economics of PV system. In addition respondents suggested several strategies such as selecting energy service companies, promote bulk purchase and maintain stocks to narrow the economic constrains of the system. Further a summary of proposed strategies of cases are presented in Table 4.40. As per Table 4.40, several strategies were proposed by all the cases such as adopting Net Plus scheme and promoting bulk purchases. And other strategies were proposed by one or more cases. As an example, selecting an energy service company was proposed by Case C. Moreover, maintaining stocks were

proposed by Case A and B. Accordingly, strategies were proposed to enhance the economics of the grid-tied PV system.

Table 4.40: Summary of Proposed Strategies across Cases

Proposed Strategies	Case			
	A	B	C	D
Adaptation of Net Plus Scheme for apparel manufacturing buildings in Sri Lank	x	x	x	x
Select solar companies registered as energy service companies under sustainable energy authority in Sri Lanka			x	
Promote bulk purchase of solar modules and solar inverters in Sri Lanka	x	x	x	x
Maintain stocks of solar modules and solar inverters	x	x		
Enhance the national level solar demand in Sri Lanka				x

4.9 Validation of Research Findings

The findings of the study validated in order to measure the reliability of outcome. To support the reliability process, the research findings were presented to three (03) experts in solar PV systems. Selected three respondents are expertise in solar PV systems and its economic aspects. The profile of the experts has been presented in Table 4.41.

Table 4.41: Profile of Experts

Expert	Designation	Experience
Expert 01	Director	45 Years
Expert 02	Senior Manager	33 Years
Expert 03	Director	40 Years

According to Table 4.36 designation and experience of service were considered when selecting the interviewees. Three experts possess the knowledge and the experience in grid-tied PV technology. The indicated experience in Table 4.36 is in the renewable industry in Sri Lanka. Furthermore, the comments from the experts were presented

under two (02) key sections. The two sections are validation of economic evaluation and economic benefits, challenges and strategies of the system.

4.9.1 Validation of Economic Evaluation

The respondents satisfied with the findings of the economic evaluation. Expert 01 commented that LCOE in Sri Lanka generally expected to be Rs. 12.00. Expert 02 explained that LCOE value can be varied based on the practitioners and solar suppliers. However, based on the practice (for 300W solar system), the estimated LCOE decided as Rs.12. 00. Expert 03 commented that there is slight variation in all four case studies are due to technology of manufacture, location and installation of the system. Accordingly, all three (03) experts recommended the LCOE calculation done for Case A,B,C, and D and the reliability of data.

Considering SPBP, all the practitioners agreed to the final value. Expert 02 stated that generally the investment is expected to recover within 06 to 07 years. However, Expert 01 mentioned that the calculated SPBP can be lesser than the actual payback period. Further to the respondents, the calculated SPBP can differ due to fluctuation in dollar value. All experts have approved the NPV values derived from each case study. Moreover, Expert 01 commented to check the total cost of the Case C to identify the reason behind high initial cost. High system quality and capacity were identified as key reasons for the high initial cost of the system. Accordingly, these comments by experts were addressed and reflected in the final conclusions of the study.

4.9.2 Validation of Economic Benefits, Challenges and Strategies of the System

Experts commented on economic benefits, challenges and proposed strategies of system. All the experts agreed to the findings under economic benefits and challenges of the system. Further, adding to identified challenges, experts indicated the lack of policy in Sri Lanka for taxing and pricing on solar energy system. Expert 02 indicated that irregular taxing system as key reason to boost the cost constraints for renewable energy technologies in Sri Lanka. Expressing similar view, Expert 01 indicated that to enhance the economic benefits of the system it is essential to improve the local policy on taxing and pricing on solar energy system.

Moreover, experts commented on strategies to overcome the economic challenges of the system. Experts highlighted the need of improving the process and approving the renewable loan scheme in Sri Lanka in order to overcome system's cost constraints. Expert 01 explained that the carbon trading as another strategy to minimize economic constraints of the system. Expressing similar view Expert 02 indicated that "It is needed to improve the carbon pricing index in Sri Lanka to enhance the carbon trading as a solution to gain economic benefits to renewable energy users in Sri Lanka". Expert 01 indicated improving solar energy system policy as a strategy to overcome gaps in taxing financing of renewable energy system. Expert 03 highlighted that a solid system policy would narrow the economic constraints for the local solar energy clients. Expert 02 proposed introducing tax reductions and relives as an economic strategy to overcome financial challenges of the system. Further, all the subject matter experts indicated minimizing inadequacy of national grid in Sri Lanka as a key strategy to reduce economic challenges of the system. Furthermore, three experts suggested to improve the local solar energy demand, in order to minimize the economic challenges of the system. Accordingly, above comments provided by respondents were considered and the final findings of the economic evaluation was derived by incorporating the suggestions made by the experts.

4.10 Chapter summary

In this chapter economic indicators were calculated for all four (04) case studies. The key economic indicators used for this study are LCOE, NPV and SPBP. The LCOE of Case A, B, C and D are Rs.11.77/kWh, Rs.11.82/ kWh, Rs.11.87/ kWh and Rs. 10.26/ kWh respectively. And the calculated NPV of Case A, B, C and D are Rs.73,490,986.93, Rs.57,539,848.71, Rs. 111,002,070.90 and Rs.48,581,907.04 respectively. Case A, B, C and D SPBP indicates as 04 years and 11 months, 04 years and 10 months, 04 years and 10 months and 04 years and 03 months respectively. Subsequently, economic benefits, challenges and strategies were discussed. The profit generation identified as the key economic benefit while initial cost recognized as the primary challenge of the system. Net plus strategy identified as the appropriate scheme to adopt grid-tied PV for apparel manufacturing industry in Sri Lanka.

5 Conclusions and Recommendations

5.1 Introduction

This chapter elaborates conclusions derived from the study and its contribution to the existing body of knowledge. In addition, this chapter discusses the limitations under which the study has been carried out. Finally, recommendations are listed for both industrial practitioners and academic researchers for further studies.

5.2 Conclusions

The aim of this study is to conduct an economic evaluation of grid-tied PV for apparel manufacturing industry in Sri Lanka. The aim is achieved through 04 primary objectives. The conclusions derived under each objective are explained below.

Objective 01: Critically review the concept and applications of grid-tied PV system in global and local context

First objective of the study was to critically review the concept and applications of grid-tied PV system in global and local context. This objective was achieved through literature review. Literature study indicates five (05) primary renewable energy sources including solar, wind, biomass, geothermal and tidal power (Section 2.5). Literature review highlights grid-tied PV system as a technology introduced under solar energy (Section 2.6.1). Major categories of grid-tied PV system includes grid-tied PV with battery and a system without battery storage (Section 2.6.2). Consequently, common economic benefits, challenges and strategies of grid-tied PV system were identified through critical literature analysis. Ease the burden on local grid, reduce electricity bill, low maintenance cost, zero requirement of additional lands and support the country's economy are the identified benefits of grid-tied PV system by many scholars (Section 2.7.2). Key economic challenges of the system are high initial cost, financial difficulties, low cost effectiveness and lack of government subsidies (Section 2.7.3). Moreover, chapter identifies Net Metering, Net Plus and Net Accounting, Feed-in tariff and capital subsidies as key economic strategies of grid-tied PV system (Section 2.7.4). Subsequently, economic indicators were identified through literature review chapter. Key economic indicators for economic evaluation includes

LCOE, NPV and SPBP (Section 2.8). Finally, a mapping of the literature findings was developed by incorporating the literature findings (Section 2.10).

Objective 02: Examine economic benefits and challenges of grid-tied PV system for apparel manufacturing industry in Sri Lanka

Objective 02 was developed to investigate economic benefits and challenges of grid-tied PV system for apparel manufacturing industry in Sri Lanka. This objective was achieved through data collection and analysis. Based on the analysis, key economic benefits of grid-tied PV for apparel manufacturing industry are identified under both at organizational level and national level (Section 4.6). The study identified the following as organization level economic benefits: the system's monthly revenue, low variation in power generation, low maintenance cost, low unit cost, minimize air conditioning cost, zero expenses on land requirements, improve direct income by attracting customers. Whereas, in national context, the use of PV technology mainly minimize national cost on traditional energy sources and reduces the burden on local utility grid. Moreover, enhances the solar market in Sri Lanka, which leads to create job opportunities. Compared to literature review, through case studies it was able to identify several additional economic benefits such as monthly revenue, minimum variations in solar power generation, attracting new and existing customers to organization and reduction in air conditioning load.

The key economic challenges of grid-tied PV identified under initial, implementation and operation stages of the system (Section 4.7). Primarily, initial cost, lack of financial support and government subsidies, conflicts with suppliers, high replacement cost, zero visible reduction in electricity bill, gradual reduction of system' solar power generation and variations in power generation due to system losses, degradation rate, cable losses and sunshine hours. In addition to the aforementioned challenges, experts highlighted the lack of policy on taxing and pricing of solar energy system as a key economic challenge of the system.

Objective 03: Proposed strategies to overcome the economic challenges of the grid-tied PV system for apparel manufacturing industry in Sri Lanka

Objective 03 was developed to propose strategies for grid-tied PV system for apparel manufacturing industry in Sri Lanka (Section 4.8). This study reveals that for apparel manufacturing industry, the most profitable economic strategy is to adopt net plus scheme to overcome high cost challenges of the system. Under net plus category, the client is able to generate a monthly income by selling generated electricity to the local electricity board. Moreover, respondents suggested several strategies such as selecting energy service companies, promote bulk purchase and maintain stocks to narrow the economic constrains of the system. In addition, experts suggested to enhance and adopt strategies such as improve the process of renewable energy loan schemes, establish carbon pricing index and promote carbon trading, improving solar energy policy, enabling tax relieves and reductions, enhance national solar energy demand and minimizing inadequacy of national grid.

Objective 04: Assess the economic gain of grid-tied PV for apparel manufacturing industry in Sri Lanka.

Final objective was to assess the economic gain of grid-tied PV for apparel manufacturing industry in Sri Lanka. The key outcomes of this objective is the evaluation of economic indicators, which reflect the economic profitability of the system (Section 4.5). In this study three (03) economic indicators were analyzed including LCOE, NPV and SPBP. LCOE of the cases resulted in a reasonable range for the cost of producing electricity using a solar PV system, ranging between Rs. 10 and Rs. 12 per kilowatt hour (kWh). Hence, the analysis reveals that, grid-tied PV systems of selected apparel buildings have achieved a LCOE which is lower than the purchase price of CEB. This guarantees a positive net earning throughout the contracted period. Moreover, continuous flow of the earnings ensures investment recovery for all (04) cases within five years, which is indicated through SPBP. Thus, NPV of the systems of selected cases indicates as a positive value, ensuring profitability of the investment. Accordingly, evaluation of economic indicators of this study ensure profitability for the selected apparel manufacturing buildings. Therefore,

based on selected cases, it is concluded that the use of grid-tied PV systems for the apparel sector ensure economic gain as a renewable energy technology.

5.3 Contributions to Knowledge

The present study makes several noteworthy contributions to the existing body of knowledge as follows:

- Investigating concept and applications of grid-tied PV system in global and local context
- Investigating prevailing economic benefits and challenges of the grid-tied PV systems in apparel manufacturing industry in Sri Lanka
- Investigating adoptable economic strategies to overcome economic constraints of the grid-tied PV systems in Sri Lanka
- Assessing and estimating current LCOE, NPV and SPBP values of the grid-tied PV systems in Sri Lanka in order to estimate the system's profitability for apparel manufacturing industry in Sri Lanka

5.4 Limitation of the study

Among apparel buildings, the study was undertaken in four apparel facilities with implemented grid-tied PV systems fulfilling the above criteria. Data collection was limited to four case studies as the data saturation was reached. Due to the absence of estimates in the selected cases, key inputs such as maintenance costs and discount factors were calculated based on the industrial practices when measuring the economic indicators. The findings of the study should be considered in light of the above discussed limitations.

5.5 Recommendations

Recommendations were derived based on the conclusions of the study. Key recommendations were suggested for industry practitioners and academic research purposes.

➤ **For Industry Practitioners**

The identified prevailing economic benefits can be monitored by the industrial practitioners to ensure that whether they are achieved after the implementation of the system. Recognized economic challenges and economic strategies provide avenue for energy users to identify challenges at the initial stages and adopt appropriate strategies to narrow the economic constraints of the system. And the calculated economic indicators can be used to encourage new users to enter solar energy market with the encouragement of ensured economic gain.

➤ **For Academic Research**

The study could be further developed by,

- Investigating economic gain of grid-tied PV system for other industries in Sri Lanka.
- Investigating social and environmental gain of grid-tied PV system for the industries in Sri Lanka.

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Appendix A - Semi-Structured Data Collection Instrument

Topic of the Study: Economic Evaluation of Grid-Tied PV Technology in Apparel Sector Sri Lanka

Aim and Objectives of the study

The aim of this research is to conduct an economic evaluation of grid-tied PV technology in apparel manufacturing industry in Sri Lanka.

This aim was achieved through the following objectives;

- i. Critically review the concept and applications of grid-tied PV system in global context
- ii. Examine the economic benefits and challenges of grid-tied PV system for apparel manufacturing industry in Sri Lanka.
- iii. Propose strategies to overcome the economic challenges of the grid-tied PV system for apparel manufacturing industry in Sri Lanka.
- iv. Assess the economic gain of grid-tied PV for apparel manufacturing industry in Sri Lanka.

Interview Guideline

Name (Optional):

.....

Designation:

.....

Name of Organization:

Date:

SECTION I – Economic Benefits of Implementing Grid-Tied PV System

1. Answer the following questions on economic benefits of grid-Tied PV system **FOR THE ORGANIZATION**
 - a. How does the power generation of grid-tied PV system, impact on organization monthly electricity bill (high/low)?
 - b. Is there a significant pattern in power generation of grid-tied PV system over its operation period? If answer is YES, What are the reason for such variations in power generation of the system?
 - c. What is your view on maintenance cost (High/ Low), of grid-tied PV system? Please provide reasons for your answer?
 - d. Compared to local utility grid, is the unit cost of grid-tied PV system is high or low? Please specify reasons for your answer?
 - e. Explain what are the other economic benefits achieved by using grid-tied PV for your organization? (Zero requirements of additional land, less expenses on supporting structures, creating job opportunities etc.)
2. Answer the following questions on economic benefits of grid-Tied PV system, **IN GENERAL**
 - a) Compared to other renewable system, what are the major reasons for selecting grid-tied PV technology for your organization?
 - b) How does your organizational grid-tied PV system support the local utility grid?
 - c) Is it cost effective to implement in grid-tied PV system for apparel sector Sri Lanka? Please provide reasons for your answer
 - d) How does the use of grid-tied PV system support the economy of the country?

