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Evaluation of Possible PV System Solutions for Streetlight´s Care Center in Tagpuro, Philippines

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Preface

This master thesis is performed spring semester 2017 as part of the study programs Energy Use and Energy Planning, and Energy and Environmental Engineering, at the Norwegian University of Science and Technology.

This thesis is a product of the collaboration between the Norwegian Universtiy of Science and Technology, Engineers Without Borders Norway, Norconsult AS and Streetlight. The thesis was brought up by Streetlight, to evaluate the possibility for a PV system designed for Streetlight´s care center in the Philippines.

Trondheim, 16-06-2017

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Summary

This thesis has evaluated different photovoltaic (PV) system solutions applicable for Streetlight in Tagpuro. The evaluation has consisted of on-grid and off-grid system designs.

Streetlight operates a care center in Tacloban and Tagpuro, on the island Leyte in the Philippines. The Philippines is located at one of earth´s most exposed and vulnerable areas considering earthquakes, volcanic eruptions and typhoons. Socio-economic challenges are products of the environmental challenges in the area.

The local energy situation is characterised by frequent power outages and voltage drops - blackouts and brownouts. This is a challenge for Streetlight´s operation, and a more reliable electricity supply is desired. According to the local grid operator, the situation will improve in the future due to implementation of a new sub-station in the area. However, there is projected a power deficit in the coming years for the region.

The Philippines has the highest electricity tariff compared to their neighbouring countries and Streetlight wishes to evaluate whether it is feasible to invest in a PV system to reduce energy costs. Further Streetlight wishes to be self-sufficient with renewable energy as the energy source.

The solar potential in the Philippines is high and there are several governmental instruments providing benefits for investors in solar energy. The benefits include net-metering, feed-in tariff, tax and fiscal incentives. However, feed-in tariff is not yet implemented in Tacloban or Tagpuro.

The annual load demand of Streetlight Tagpuro was theoretically estimated to 54.94 MWh and annual critical load demand was estimated to 32.22 MWh. This is based on daily load profiles for Monday-Friday, Saturday and Sunday. The daily profiles illustrate a peak power demand during day-time 08:00-17:00 and lower power demand during the night. The power demand at night is related to outside lighting which is categorised as a critical load regarding safety concerns.

The on-grid cases evaluated PV modules located at all buildings (Office, Study Center and Orphanage), two buildings (Office and Study Center) and one building (Office), separately. The off-grid case evaluated PV modules at all buildings with different battery capacity and a maximised roof area. The on-grid an off-grid cases provides different possibilities and limitations, and the most feasible solution will depend on which factors Streetlight highlights.

A Levelized Cost of Energy (LCOE) analysis was conducted for all the cases, emphasising the sensitivity of the input parameters discount rate, battery price and net-metering rate. With a discount rate of 10 %, the PV system with modules at the Office at 7.71 PhP/kWh proved to be profitable compared to today´s situation with energy from utility at 7.93 PhP/kWh. Further, when utilising all buildings the LCOE was 8.79 PhP/kWh for the on-grid system compared to 30.32 PhP/kWh for the off-grid system.

Sammendrag

Denne masteroppgaven har evaluert ulike løsninger på solcellesystemer for Streetlight sitt senter i Tagpuro. Evalueringen har inkludert netttilkoblede og nettfrakoblede systemer.

Streetlight driver et hjelpesenter i Tacloban og Tagpuro, på øyen Leyte på Filippinene. Landet tilhører et av verdens mest utsatte og sårbare områder når det kommer til jordskjelv, vulkanutbrudd og tyfoner. Dette medfører store samfunnsøkonomiske utfordringer.

Den lokale energisituasjonen er karakterisert av hyppige strømbrudd og spenningsfall. Dette er en utfordring for Streetlight sin virksomhet og drift, og de ønsker en mer pålitelig strømforsyning. Ifølge det lokale nettselskapet vil situasjonen forbedres som følge av installering av en ny nettstasjon i området. Et effektunderskudd for området er likevel forventet de kommende årene.

Filippinene har den høyeste strømprisen sammenlignet med nabolandene, og Streetlight ønsker en vurdering på om det er lønnsomt å investere i et solcelleanlegg for å redusere strømutgifter. Videre ønsker Streetlight å være selvforsynt med fornybar energi som energikilde.

Filippinene har et stort solpotensiale og det er flere statlige reguleringer som gir fordeler ved å investere i solenergi. Fordelene inkluderer plusskundeordningen, innmatingstariffer, og skatte- og avgiftsinsentiver. Innmatingstariffer er ikke implementert i Tacloban eller Tagpuro.

Årlig energiforbruk har blitt teoretisk estimert til å være 54.94 MWh og årlig kritisk lastforbruk har blitt estimert til 32.22 MWh. Dette er basert på daglige lastprofiler for mandag-fredag, lørdag og søndag. De illustrerer en topplast på dagtid mellom kl. 08:00-17:00 og lavt forbruk på natten. Energiforbruket på natten er en følge av utelys, som er kategorisert til å være en kritisk last på grunn av sikkerhet.

De nettilkoblede løsningene har undersøkt solcellemoduler på alle bygg (Office, Study Center og Orphanage), to bygg (Office og Study Center) og et bygg (Office), hver for seg. Løsningene som er frakoblet strømnettet har undersøkt solcellemoduler på alle bygg med ulike batteristørrelser og maksimert tilgjengelig takareal. Løsningene representerer ulike muligheter og begrensninger, og den mest optimale løsningen avhenger av hvilke faktorer Streetlight vektlegger.

En analyse på energikostnaden over levetiden (LCOE) har blitt gjennomført for alle systemløsningene, og understreker sensitiviteten til parameterne diskonteringsrente, batteripris og reguleringene for plusskundeordningen. Med en diskonteringsrente på 10 %, er solcelleanlegget med moduler på et bygg (Office) lønnsomt med 7.71 PhP/kWh i forhold til dagens situasjon med energi fra nettleverandør til 7.93 PhP/kWh. LCOE for solcelleanlegget med moduler på alle bygg er 8.79 PhP/kWh for den nettilkoblede løsningen og 30.32 PhP/kWh for løsningen frakoblet strømnettet.

Acknowledgement

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We would like to thank Streetlight administration and children in the Philippines - Danica, for answering all our e-mails and providing information needed. - Michelle and Precious, for taking good care of us in Tacloban and Tagpuro, and making us feel safe. - Letlet and Richard for providing technical information. - Everyone we met at the center in Tagpuro, for cooking for us, for collecting coconuts, answering all our questions and for letting us intrude and measure your home.

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