SECTION II – Economic Challenges of Implementing Grid-Tied PV System

3. In the **initial stage** of the system, what are the economic challenges faced by your organization? In terms of,
 - a) High initial/ investment cost (Material, installation etc.)

- b) Financing difficulties
 - c) Do you believe that lack of subsidies is a challenge to implementation of grid-tied PV system? (Example - Inadequate support from government etc.)
4. In the **implementation stage** of the system, what are the economic challenges faced by your organization? In terms of,
- a) Supplier
 - b) Material/ components
 - c) Labor
5. What are the economic challenges encountered by your organization when **operating** the grid-tied PV system? In terms of,
- a) Maintenance (how often and any issues faced)
 - b) Replacement (Materials, etc.)
 - c) Coordinating Supplier
6. Did your organization recover the initial cost of the system (Simple payback period)? If not please provide reasons for your answer
7. Compared to other energy sources, what is your view on economic aspects of grid-tied PV technology for apparel manufacturing buildings? Please provide reasons for your answer in terms of,
- a) Renewable Sources
 - b) Conventional sources
8. Any other economic challenges of grid-tied PV technology for apparel manufacturing buildings in Sri Lanka?

SECTION III – Economic Strategies of Grid-Tied PV System

9. What are the financial strategies adopted by your organization to overcome the above mentioned (Q17 part k) economic challenges?
10. Have your organization been adopted the following economic/financial strategies of grid-tied PV system?
- Net Metering
 - Feed in Tariff

- Capital Subsidies
- Any Other

11. What is the nature of gain received by adopting above mentioned financial strategies for your organization?
12. Have you identified any stakeholders who can support the implementation of PV system?
13. Any suggestion would you like to make to improve the application of PV systems as an energy solution

Appendix B - Semi-Structured Data Collection Instrument – Document Review

Topic of the Study: Economic Evaluation of Grid-Tied PV Technology in Apparel Sector Sri Lanka

Aim and Objectives of the study

The aim of this research is to conduct an economic evaluation of grid-tied PV technology in apparel manufacturing industry in Sri Lanka.

This aim was achieved through the following objectives;

- v. Critically review the concept and applications of grid-tied PV system in global context
- vi. Examine the economic benefits and challenges of grid-tied PV system for apparel manufacturing industry in Sri Lanka.
- vii. Propose strategies to overcome the economic challenges of the grid-tied PV system for apparel manufacturing industry in Sri Lanka.
- viii. Assess the economic gain of grid-tied PV for apparel manufacturing industry in Sri Lanka.

Name (Optional):

Designation:

Name of Organization:

Date:

SECTION I – Information of the selected Apparel

01. Please answer the following general information of the building

- a) Number of floors of the building?
- b) Height of the building?
- c) Area of the building?

- d) Number of staff in the building?
- e) Rooftop area of the building?
- f) Type and material used for the roof?
- g) Direction of the roof?
- h) What are the electricity consuming services of the building?

SECTION II – Solar PV System Information

02. Please answer the following questions on the grid-tied PV system in your organization

- a. What is the available rooftop area of which the solar panel can be installed?
- b. What is the rooftop area utilized with solar PV panels?
- c. What is the type of PV panel used for the building?
- d. What is the year solar PV system installed?
- e. What is the life span of the solar PV system?
- f. Specify available warranties and guaranties for the installed PV system?
- g. How often maintenance perform for the installed PV system?
- h. How the solar panels are connected in the building?
 - i. Parallel
 - ii. Series
 - iii. Combination of Both

03. What is total capacity of the solar system?

04. What is the capacity of the PV panel?

05. What is total number of utilized PV panels?
06. What is the efficiency of the system?
- i. Design Efficiency :
 - ii. Actual Efficiency :
07. What is the type of inverter used for the solar system?
08. What is the efficiency of the inverter used for the solar system?
- i. Design Efficiency :
 - ii. Actual Efficiency :
09. Does the solar panels permanently fix to the roof?
 If yes, what is the slope of the panel?
 If not, please specify the used fixing technology?
10. What is the azimuth of the installed PV panels?
11. What is the solar insolation (KWh/m² per day) of the location?
12. Do you have any plans to expand the capacity of existing solar PV system?
 Please elaborate your answer

SECTION III – Costs Associated with Solar PV Systems

13. What are the costs associated with the solar PV system? (Please fill the following table)

Planning Stage	
Feasibility Study	
Consultant Fee	
Authority and Institution Costs	
Construction Stage	
Site set-up (Roof)	
Transportation Cost (Freight)	
Mounting additional structure	
PV Module Costs	
PV Inverter Cost	
Balance of the System Cost (BOS)	
Taxes and Customs	
Interest expenditures	
Civil Work	
System Interconnection Cost	
Operation and maintenance	
Operation (Labor)	
Maintenance (Cleaning, component replacement)	
Any Replacement Cost (Inverter)	
Disposal	
Disposal Costs	

14. What are the sources of financing used for your organization's grid-tied PV system?
15. What are the capital subsidies received by your organization when implementing grid-tied PV system? Please provide the amount received as subsidies in Rupees (Rs.)

SECTION IV – Revenues Associated with Solar PV

16. What is the monthly power generation by solar PV system and utility grid?
(Please fill the following table)

	2019		
Month	Power generated by solar PV system (KWh)	Power generated by utility grid (KWh)	Monthly Electricity Bill (Rs)
January			
February			
March			
April			
May			
June			
July			
August			
September			
October			
November			
December			

	2020		
Month	Power generated by solar PV system (KWh)	Power generated by utility grid (KWh)	Monthly Electricity Bill (Rs)
January			
February			
March			
April			
May			
June			
July			
August			
September			
October			
November			
December			

Appendix C – LCOE Calculation Table

LCOE of Case A

Yr.	I_t (Rs.)	$M\&O_t$ (Rs.)	$\frac{(I_t + O_t + M_t + F_t)}{(1+r)^t}$	S_t (kWh)	$S_t \frac{(1-d)^t}{(1+r)^t}$
0	159,398,340.70		159,398,340.70		
1		1,593,983.40	1,449,075.82	1,797,958.90	1,625,518.30
2		1,593,983.40	1,317,341.65	1,797,958.90	1,469,616.31
3		1,593,983.40	1,197,583.32	1,797,958.90	1,328,666.75
4		1,593,983.40	1,088,712.11	1,797,958.90	1,201,235.53
5		1,593,983.40	989,738.28	1,797,958.90	1,086,026.12
6		1,593,983.40	899,762.07	1,797,958.90	981,866.34
7		1,593,983.40	817,965.52	1,797,958.90	887,696.44
8		1,593,983.40	743,605.02	1,797,958.90	802,558.28
9		1,593,983.40	676,004.56	1,797,958.90	725,585.64
10		1,593,983.40	614,549.60	1,797,958.90	655,995.38
11		1,593,983.40	558,681.46	1,797,958.90	593,079.46
12		1,593,983.40	507,892.23	1,797,958.90	536,197.75
13		1,593,983.40	461,720.21	1,797,958.90	484,771.51
14		1,593,983.40	419,745.65	1,797,958.90	438,277.52
15		1,593,983.40	381,586.95	1,797,958.90	396,242.72
16		1,593,983.40	346,897.23	1,797,958.90	358,239.44
17		1,593,983.40	315,361.12	1,797,958.90	323,881.02
18		1,593,983.40	286,691.93	1,797,958.90	292,817.89
19		1,593,983.40	260,629.02	1,797,958.90	264,733.99
20		1,593,983.40	236,935.48	1,797,958.90	239,343.59
			Rs. 172,968,819.94		14,692,349.98 kWh

LCOE of Case B

Yr.	I_t (Rs.)	M&O _t (Rs.)	$\frac{(I_t + O_t + M_t + F_t)}{(1+r)^t}$	S_t (kWh)	$S_t \frac{(1-d)^t}{(1+r)^t}$
0	119,714,333.23		119,714,333.23		
1		1,197,143.33	1,088,312.12	1,345,503.15	1,216,457.17
2		1,197,143.33	989,374.65	1,345,503.15	1,099,787.87
3		1,197,143.33	899,431.50	1,345,503.15	994,308.21
4		1,197,143.33	817,665.00	1,345,503.15	898,945.01
5		1,197,143.33	743,331.82	1,345,503.15	812,728.02
6		1,197,143.33	675,756.20	1,345,503.15	734,780.01
7		1,197,143.33	614,323.82	1,345,503.15	664,307.93
8		1,197,143.33	558,476.20	1,345,503.15	600,594.76
9		1,197,143.33	507,705.64	1,345,503.15	542,992.26
10		1,197,143.33	461,550.58	1,345,503.15	490,914.37
11		1,197,143.33	419,591.43	1,345,503.15	443,831.22
12		1,197,143.33	381,446.76	1,345,503.15	401,263.77
13		1,197,143.33	346,769.78	1,345,503.15	362,778.92
14		1,197,143.33	315,245.25	1,345,503.15	327,985.13
15		1,197,143.33	286,586.60	1,345,503.15	296,528.37
16		1,197,143.33	260,533.27	1,345,503.15	268,088.61
17		1,197,143.33	236,848.43	1,345,503.15	242,376.47
18		1,197,143.33	215,316.75	1,345,503.15	219,130.36
19		1,197,143.33	195,742.50	1,345,503.15	198,113.77
20		1,197,143.33	177,947.73	1,345,503.15	179,112.86
			Rs. 129,906,289.25		10,995,025.07kWh

LCOE of Case C

Yr.	I _t (Rs.)	M&O _t (Rs.)	$\frac{(It + Ot + Mt + Ft)}{(1+r)^t}$	S _t (kWh)	$S_t \frac{(1-d)^t}{(1+r)^t}$
0	239,350,664.18		239,350,664.18		
1		2,393,506.64	2,175,915.13	2,707,168.50	2,443,834.84
2		2,393,506.64	1,978,104.66	2,707,168.50	2,206,116.36
3		2,393,506.64	1,798,276.96	2,707,168.50	1,991,521.40
4		2,393,506.64	1,634,797.24	2,707,168.50	1,797,800.68
5		2,393,506.64	1,486,179.31	2,707,168.50	1,622,923.71
6		2,393,506.64	1,351,072.10	2,707,168.50	1,465,057.49
7		2,393,506.64	1,228,247.36	2,707,168.50	1,322,547.36
8		2,393,506.64	1,116,588.51	2,707,168.50	1,193,899.57
9		2,393,506.64	1,015,080.47	2,707,168.50	1,077,765.70
10		2,393,506.64	922,800.42	2,707,168.50	972,928.49
11		2,393,506.64	838,909.48	2,707,168.50	878,289.08
12		2,393,506.64	762,644.98	2,707,168.50	792,855.51
13		2,393,506.64	693,313.62	2,707,168.50	715,732.29
14		2,393,506.64	630,285.11	2,707,168.50	646,111.06
15		2,393,506.64	572,986.46	2,707,168.50	583,262.07
16		2,393,506.64	520,896.78	2,707,168.50	526,526.58
17		2,393,506.64	473,542.53	2,707,168.50	475,309.91
18		2,393,506.64	430,493.21	2,707,168.50	429,075.21
19		2,393,506.64	391,357.46	2,707,168.50	387,337.90
20		2,393,506.64	355,779.51	2,707,168.50	349,660.48
			Rs 259,727,935.47		21,878,555.70 kWh

LCOE of Case D

Year	I_t (Rs.)	M&O _t (Rs.)	$\frac{(I_t + O_t + M_t + F_t)}{(1+r)^t}$	S_t (kWh)	$St \frac{(1-d)^t}{(1+r)^t}$
0	69,088,000.00		69,088,000.00		
1		690,880.00	628072.73	904,294.8	816331.58
2		690,880.00	570975.21	904,294.8	736924.78
3		690,880.00	519068.37	904,294.8	665242.10
4		690,880.00	471880.34	904,294.8	600532.18
5		690,880.00	428982.12	904,294.8	542116.78
6		690,880.00	389983.75	904,294.8	489383.60
7		690,880.00	354530.68	904,294.8	441779.92
8		690,880.00	322300.62	904,294.8	398806.79
9		690,880.00	293000.56	904,294.8	360013.76
10		690,880.00	266364.15	904,294.8	324994.24
11		690,880.00	242149.23	904,294.8	293381.17
12		690,880.00	220135.66	904,294.8	264843.18
13		690,880.00	200123.33	904,294.8	239081.16
14		690,880.00	181930.30	904,294.8	215825.08
15		690,880.00	165391.18	904,294.8	194831.19
16		690,880.00	150355.62	904,294.8	175879.43
17		690,880.00	136686.92	904,294.8	158771.16
18		690,880.00	124260.84	904,294.8	143327.05
19		690,880.00	112964.40	904,294.8	129385.24
20		690,880.00	102694.91	904,294.8	116799.59
			Rs. 74,969,850.90		7,308,249.98 kWh

PVSYST V6.88		07/09/20	Page 1/7
Grid-Connected System: Simulation parameters			
Project :	CaseA_Wathupitiwala		
Geographical Site	Watupitiwala	Country	Sri Lanka
Situation	Latitude	7.12° N	Longitude 80.11° E
Time defined as	Legal Time	Time zone UT+5.5	Altitude 19 m
	Albedo	0.20	
Meteo data:	Watupitiwala	Meteonorm 7.2, Sat=5% - Synthetic	
Simulation variant :	CaseA_Wathupitiwala		
	Simulation date	07/09/20 23h01	
Simulation parameters	System type	No 3D scene defined, no shadings	
2 orientations	tilts/azimuths	10°/135° and 10°/-45°	
Models used	Transposition	Perez	Diffuse Perez, Meteonorm
Horizon	Average Height	2.2°	
Near Shadings	No Shadings		
User's needs :	Unlimited load (grid)		
PV Arrays Characteristics (8 kinds of array defined)			
Sub-array "Sub-array #1"	Orientation	#1	Tilt/Azimuth 10°/135°
PV module	Si-mono	Model	LR6-72 PE 360 M
Original PVsyst database	Manufacturer	Longi Solar	
Number of PV modules	In series	18 modules	In parallel 13 strings
Total number of PV modules	Nb. modules	234	Unit Nom. Power 360 Wp
Array global power	Nominal (STC)	84.2 kWp	At operating cond. 76.4 kWp (50°C)
Array operating characteristics (50°C)	U mpp	630 V	I mpp 121 A
Sub-array "Sub-array #2"	Orientation	#2	Tilt/Azimuth 10°/-45°
PV module	Si-mono	Model	LR6-72 PE 365 M
Original PVsyst database	Manufacturer	Longi Solar	
Number of PV modules	In series	18 modules	In parallel 5 strings
Total number of PV modules	Nb. modules	90	Unit Nom. Power 365 Wp
Array global power	Nominal (STC)	32.9 kWp	At operating cond. 29.78 kWp (50°C)
Array operating characteristics (50°C)	U mpp	635 V	I mpp 47 A
Sub-array "Sub-array #3"	Orientation	#2	Tilt/Azimuth 10°/-45°
PV module	Si-mono	Model	LR6-72 PE 360 M
Original PVsyst database	Manufacturer	Longi Solar	
Number of PV modules	In series	19 modules	In parallel 8 strings
Total number of PV modules	Nb. modules	152	Unit Nom. Power 360 Wp
Array global power	Nominal (STC)	54.7 kWp	At operating cond. 49.6 kWp (50°C)
Array operating characteristics (50°C)	U mpp	665 V	I mpp 75 A
Sub-array "Sub-array #4"	Orientation	#2	Tilt/Azimuth 10°/-45°
PV module	Si-mono	Model	LR6-72 PE 365 M
Original PVsyst database	Manufacturer	Longi Solar	
Number of PV modules	In series	20 modules	In parallel 50 strings
Total number of PV modules	Nb. modules	1000	Unit Nom. Power 365 Wp
Array global power	Nominal (STC)	365 kWp	At operating cond. 331 kWp (50°C)
Array operating characteristics (50°C)	U mpp	705 V	I mpp 469 A

Grid-Connected System: Simulation parameters

Sub-array "Sub-array #5"	Orientation	#2	Tilt/Azimuth	10°/-45°
PV module	Si-mono	Model	LR6-72 PE 360 M	
Original PVsyst database	Manufacturer	Longi Solar		
Number of PV modules	In series	18 modules	In parallel	10 strings
Total number of PV modules	Nb. modules	180	Unit Nom. Power	360 Wp
Array global power	Nominal (STC)	64.8 kWp	At operating cond.	58.8 kWp (50°C)
Array operating characteristics (50°C)	U mpp	630 V	I mpp	93 A
Sub-array "Sub-array #6"	Orientation	#1	Tilt/Azimuth	10°/135°
PV module	Si-mono	Model	LR6-72 PE 365 M	
Original PVsyst database	Manufacturer	Longi Solar		
Number of PV modules	In series	20 modules	In parallel	20 strings
Total number of PV modules	Nb. modules	400	Unit Nom. Power	365 Wp
Array global power	Nominal (STC)	146 kWp	At operating cond.	132 kWp (50°C)
Array operating characteristics (50°C)	U mpp	705 V	I mpp	188 A
Sub-array "Sub-array #7"	Orientation	#1	Tilt/Azimuth	10°/135°
PV module	Si-mono	Model	LR6-72 PE 360 M	
Original PVsyst database	Manufacturer	Longi Solar		
Number of PV modules	In series	18 modules	In parallel	50 strings
Total number of PV modules	Nb. modules	900	Unit Nom. Power	360 Wp
Array global power	Nominal (STC)	324 kWp	At operating cond.	294 kWp (50°C)
Array operating characteristics (50°C)	U mpp	630 V	I mpp	467 A
Sub-array "Sub-array #8"	Orientation	#1	Tilt/Azimuth	10°/135°
PV module	Si-mono	Model	LR6-72 PE 360 M	
Original PVsyst database	Manufacturer	Longi Solar		
Number of PV modules	In series	16 modules	In parallel	4 strings
Total number of PV modules	Nb. modules	64	Unit Nom. Power	360 Wp
Array global power	Nominal (STC)	23.04 kWp	At operating cond.	20.90 kWp (50°C)
Array operating characteristics (50°C)	U mpp	560 V	I mpp	37 A
Total Arrays global power	Nominal (STC)	1095 kWp	Total	3020 modules
	Module area	5854 m²	Cell area	5327 m ²
Sub-array "Sub-array #1" : Inverter	Model	Sunny Tripower_Core1_MOW		
Custom parameters definition	Manufacturer	SMA		
Characteristics	Operating Voltage	150-1000 V	Unit Nom. Power	50.0 kWac
Inverter pack	Nb. of inverters	7 * MPPT 17 %	Total Power	58 kWac
			Pnom ratio	1.44
Sub-array "Sub-array #2" : Inverter	Model	Sunny Tripower_Core1_MOW		
Custom parameters definition	Manufacturer	SMA		
Characteristics	Operating Voltage	150-1000 V	Unit Nom. Power	50.0 kWac
Inverter pack	Nb. of inverters	5 * MPPT 17 %	Total Power	42 kWac
			Pnom ratio	0.79
Sub-array "Sub-array #3" : Inverter	Model	Sunny Tripower_Core1_MOW		
Custom parameters definition	Manufacturer	SMA		
Characteristics	Operating Voltage	150-1000 V	Unit Nom. Power	50.0 kWac
Inverter pack	Nb. of inverters	6 * MPPT 17 %	Total Power	50 kWac
			Pnom ratio	1.09
Sub-array "Sub-array #4" : Inverter	Model	Sunny Tripower 60-10		
Original PVsyst database	Manufacturer	SMA		
Characteristics	Operating Voltage	570-800 V	Unit Nom. Power	60.0 kWac
Inverter pack	Nb. of inverters	5 units	Total Power	300 kWac
			Pnom ratio	1.22

Grid-Connected System: Simulation parameters

Sub-array "Sub-array #5" : Inverter		Model	Sunny Tripower 60-10		
Original PVsyst database		Manufacturer	SMA		
Characteristics		Operating Voltage	570-800 V	Unit Nom. Power	60.0 kWac
Inverter pack		Nb. of inverters	1 units	Total Power	60 kWac
				Pnom ratio	1.08
Sub-array "Sub-array #6" : Inverter		Model	Sunny Tripower 60-10		
Original PVsyst database		Manufacturer	SMA		
Characteristics		Operating Voltage	570-800 V	Unit Nom. Power	60.0 kWac
Inverter pack		Nb. of inverters	2 units	Total Power	120 kWac
				Pnom ratio	1.22
Sub-array "Sub-array #7" : Inverter		Model	Sunny Tripower 60-10		
Original PVsyst database		Manufacturer	SMA		
Characteristics		Operating Voltage	570-800 V	Unit Nom. Power	60.0 kWac
Inverter pack		Nb. of inverters	5 units	Total Power	300 kWac
				Pnom ratio	1.08
Sub-array "Sub-array #8" : Inverter		Model	Sunny Tripower 20000TL-30		
Original PVsyst database		Manufacturer	SMA		
Characteristics		Operating Voltage	320-800 V	Unit Nom. Power	20.0 kWac
Inverter pack		Nb. of inverters	2 * MPPT 50 %	Total Power	20 kWac
				Pnom ratio	1.15
Total		Nb. of inverters	17	Total Power	950 kWac

PV Array loss factors

Array Soiling Losses			Loss Fraction	3.0 %
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Array#1	87 mOhm	Loss Fraction	1.5 % at STC
	Array#2	226 mOhm	Loss Fraction	1.5 % at STC
	Array#3	149 mOhm	Loss Fraction	1.5 % at STC
	Array#4	25 mOhm	Loss Fraction	1.5 % at STC
	Array#5	113 mOhm	Loss Fraction	1.5 % at STC
	Array#6	63 mOhm	Loss Fraction	1.5 % at STC
	Array#7	23 mOhm	Loss Fraction	1.5 % at STC
	Array#8	250 mOhm	Loss Fraction	1.5 % at STC
	Global		Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.1 % at STC
LID - Light Induced Degradation			Loss Fraction	1.5 %
Module Quality Loss			Loss Fraction	2.0 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect (IAM): User defined profile				

0°	25°	45°	60°	65°	70°	75°	80°	90°
1.000	1.000	0.995	0.962	0.936	0.903	0.851	0.754	0.000

System loss factors	Wires: 3x1000.0 mm²	120 m	Loss Fraction	1.5 % at STC
Unavailability of the system		10.9 days, 3 periods	Time fraction	3.0 %

Grid-Connected System: Horizon definition

Project : CaseA_Wathupitiwala

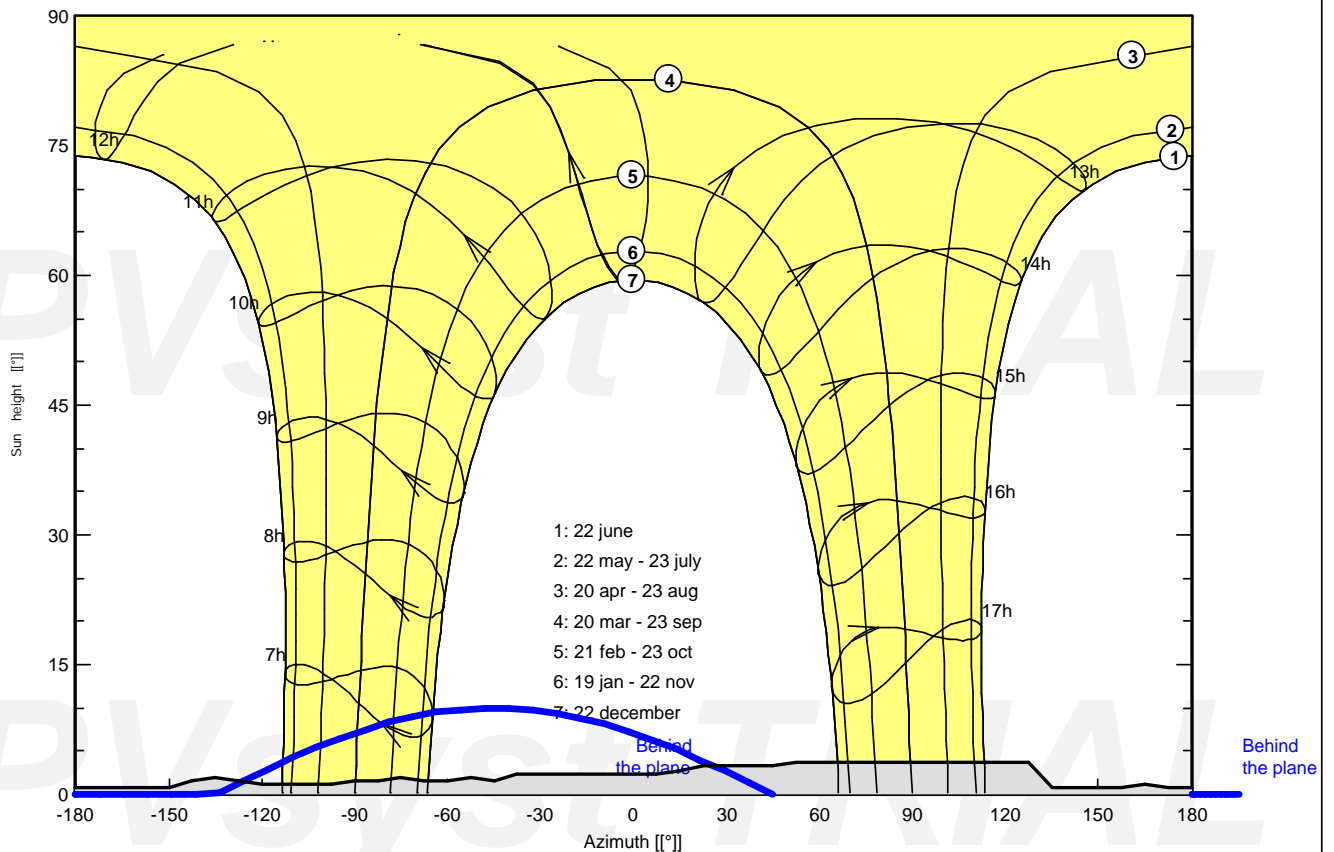
Simulation variant : CaseA_Wathupitiwala

Main system parameters	System type	No 3D scene defined, no shadings		
Horizon	Average Height	2.2°		
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/135° and 10°/-45°		
PV modules	Model	LR6-72 PE 360 M	Pnom	360 Wp
PV modules	Model	LR6-72 PE 365 M	Pnom	365 Wp
PV Array	Nb. of modules	3020	Pnom total	1095 kWp
Inverter	Model	Sunny Tripower_Core1_MOWP	Pnom	50.0 kW ac
Inverter	Model	Sunny Tripower 60-10	Pnom	60.0 kW ac
Inverter	Model	Sunny Tripower 20000TL-30	Pnom	20.00 kW ac
Inverter pack	Nb. of units	17.0	Pnom total	950 kW ac
User's needs	Unlimited load (grid)			

Horizon	Average Height	2.2°	Diffuse Factor	0.99
	Albedo Factor	100 %	Albedo Fraction	0.90

Height [°]	0.8	0.8	1.5	1.9	1.5	1.1	1.1	1.5	1.5	1.9	1.5	1.5	1.9
Azimuth [°]	-180	-150	-143	-135	-128	-120	-98	-90	-83	-75	-68	-60	-53
Height [°]	1.5	2.3	2.3	2.7	3.4	3.4	3.8	3.8	0.8	0.8	1.1	0.8	0.8
Azimuth [°]	-45	-38	8	15	23	45	53	128	135	158	165	173	180

Horizon from PVGIS website API, Lat=7°7'25', Long=80°6'18', Alt=19m



Grid-Connected System: Main results

Project : CaseA_Wathupitiwala

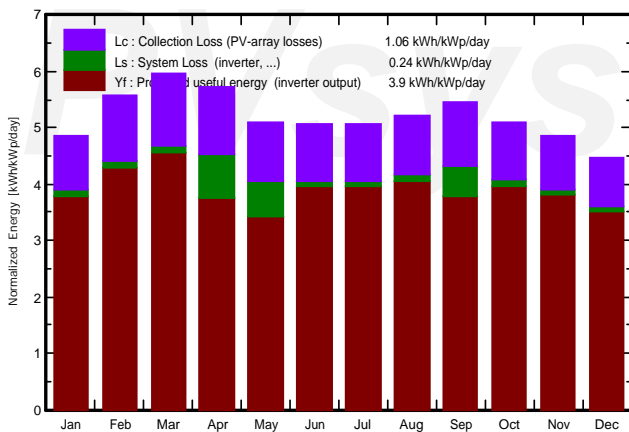
Simulation variant : CaseA_Wathupitiwala

Main system parameters	System type	No 3D scene defined, no shadings		
Horizon	Average Height	2.2°		
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/135° and 10°/-45°		
PV modules	Model	LR6-72 PE 360 M	Pnom	360 Wp
PV modules	Model	LR6-72 PE 365 M	Pnom	365 Wp
PV Array	Nb. of modules	3020	Pnom total	1095 kWp
Inverter	Model	Sunny Tripower_Core1_MOWP	Pnom	50.0 kW ac
Inverter	Model	Sunny Tripower 60-10	Pnom	60.0 kW ac
Inverter	Model	Sunny Tripower 20000TL-30	Pnom	20.00 kW ac
Inverter pack	Nb. of units	17.0	Pnom total	950 kW ac
User's needs	Unlimited load (grid)			

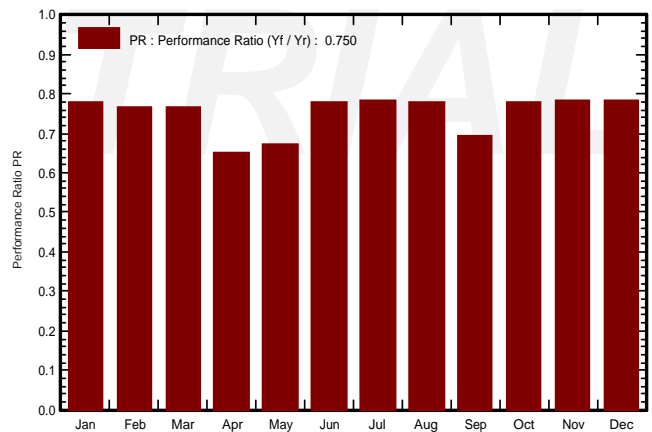
Main simulation results

System Production **Produced Energy 1559 MWh/year** Specific prod. 1424 kWh/kWp/year
 Performance Ratio PR 75.02 %

Normalized productions (per installed kWp): Nominal power 1095 kWp



Performance Ratio PR



CaseA_Wathupitiwala
Balances and main results

	GlobHor kWh/m ²	DiffHor kWh/m ²	T_Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray MWh	E_Grid MWh	PR
January	152.7	74.09	26.39	151.0	141.9	132.1	128.7	0.778
February	158.0	60.86	26.92	156.3	147.6	135.0	131.4	0.768
March	186.1	73.59	27.63	184.5	174.5	158.8	154.6	0.765
April	173.0	70.33	27.27	171.8	162.6	148.4	122.8	0.653
May	159.3	76.66	28.57	158.4	149.4	137.7	116.6	0.673
June	153.1	75.42	27.56	152.3	143.7	133.5	130.1	0.780
July	157.8	86.00	27.76	156.8	147.8	137.9	134.4	0.783
August	163.0	83.75	27.68	162.0	153.0	141.7	138.0	0.778
September	164.5	70.93	27.06	163.3	154.4	141.7	124.2	0.695
October	159.4	75.93	26.95	157.9	149.1	138.2	134.6	0.778
November	147.2	67.37	25.93	145.6	137.4	128.2	124.9	0.783
December	140.3	66.71	26.18	138.6	130.6	122.1	118.9	0.783
Year	1914.4	881.64	27.16	1898.6	1792.0	1655.4	1559.0	0.750

Legends: GlobHor Horizontal global irradiation GlobEff Effective Global, corr. for IAM and shadings
 DiffHor Horizontal diffuse irradiation EArray Effective energy at the output of the array
 T_Amb T amb. E_Grid Energy injected into grid
 GlobInc Global incident in coll. plane PR Performance Ratio

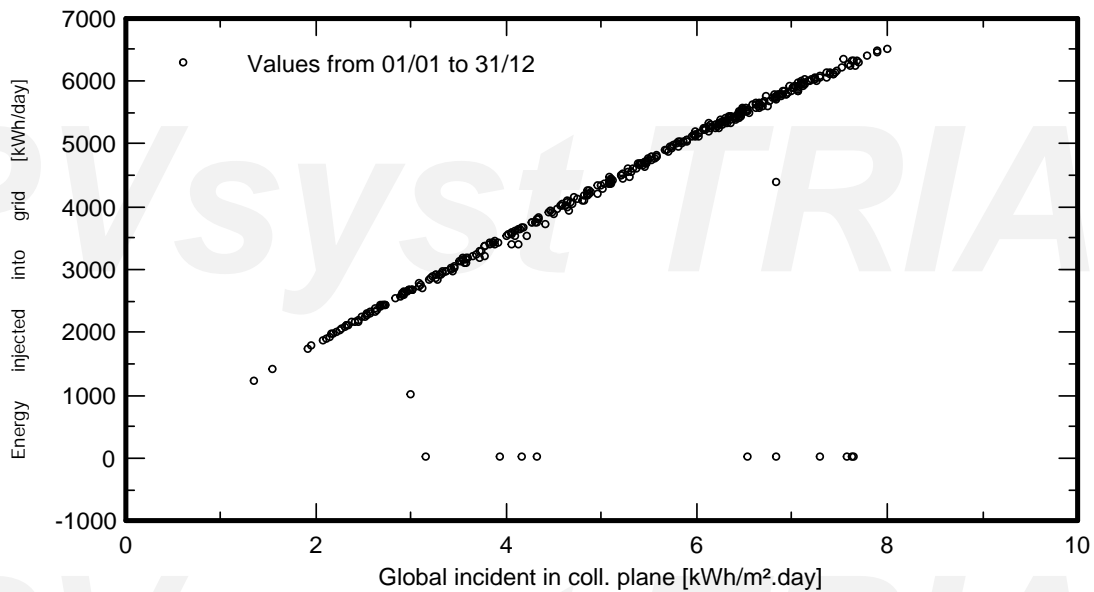
Grid-Connected System: Special graphs

Project : CaseA_Wathupitiwala

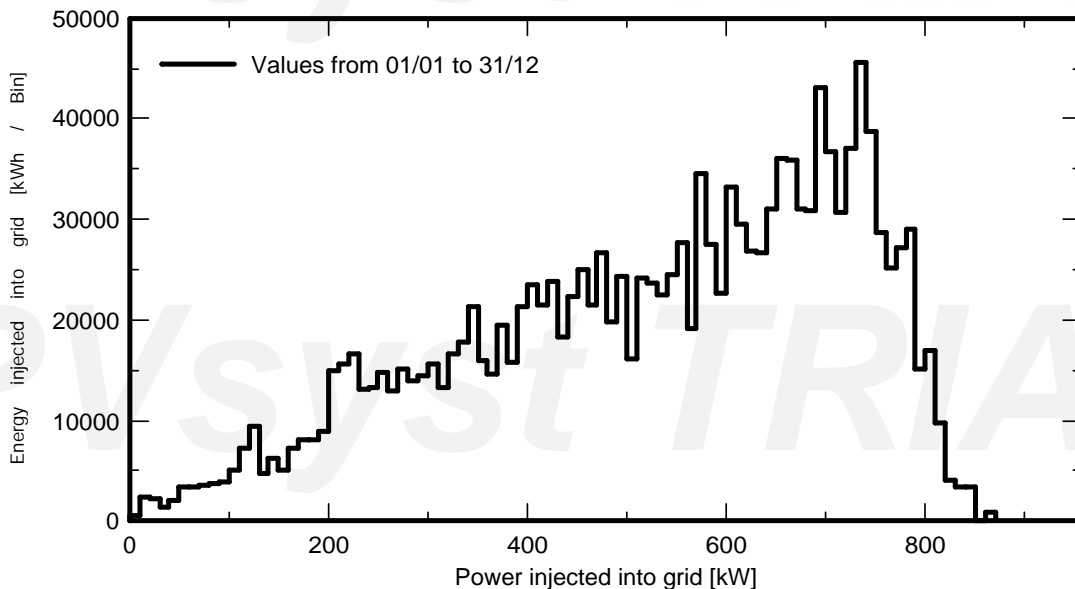
Simulation variant : CaseA_Wathupitiwala

Main system parameters	System type	No 3D scene defined, no shadings		
Horizon	Average Height	2.2°		
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/135° and 10°/-45°		
PV modules	Model	LR6-72 PE 360 M	Pnom	360 Wp
PV modules	Model	LR6-72 PE 365 M	Pnom	365 Wp
PV Array	Nb. of modules	3020	Pnom total	1095 kWp
Inverter	Model	Sunny Tripower_Core1_MOWP	Pnom	50.0 kW ac
Inverter	Model	Sunny Tripower 60-10	Pnom	60.0 kW ac
Inverter	Model	Sunny Tripower 20000TL-30	Pnom	20.00 kW ac
Inverter pack	Nb. of units	17.0	Pnom total	950 kW ac
User's needs	Unlimited load (grid)			

Daily Input/Output diagram



System Output Power Distribution



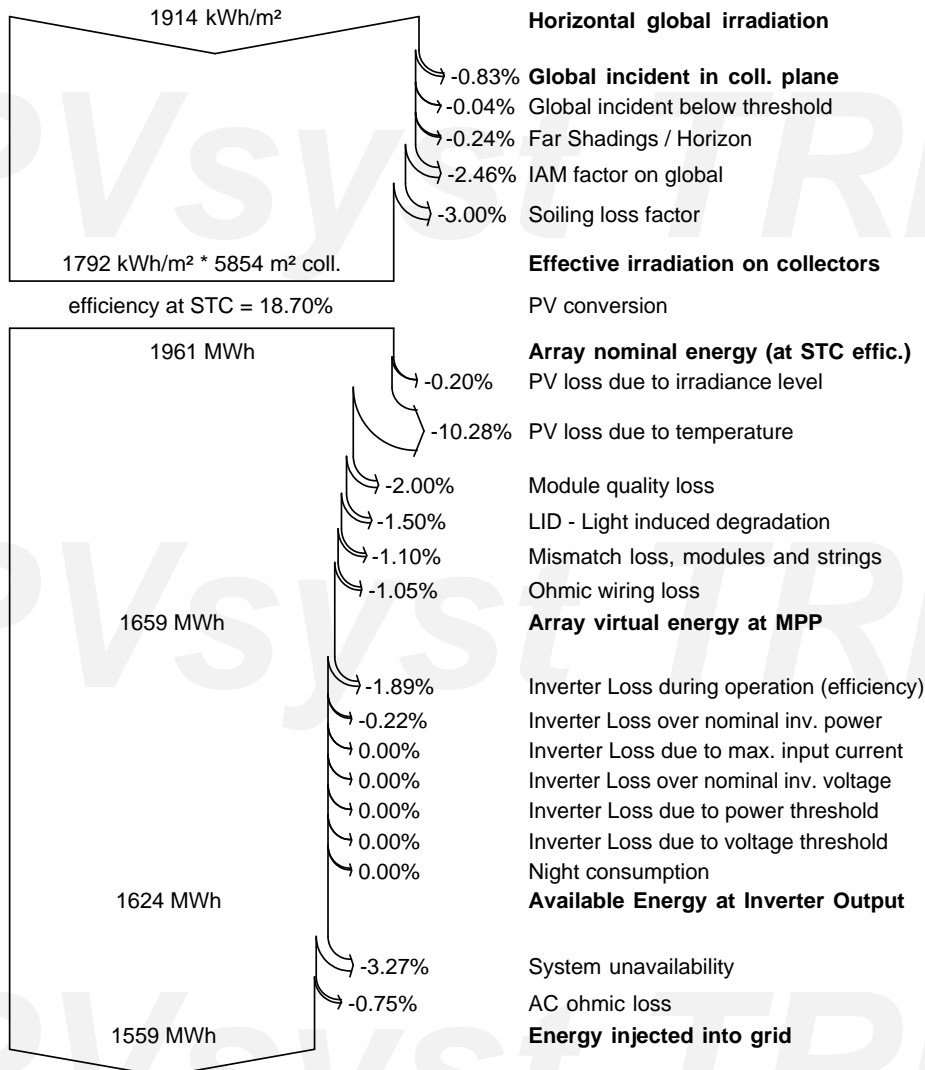
Grid-Connected System: Loss diagram

Project : CaseA_Wathupitiwala

Simulation variant : CaseA_Wathupitiwala

Main system parameters	System type	No 3D scene defined, no shadings		
Horizon	Average Height	2.2°		
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/135° and 10°/-45°		
PV modules	Model	LR6-72 PE 360 M	Pnom	360 Wp
PV modules	Model	LR6-72 PE 365 M	Pnom	365 Wp
PV Array	Nb. of modules	3020	Pnom total	1095 kWp
Inverter	Model	Sunny Tripower_Core1_MOWP	Pnom	50.0 kW ac
Inverter	Model	Sunny Tripower 60-10	Pnom	60.0 kW ac
Inverter	Model	Sunny Tripower 20000TL-30	Pnom	20.00 kW ac
Inverter pack	Nb. of units	17.0	Pnom total	950 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Grid-Connected System: Simulation parameters

Project : **CaseB_Biyagama**

Geographical Site **Yatihena** Country **Sri Lanka**

Situation Latitude 6.96° N Longitude 80.01° E

Time defined as Legal Time Time zone UT+5.5 Altitude 12 m

Albedo 0.20

Meteo data: **Yatihena** Meteonorm 7.2 - Synthetic

Simulation variant : **CaseB_Biyagama**

Simulation date 07/09/20 23h33

Simulation parameters System type **No 3D scene defined, no shadings**

2 orientations tilts/azimuths 10°/-135° and 10°/45°

Models used Transposition Perez Diffuse Perez, Meteonorm

Horizon Average Height 1.1°

Near Shadings No Shadings

User's needs : Unlimited load (grid)

PV Arrays Characteristics (5 kinds of array defined)

PV module	Si-mono	Model	LR6-72 PE 370 M
Original PVSyst database	Manufacturer	Longi Solar	
Sub-array "Sub-array #1"	Orientation	#1	Tilt/Azimuth 10°/-135°
Number of PV modules	In series	19 modules	In parallel 40 strings
Total number of PV modules	Nb. modules	760	Unit Nom. Power 370 Wp
Array global power	Nominal (STC)	281 kWp	At operating cond. 255 kWp (50°C)
Array operating characteristics (50°C)	U mpp	676 V	I mpp 377 A
Sub-array "Sub-array #2"	Orientation	#1	Tilt/Azimuth 10°/-135°
Number of PV modules	In series	19 modules	In parallel 4 strings
Total number of PV modules	Nb. modules	76	Unit Nom. Power 370 Wp
Array global power	Nominal (STC)	28.12 kWp	At operating cond. 25.52 kWp (50°C)
Array operating characteristics (50°C)	U mpp	676 V	I mpp 38 A
Sub-array "Sub-array #3"	Orientation	#2	Tilt/Azimuth 10°/45°
Number of PV modules	In series	19 modules	In parallel 60 strings
Total number of PV modules	Nb. modules	1140	Unit Nom. Power 370 Wp
Array global power	Nominal (STC)	422 kWp	At operating cond. 383 kWp (50°C)
Array operating characteristics (50°C)	U mpp	676 V	I mpp 566 A
Sub-array "Sub-array #4"	Orientation	#2	Tilt/Azimuth 10°/45°
Number of PV modules	In series	19 modules	In parallel 4 strings
Total number of PV modules	Nb. modules	76	Unit Nom. Power 370 Wp
Array global power	Nominal (STC)	28.12 kWp	At operating cond. 25.52 kWp (50°C)
Array operating characteristics (50°C)	U mpp	676 V	I mpp 38 A
Sub-array "Sub-array #5"	Orientation	#2	Tilt/Azimuth 10°/45°
Number of PV modules	In series	18 modules	In parallel 9 strings
Total number of PV modules	Nb. modules	162	Unit Nom. Power 370 Wp
Array global power	Nominal (STC)	59.9 kWp	At operating cond. 54.4 kWp (50°C)
Array operating characteristics (50°C)	U mpp	641 V	I mpp 85 A
Total Arrays global power	Nominal (STC)	819 kWp	Total 2214 modules
	Module area	4292 m²	Cell area 3905 m ²

Grid-Connected System: Simulation parameters

Sub-array "Sub-array #1" : Inverter		Model	Sunny Tripower 60-10	
Original PVsyst database	Manufacturer	SMA		
Characteristics	Operating Voltage	570-800 V	Unit Nom. Power	60.0 kWac
Inverter pack	Nb. of inverters	4 units	Total Power	240 kWac
			Pnom ratio	1.17
Sub-array "Sub-array #2" : Inverter		Model	Sunny Tripower_Core1_MOW	
Custom parameters definition	Manufacturer	SMA		
Characteristics	Operating Voltage	150-1000 V	Unit Nom. Power	50.0 kWac
Inverter pack	Nb. of inverters	3 * MPPT 17 %	Total Power	25 kWac
			Pnom ratio	1.12
Sub-array "Sub-array #3" : Inverter		Model	Sunny Tripower 60-10	
Original PVsyst database	Manufacturer	SMA		
Characteristics	Operating Voltage	570-800 V	Unit Nom. Power	60.0 kWac
Inverter pack	Nb. of inverters	6 units	Total Power	360 kWac
			Pnom ratio	1.17
Sub-array "Sub-array #4" : Inverter		Model	Sunny Tripower_Core1_MOW	
Custom parameters definition	Manufacturer	SMA		
Characteristics	Operating Voltage	150-1000 V	Unit Nom. Power	50.0 kWac
Inverter pack	Nb. of inverters	3 * MPPT 17 %	Total Power	25 kWac
			Pnom ratio	1.12
Sub-array "Sub-array #5" : Inverter		Model	Sunny Tripower_Core1_MOW	
Custom parameters definition	Manufacturer	SMA		
Characteristics	Operating Voltage	150-1000 V	Unit Nom. Power	50.0 kWac
Inverter pack	Nb. of inverters	6 * MPPT 17 %	Total Power	50 kWac
			Pnom ratio	1.20
Total	Nb. of inverters	12	Total Power	700 kWac

PV Array loss factors

Array Soiling Losses		Loss Fraction	3.0 %
Thermal Loss factor	Uc (const) 20.0 W/m²K	Uv (wind) 0.0 W/m²K / m/s	
Wiring Ohmic Loss	Array#1 30 mOhm	Loss Fraction	1.5 % at STC
	Array#2 299 mOhm	Loss Fraction	1.5 % at STC
	Array#3 20 mOhm	Loss Fraction	1.5 % at STC
	Array#4 299 mOhm	Loss Fraction	1.5 % at STC
	Array#5 126 mOhm	Loss Fraction	1.5 % at STC
	Global	Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage Drop 0.7 V	Loss Fraction	0.1 % at STC
LID - Light Induced Degradation		Loss Fraction	1.5 %
Module Quality Loss		Loss Fraction	2.0 %
Module Mismatch Losses		Loss Fraction	1.0 % at MPP
Strings Mismatch loss		Loss Fraction	0.10 %
Incidence effect (IAM): User defined profile			

0°	25°	45°	60°	65°	70°	75°	80°	90°
1.000	1.000	0.995	0.962	0.936	0.903	0.851	0.754	0.000

System loss factors	Wires: 3x1000.0 mm² 25 m	Loss Fraction	0.2 % at STC
Unavailability of the system	10.9 days, 3 periods	Time fraction	3.0 %

Grid-Connected System: Horizon definition

Project : CaseB_Biyagama

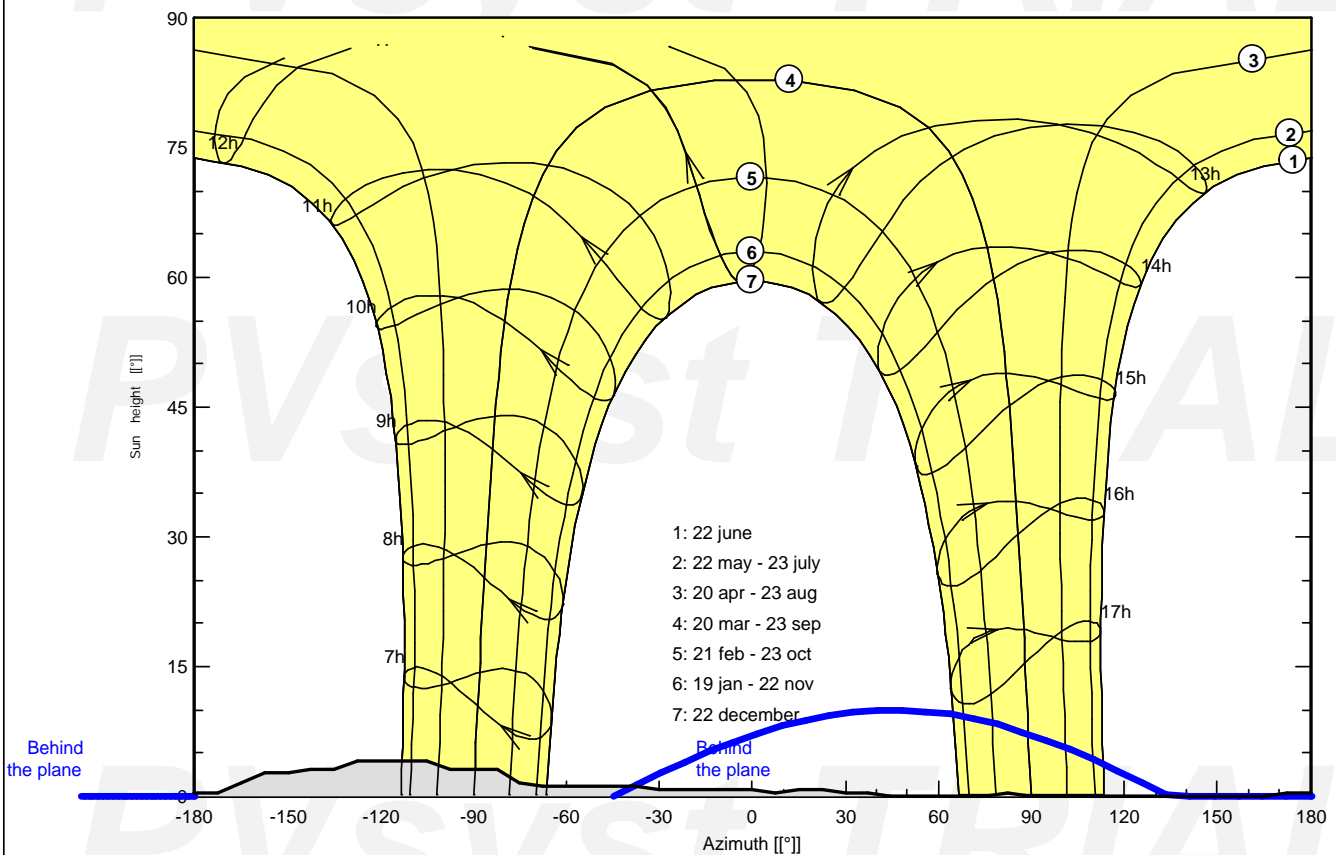
Simulation variant : CaseB_Biyagama

Main system parameters	System type	No 3D scene defined, no shadings		
Horizon	Average Height	1.1°		
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/-135° and 10°/45°		
PV modules	Model	LR6-72 PE 370 M	Pnom	370 Wp
PV Array	Nb. of modules	2214	Pnom total	819 kWp
Inverter	Model	Sunny Tripower 60-10	Pnom	60.0 kW ac
Inverter	Model	Sunny Tripower_Core1_MOWP	Pnom	50.0 kW ac
Inverter pack	Nb. of units	12.0	Pnom total	700 kW ac
User's needs	Unlimited load (grid)			

Horizon	Average Height	1.1°	Diffuse Factor	1.00
	Albedo Factor	100 %	Albedo Fraction	0.98

Height [°]	0.4	0.4	1.5	2.7	2.7	3.1	3.1	4.2	4.2	3.1	3.1	1.5	1.1	1.1
Azimuth [°]	-180	-173	-165	-158	-150	-143	-135	-128	-105	-98	-83	-75	-68	-38
Height [°]	0.8	0.8	0.4	0.8	0.8	0.4	0.4	0.0	0.0	0.4	0.0	0.0	0.4	0.4
Azimuth [°]	-30	0	8	15	23	30	38	45	75	83	90	165	173	180

Horizon from PVGIS website API, Lat=6°57'54', Long=80°0'19', Alt=12m



Grid-Connected System: Main results

Project : CaseB_Biyagama

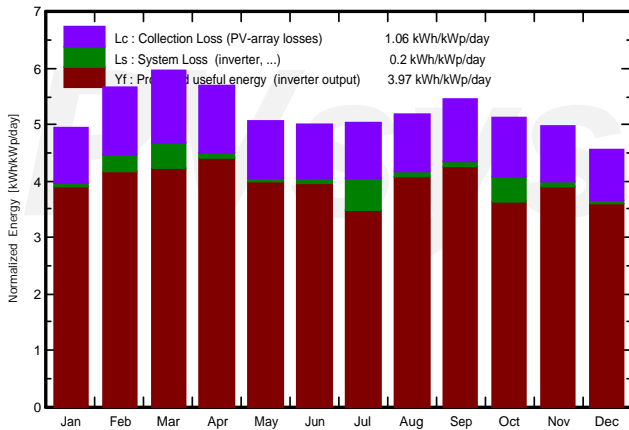
Simulation variant : CaseB_Biyagama

Main system parameters	System type	No 3D scene defined, no shadings	
Horizon	Average Height	1.1°	
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/-135° and 10°/45°	
PV modules	Model	LR6-72 PE 370 M	Pnom 370 Wp
PV Array	Nb. of modules	2214	Pnom total 819 kWp
Inverter	Model	Sunny Tripower 60-10	Pnom 60.0 kW ac
Inverter	Model	Sunny Tripower_Core1_MOWP	Pnom 50.0 kW ac
Inverter pack	Nb. of units	12.0	Pnom total 700 kW ac
User's needs	Unlimited load (grid)		

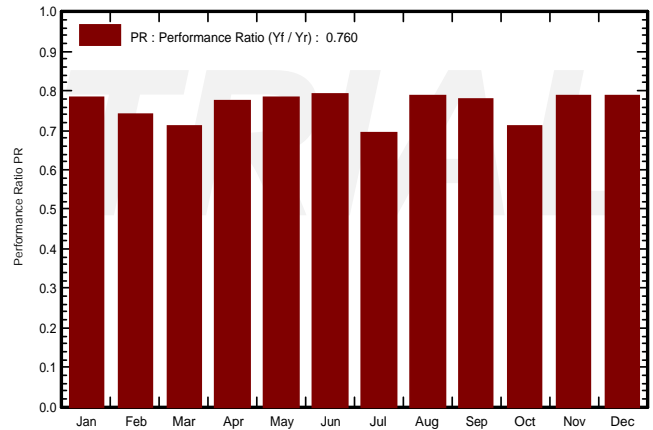
Main simulation results

System Production **Produced Energy 1187 MWh/year** Specific prod. 1449 kWh/kWp/year
 Performance Ratio PR 75.99 %

Normalized productions (per installed kWp): Nominal power 819 kWp



Performance Ratio PR



CaseB_Biyagama
Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	MWh	MWh	
January	152.8	73.73	26.39	153.8	145.0	100.8	98.8	0.784
February	158.0	60.50	26.92	158.4	149.9	102.3	95.9	0.739
March	185.3	71.12	27.62	184.7	174.9	118.8	107.4	0.710
April	172.8	71.87	27.27	171.3	162.2	110.9	108.6	0.774
May	159.4	89.72	28.57	157.1	147.9	103.1	101.0	0.785
June	153.4	84.96	27.56	150.6	141.9	99.5	97.5	0.790
July	158.4	84.07	27.76	155.9	147.2	102.8	88.8	0.695
August	163.0	90.95	27.68	161.0	151.9	105.9	103.8	0.787
September	164.8	73.45	27.07	164.0	155.2	106.9	104.7	0.779
October	159.2	73.46	26.95	159.1	150.5	103.6	92.6	0.711
November	148.1	69.25	25.93	149.1	140.9	98.1	96.1	0.787
December	140.5	69.97	26.18	141.2	133.2	93.1	91.3	0.789
Year	1915.9	913.04	27.16	1906.2	1800.6	1245.8	1186.6	0.760

- | | | | | |
|----------|---------|--------------------------------|---------|--|
| Legends: | GlobHor | Horizontal global irradiation | GlobEff | Effective Global, corr. for IAM and shadings |
| | DiffHor | Horizontal diffuse irradiation | EArray | Effective energy at the output of the array |
| | T_Amb | T amb. | E_Grid | Energy injected into grid |
| | GlobInc | Global incident in coll. plane | PR | Performance Ratio |

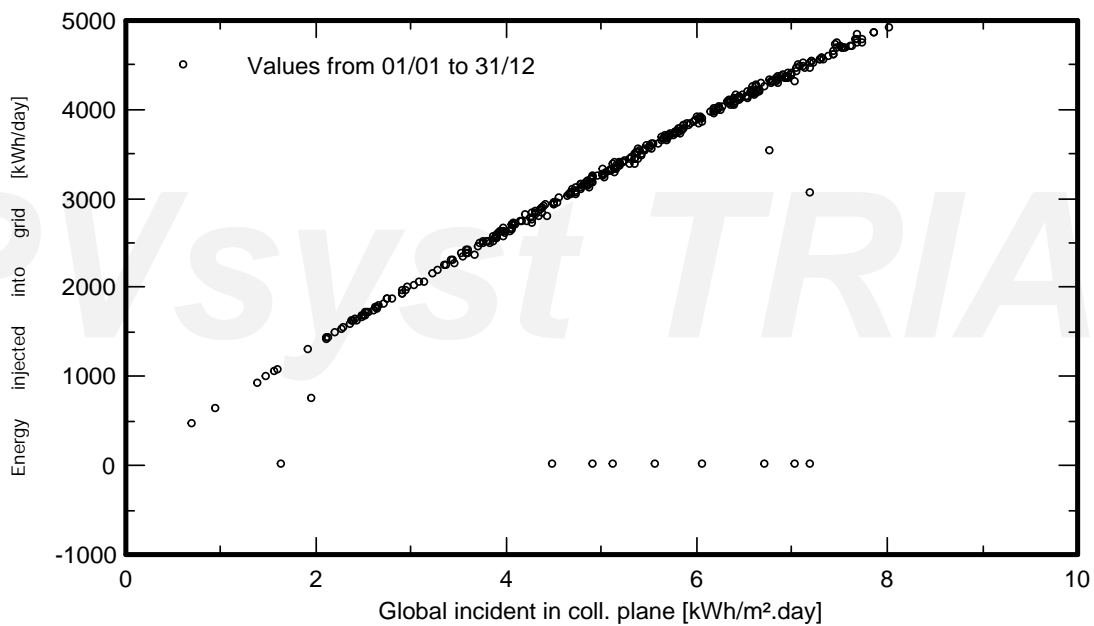
Grid-Connected System: Special graphs

Project : CaseB_Biyagama

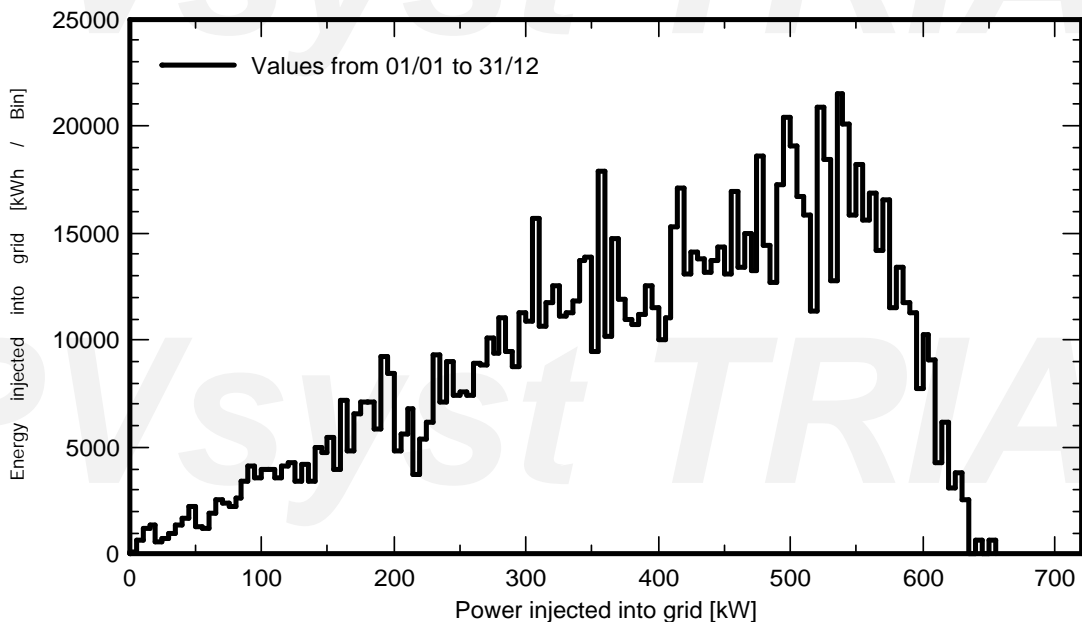
Simulation variant : CaseB_Biyagama

Main system parameters	System type	No 3D scene defined, no shadings		
Horizon	Average Height	1.1°		
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/-135° and 10°/45°		
PV modules	Model	LR6-72 PE 370 M	Pnom	370 Wp
PV Array	Nb. of modules	2214	Pnom total	819 kWp
Inverter	Model	Sunny Tripower 60-10	Pnom	60.0 kW ac
Inverter	Model	Sunny Tripower_Core1_MOWP	Pnom	50.0 kW ac
Inverter pack	Nb. of units	12.0	Pnom total	700 kW ac
User's needs	Unlimited load (grid)			

Daily Input/Output diagram



System Output Power Distribution



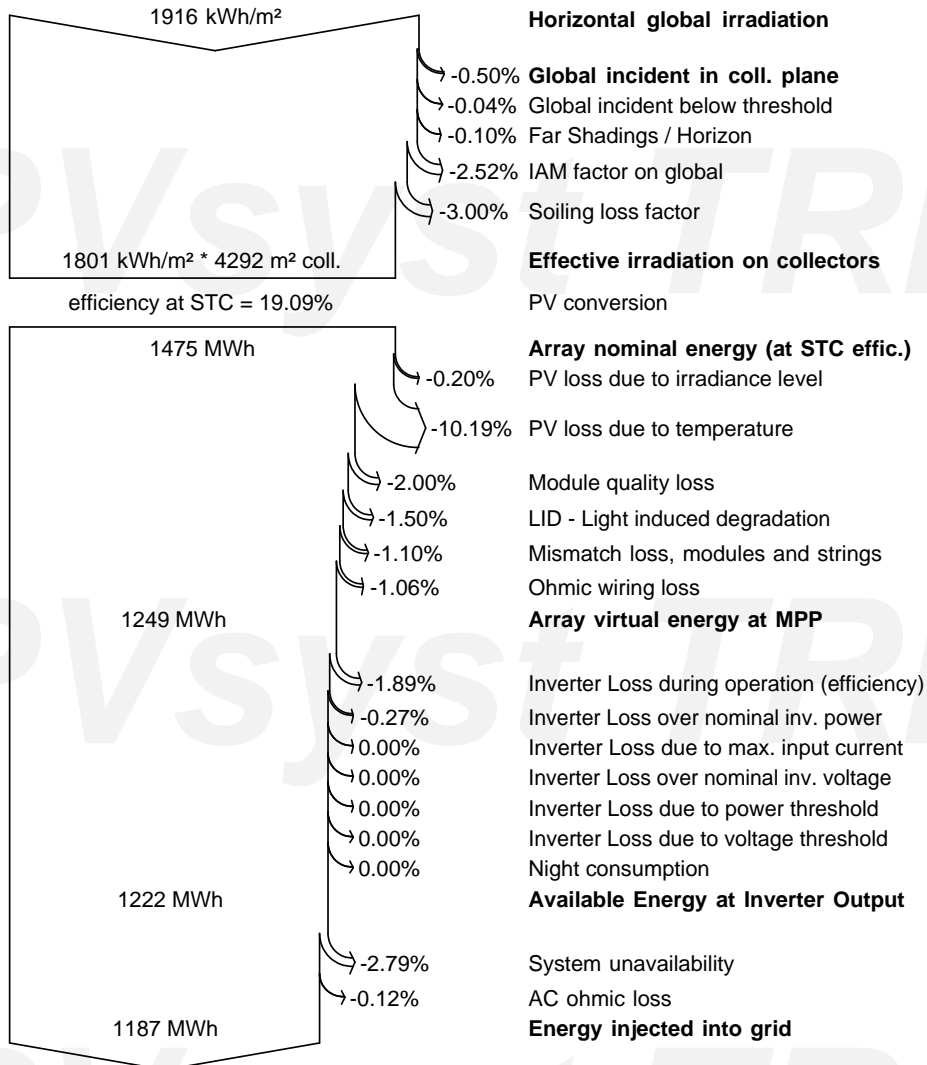
Grid-Connected System: Loss diagram

Project : CaseB_Biyagama

Simulation variant : CaseB_Biyagama

Main system parameters	System type	No 3D scene defined, no shadings		
Horizon	Average Height	1.1°		
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/-135° and 10°/45°		
PV modules	Model	LR6-72 PE 370 M	Pnom	370 Wp
PV Array	Nb. of modules	2214	Pnom total	819 kWp
Inverter	Model	Sunny Tripower 60-10	Pnom	60.0 kW ac
Inverter	Model	Sunny Tripower_Core1_MOWP	Pnom	50.0 kW ac
Inverter pack	Nb. of units	12.0	Pnom total	700 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Grid-Connected System: Simulation parameters

Project : **CaseC_Batticaloa**

Geographical Site **Arapattai** Country **Sri Lanka**

Situation Latitude 7.66° N Longitude 81.74° E

Time defined as Legal Time Time zone UT+5.5 Altitude 5 m

Albedo 0.20

Meteo data: **Arapattai** Meteonorm 7.2, Sat=100% - Synthetic

Simulation variant : **CaseC_Batticaloa**

Simulation date 08/09/20 00h12

Simulation parameters System type **No 3D scene defined, no shadings**

2 orientations tilts/azimuths 10°/0° and 10°/180°

Models used Transposition Perez Diffuse Perez, Meteonorm

Horizon Free Horizon

Near Shadings No Shadings

User's needs : Unlimited load (grid)

PV Arrays Characteristics (2 kinds of array defined)

PV module	Si-poly	Model	REC 335TP2S 72
Original PVsyst database		Manufacturer	REC
Sub-array "Sub-array #1"		Orientation	#2
		Tilt/Azimuth	10°/180°
Number of PV modules		In series	20 modules
		In parallel	110 strings
Total number of PV modules		Nb. modules	2200
Array global power		Nominal (STC)	737 kWp
		At operating cond.	673 kWp (50°C)
Array operating characteristics (50°C)		U mpp	678 V
		I mpp	992 A
Sub-array "Sub-array #2"		Orientation	#1
		Tilt/Azimuth	10°/0°
Number of PV modules		In series	20 modules
		In parallel	136 strings
Total number of PV modules		Nb. modules	2720
Array global power		Nominal (STC)	911 kWp
		At operating cond.	832 kWp (50°C)
Array operating characteristics (50°C)		U mpp	678 V
		I mpp	1226 A
Total Arrays global power		Nominal (STC)	1648 kWp
		Total	4920 modules
		Module area	9874 m²
		Cell area	8707 m ²

Inverter		Model	Sunny Tripower 60-10
Original PVsyst database		Manufacturer	SMA
Characteristics		Operating Voltage	570-800 V
		Unit Nom. Power	60.0 kWac
Sub-array "Sub-array #1"		Nb. of inverters	11 units
		Total Power	660 kWac
		Pnom ratio	1.12
Sub-array "Sub-array #2"		Nb. of inverters	14 units
		Total Power	840 kWac
		Pnom ratio	1.08
Total		Nb. of inverters	25
		Total Power	1500 kWac

PV Array loss factors

Array Soiling Losses		Loss Fraction	3.0 %	
Thermal Loss factor	Uc (const)	20.0 W/m ² K	Uv (wind)	0.0 W/m ² K / m/s
Wiring Ohmic Loss	Array#1	11 mOhm	Loss Fraction	1.5 % at STC
	Array#2	9.3 mOhm	Loss Fraction	1.5 % at STC
	Global		Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.1 % at STC

Grid-Connected System: Simulation parameters

LID - Light Induced Degradation

Loss Fraction 1.5 %

Module Quality Loss

Loss Fraction 2.0 %

Module Mismatch Losses

Loss Fraction 1.0 % at MPP

Strings Mismatch loss

Loss Fraction 0.10 %

Incidence effect (IAM): User defined profile

0°	30°	45°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	0.974	0.907	0.832	0.688	0.445	0.000

System loss factors

Wires: 3x1500.0 mm² 119 m

Loss Fraction 1.5 % at STC

Unavailability of the system

10.9 days, 3 periods

Time fraction 3.0 %

Grid-Connected System: Main results

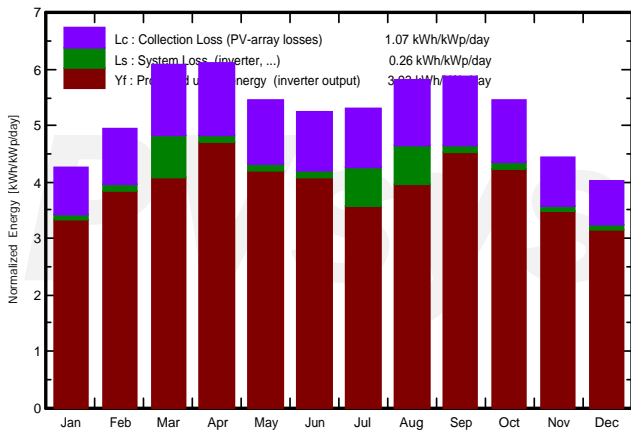
Project : CaseC_Batticaloa

Simulation variant : CaseC_Batticaloa

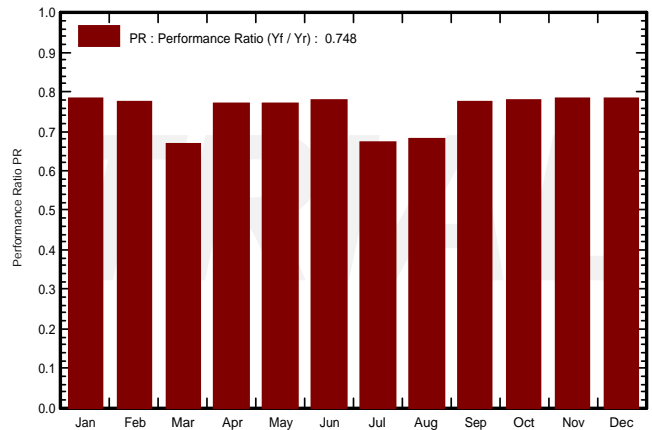
Main system parameters		System type	No 3D scene defined, no shadings		
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/0° and 10°/180°			
PV modules	Model	REC 335TP2S 72	Pnom	335 Wp	
PV Array	Nb. of modules	4920	Pnom total	1648 kWp	
Inverter	Model	Sunny Tripower 60-10	Pnom	60.0 kW ac	
Inverter pack	Nb. of units	25.0	Pnom total	1500 kW ac	
User's needs	Unlimited load (grid)				

Main simulation results	
System Production	Produced Energy 2365 MWh/year Specific prod. 1435 kWh/kWp/year
	Performance Ratio PR 74.83 %

Normalized productions (per installed kWp): Nominal power 1648 kWp



Performance Ratio PR



CaseC_Batticaloa Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m ²	kWh/m ²	°C	kWh/m ²	kWh/m ²	MWh	MWh	
January	132.5	70.78	26.38	132.3	125.0	174.8	170.5	0.782
February	139.1	70.60	26.91	138.8	131.2	182.4	177.8	0.777
March	189.7	79.29	27.63	188.9	179.3	246.2	207.9	0.668
April	184.8	74.50	27.28	183.3	173.8	239.0	232.7	0.770
May	170.7	72.62	28.58	168.7	159.7	220.2	214.6	0.772
June	159.6	77.24	27.58	157.5	149.1	207.8	202.6	0.780
July	166.3	83.26	27.78	164.3	155.4	217.0	182.8	0.675
August	182.3	82.21	27.69	180.6	171.2	237.3	202.3	0.679
September	176.9	71.21	27.08	175.8	166.8	230.2	224.1	0.774
October	169.2	74.09	26.96	168.9	160.1	222.2	216.4	0.777
November	133.6	65.50	25.92	133.5	126.2	176.5	172.0	0.782
December	124.9	66.72	26.19	124.7	118.0	165.3	161.2	0.784
Year	1929.5	888.03	27.17	1917.4	1815.8	2519.0	2364.7	0.748

Legends:	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T_Amb	T amb.	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

Grid-Connected System: Special graphs

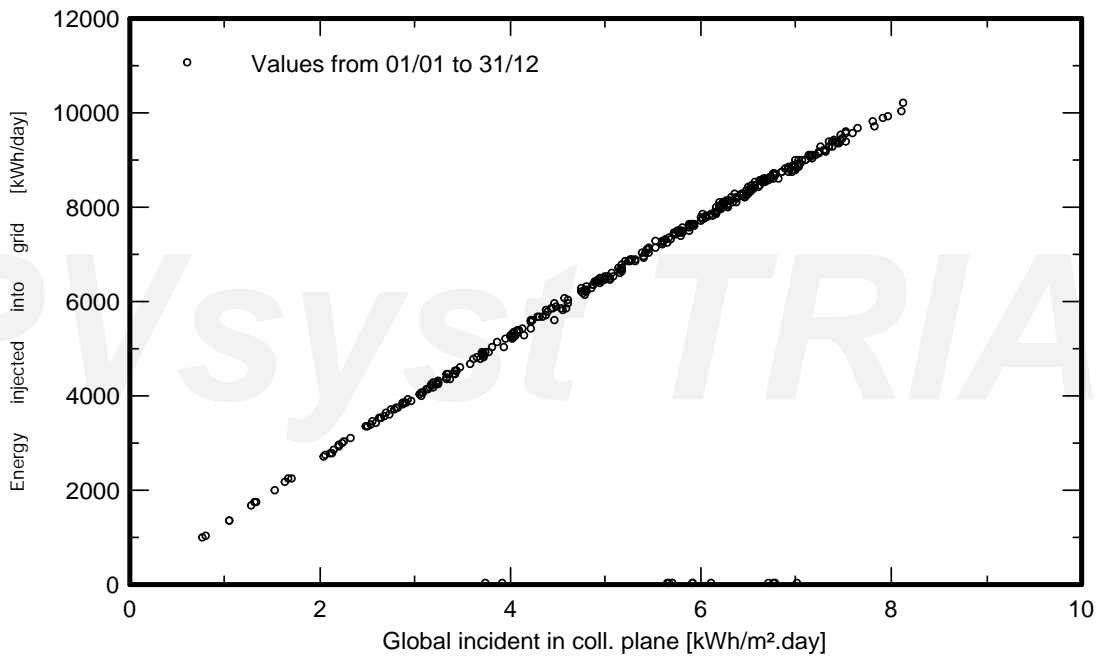
Project : CaseC_Batticaloa

Simulation variant : CaseC_Batticaloa

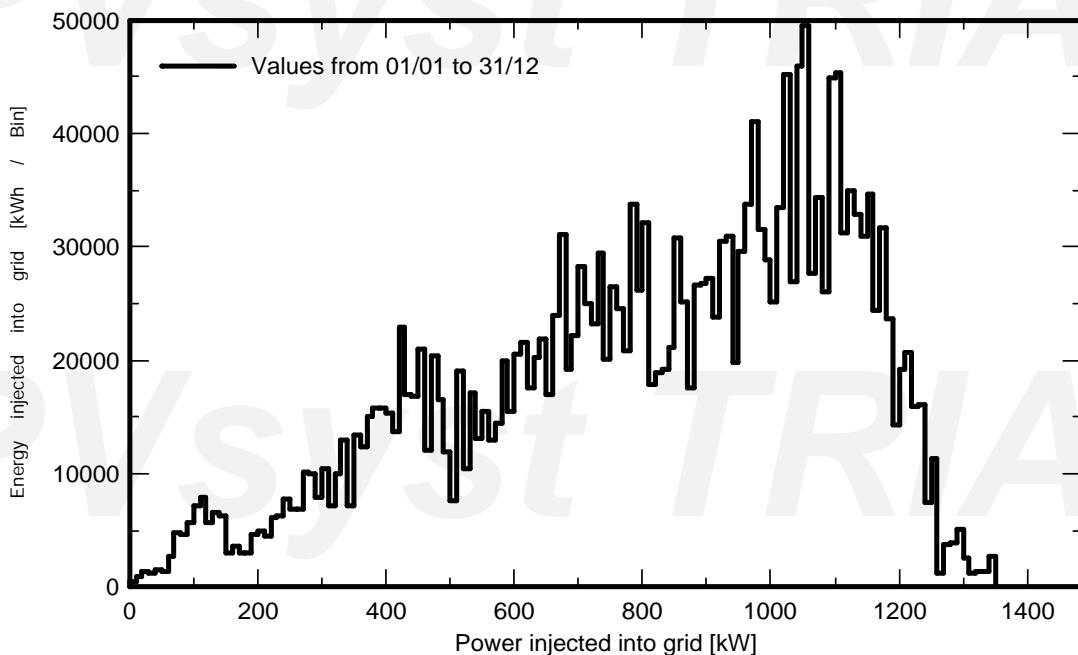
Main system parameters

System type	No 3D scene defined, no shadings		
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/0° and 10°/180°	
PV modules	Model	REC 335TP2S 72	Pnom 335 Wp
PV Array	Nb. of modules	4920	Pnom total 1648 kWp
Inverter	Model	Sunny Tripower 60-10	Pnom 60.0 kW ac
Inverter pack	Nb. of units	25.0	Pnom total 1500 kW ac
User's needs	Unlimited load (grid)		

Daily Input/Output diagram



System Output Power Distribution



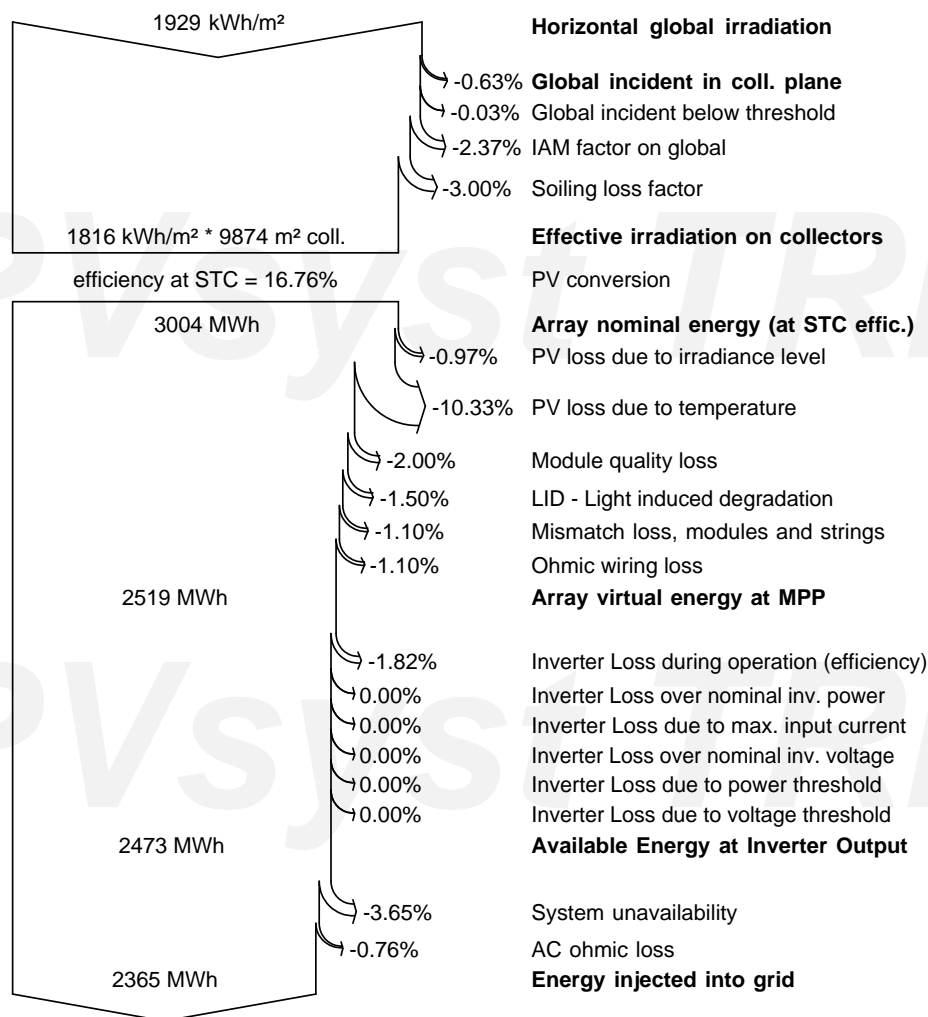
Grid-Connected System: Loss diagram

Project : CaseC_Batticaloa

Simulation variant : CaseC_Batticaloa

Main system parameters	System type	No 3D scene defined, no shadings		
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/0° and 10°/180°		
PV modules	Model	REC 335TP2S 72	Pnom	335 Wp
PV Array	Nb. of modules	4920	Pnom total	1648 kWp
Inverter	Model	Sunny Tripower 60-10	Pnom	60.0 kW ac
Inverter pack	Nb. of units	25.0	Pnom total	1500 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Grid-Connected System: Simulation parameters

Project :	CaseD_Panadura			
Geographical Site	Mahawila	Country	Sri Lanka	
Situation	Latitude	6.70° N	Longitude	79.94° E
Time defined as	Legal Time	Time zone UT+5.5	Altitude	10 m
	Albedo	0.20		
Meteo data:	Mahawila	Meteonorm 7.3 - Synthetic		

Simulation variant :	CaseD_Panadura		
	Simulation date	08/09/20 23h20	

Simulation parameters	System type	No 3D scene defined, no shadings		
2 orientations	tilts/azimuths	10°/-70° and 10°/110°		
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
			Circumsolar	separate
Horizon	Average Height	1.2°		
Near Shadings	No Shadings			
User's needs :	Unlimited load (grid)			

PV Arrays Characteristics (2 kinds of array defined)				
PV module	Si-mono	Model	TSM-DEG14-(II)-370	
Original PVsyst database		Manufacturer	Trina Solar	
SolarEdge Power Optimizer		Model	P801 Worldwide	Unit Nom. Power
PV modules per optimizer		in series	2	in parallel
				1
Sub-arrays				
#1 - PV Array	Orientation	#2	Tilt/Azimuth	10°/110°
Nb. of optimizers	In series	20	In parallel	22 strings
Total number of PV modules	nb. modules	880	Unit Nom. Power	370 Wp
Array global power	Nominal (STC)	326 kWp	At operating cond.	294 kWp (50°C)
Output of optimizers	Voper	750 V	I at Poper	392 A
#2 - Sub-array #2	Orientation	#1	Tilt/Azimuth	10°/-70°
Nb. of optimizers	In series	19	In parallel	16 strings
Total number of PV modules	nb. modules	608	Unit Nom. Power	370 Wp
Array global power	Nominal (STC)	225 kWp	At operating cond.	203 kWp (50°C)
Output of optimizers	Voper	750 V	I at Poper	271 A
Total Arrays global power	Nominal (STC)	551 kWp	Total	1488 modules
	Module area	2946 m²	Cell area	2603 m²

Inverter	Model	SE55K/SE82.8K Unit		
Original PVsyst database	Manufacturer	SolarEdge		
Characteristics	Unit Nom. Power	27.6 kWac	Oper. Voltage	750 V
Sub-arrays				
#1 - PV Array	Total power	310 kWac	Pnom ratio	0.94
	Nb. of inverters	11 units		
#2 - Sub-array #2	Total power	214 kWac	Pnom ratio	0.95
	Nb. of inverters	8 units		

Physical inverters				
SE55K/SE82.8K Unit	10 units 2 strings	2 strings of 20 optimizers P801 Worldwide		
SE55K/SE82.8K Unit	7 units 2 strings	2 strings of 19 optimizers P801 Worldwide		
SE55K/SE82.8K Unit	2 units 2 strings	1 * 20 and 1 * 19 optimizers P801 Worldwide		

Grid-Connected System: Simulation parameters

PV Array loss factors

Array Soiling Losses		Loss Fraction	3.0 %
Thermal Loss factor	Uc (const) 20.0 W/m ² K	Uv (wind)	0.0 W/m ² K / m/s
Wiring Ohmic Loss	Array #1 26 m	Loss Fraction	1.5 % at STC
	Array #2 38 m	Loss Fraction	1.5 % at STC
	Global	Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage drop 0.7 V	Loss Fraction	0.1 % at STC
LID - Light Induced Degradation		Loss Fraction	1.5 %
Module Quality Loss		Loss Fraction	2.0 %
Module mismatch losses		Loss Fraction	0.0 % (fixed voltage)

#1 - PV Array

Incidence effect (IAM): Fresnel AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

#2 - Sub-array #2

Incidence effect (IAM): Fresnel AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

System loss factors

AC loss, inverter to injection	Inverter voltage 400 Vac tri		
Whole system	Wires: 3 x 500 mm ² 115 m	Loss Fraction	1.5 % at STC
Unavailability of the system	10.9 days, 3 periods	Time fraction	3.0 %

Grid-Connected System: Horizon definition

Project : CaseD_Panadura

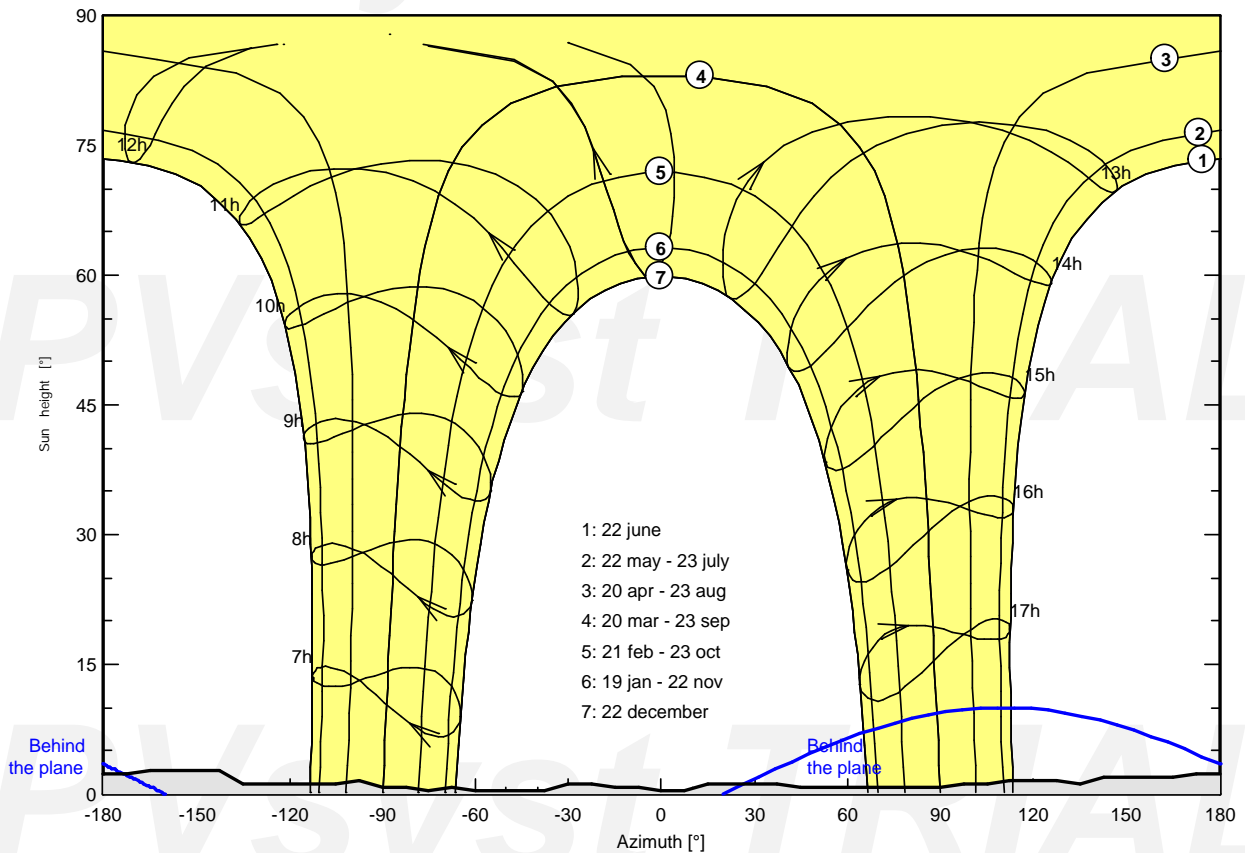
Simulation variant : CaseD_Panadura

Main system parameters	System type	No 3D scene defined, no shadings		
Horizon	Average Height	1.2°		
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/-70° and 10°/110°		
PV modules	Model	TSM-DEG14-(II)-370	Pnom	370 Wp
PV Array	Nb. of modules	1488	Pnom total	551 kWp
Inverter	Model	SE55K/SE82.8K Unit	Pnom	27.60 kW ac
Inverter pack	Nb. of units	19.0	Pnom total	524 kW ac
User's needs	Unlimited load (grid)			

Horizon	Average Height	1.2°	Diffuse Factor	1.00
	Albedo Factor	100%	Albedo Fraction	0.94

Height [°]	2.3	2.3	2.7	2.7	1.1	1.1	1.5	0.8	0.8	0.4	0.8
Azimuth [°]	-180	-173	-165	-143	-135	-105	-98	-90	-83	-75	-68
Height [°]	0.4	0.4	1.1	1.1	0.8	0.8	0.4	0.4	1.1	1.1	0.8
Azimuth [°]	-60	-38	-30	-23	-15	-8	0	8	15	38	45
Height [°]	0.8	1.1	1.1	1.5	1.5	1.1	1.9	1.9	2.3	2.3	
Azimuth [°]	90	98	105	113	128	135	143	165	173	180	

Horizon from PVGIS website API, Lat=6°42'15', Long=79°56'8', Alt=10m



Grid-Connected System: Main results

Project : CaseD_Panadura

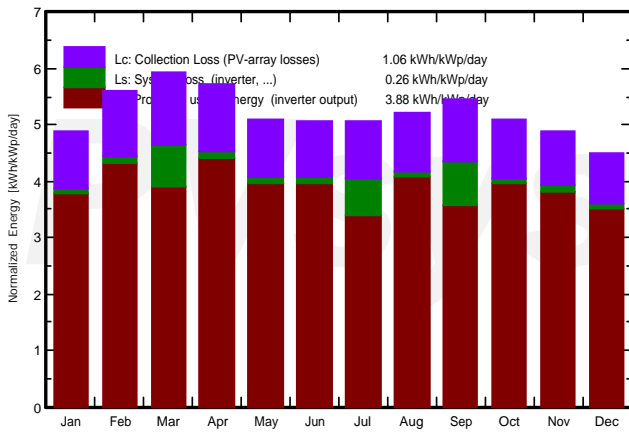
Simulation variant : CaseD_Panadura

Main system parameters	System type	No 3D scene defined, no shadings	
Horizon	Average Height	1.2°	
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/-70° and 10°/110°	
PV modules	Model	TSM-DEG14-(II)-370	Pnom 370 Wp
PV Array	Nb. of modules	1488	Pnom total 551 kWp
Inverter	Model	SE55K/SE82.8K Unit	Pnom 27.60 kW ac
Inverter pack	Nb. of units	19.0	Pnom total 524 kW ac
User's needs	Unlimited load (grid)		

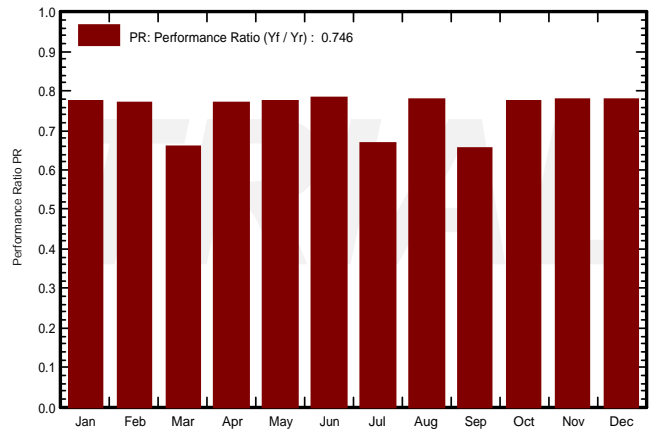
Main simulation results

System Production **Produced Energy 780.6 MWh/year** Specific prod. 1418 kWh/kWp/year
 Performance Ratio PR 74.55 %

Normalized productions (per installed kWp): Nominal power 551 kWp



Performance Ratio PR



CaseD_Panadura
Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m ²	kWh/m ²	°C	kWh/m ²	kWh/m ²	MWh	MWh	ratio
January	153.3	67.54	26.46	151.4	142.8	66.18	64.45	0.773
February	158.5	73.72	27.03	156.8	148.5	68.40	66.60	0.771
March	185.5	75.86	27.73	183.9	174.6	79.54	66.84	0.660
April	172.6	80.75	27.38	171.7	163.2	74.83	72.82	0.770
May	158.9	91.06	28.65	158.2	149.7	69.49	67.70	0.777
June	153.0	88.28	27.67	152.3	144.0	67.38	65.66	0.783
July	158.1	82.80	27.87	157.5	149.2	69.35	57.80	0.666
August	162.8	94.37	27.79	161.9	153.5	71.40	69.54	0.780
September	164.9	74.20	27.17	163.8	155.3	71.64	58.96	0.654
October	159.3	78.39	27.06	158.0	149.6	69.30	67.46	0.776
November	148.6	69.56	26.04	147.0	139.0	64.72	63.02	0.779
December	141.1	69.32	26.28	139.4	131.5	61.37	59.78	0.779
Year	1916.7	945.85	27.26	1901.9	1801.0	833.60	780.63	0.746

Legends:	GlobHor	Global horizontal irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T_Amb	T amb.	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

Grid-Connected System: Special graphs

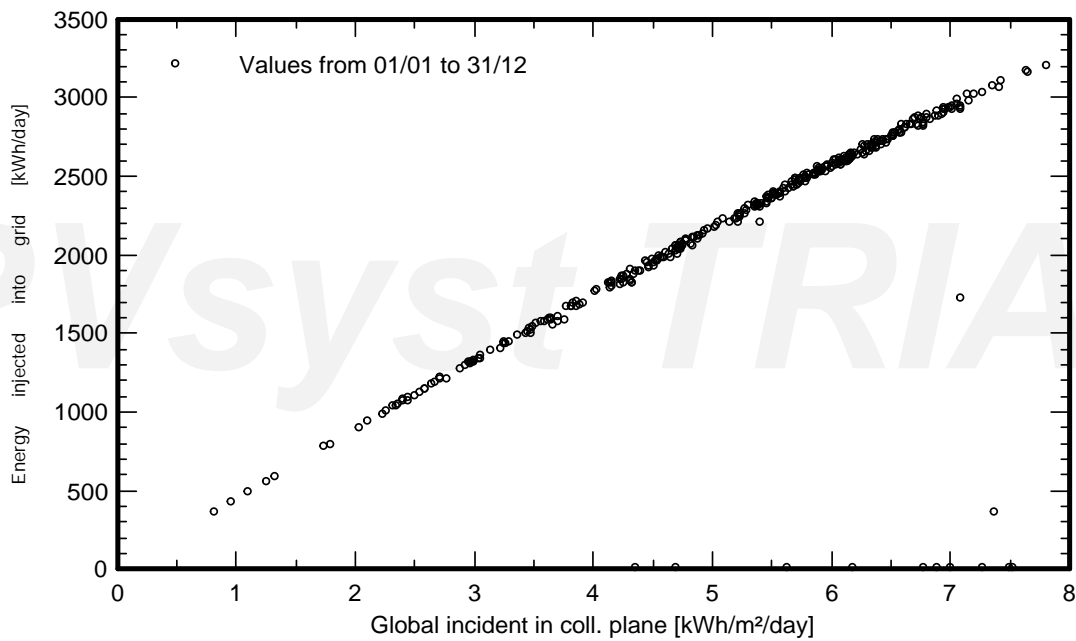
Project : CaseD_Panadura

Simulation variant : CaseD_Panadura

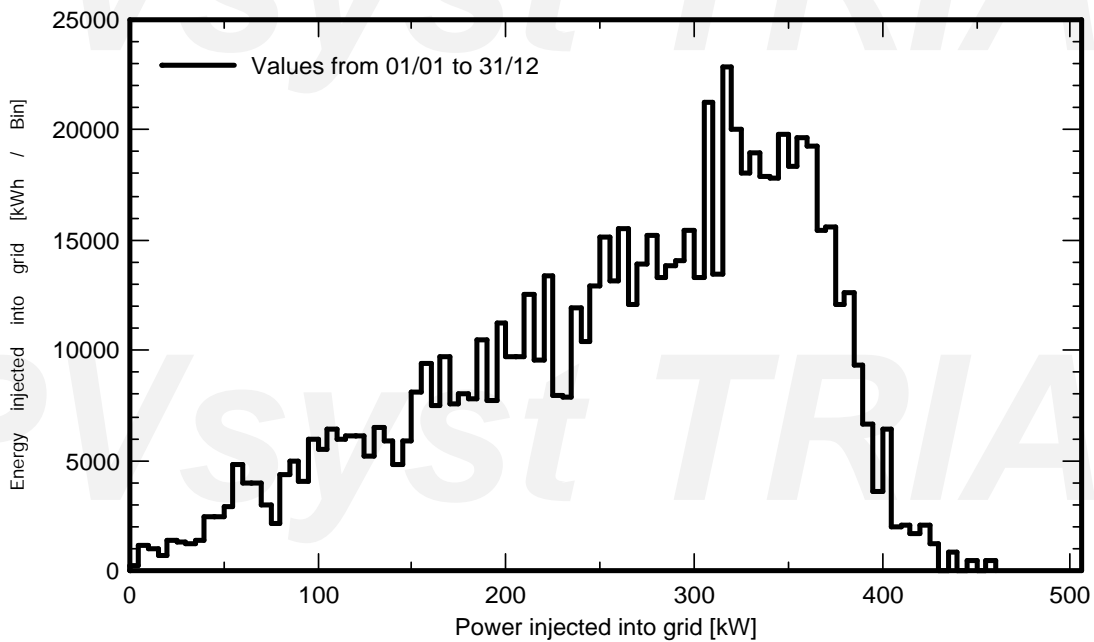
Main system parameters

	System type	No 3D scene defined, no shadings		
Horizon	Average Height	1.2°		
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/-70° and 10°/110°		
PV modules	Model	TSM-DEG14-(II)-370	Pnom	370 Wp
PV Array	Nb. of modules	1488	Pnom total	551 kWp
Inverter	Model	SE55K/SE82.8K Unit	Pnom	27.60 kW ac
Inverter pack	Nb. of units	19.0	Pnom total	524 kW ac
User's needs	Unlimited load (grid)			

Daily Input/Output diagram



System Output Power Distribution



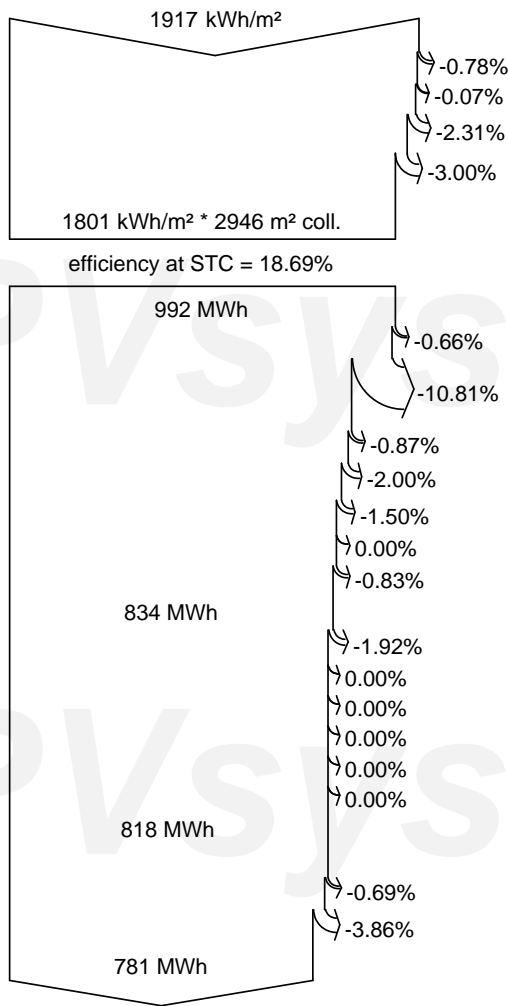
Grid-Connected System: Loss diagram

Project : CaseD_Panadura

Simulation variant : CaseD_Panadura

Main system parameters	System type	No 3D scene defined, no shadings		
Horizon	Average Height	1.2°		
PV Field Orientation	2 orientations	Tilt/Azimuth = 10°/-70° and 10°/110°		
PV modules	Model	TSM-DEG14-(II)-370	Pnom	370 Wp
PV Array	Nb. of modules	1488	Pnom total	551 kWp
Inverter	Model	SE55K/SE82.8K Unit	Pnom	27.60 kW ac
Inverter pack	Nb. of units	19.0	Pnom total	524 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Global horizontal irradiation

Global incident in coll. plane

Far Shadings / Horizon

IAM factor on global

Soiling loss factor

Effective irradiation on collectors

PV conversion

Array nominal energy (at STC effic.)

PV loss due to irradiance level

PV loss due to temperature

Optimizer efficiency loss

Module quality loss

LID - Light induced degradation

Module array mismatch loss

Ohmic wiring loss

Array virtual energy at MPP

Inverter Loss during operation (efficiency)

Inverter Loss over nominal inv. power

Inverter Loss due to max. input current

Inverter Loss over nominal inv. voltage

Inverter Loss due to power threshold

Inverter Loss due to voltage threshold

Available Energy at Inverter Output

AC ohmic loss

System unavailability

Energy injected into grid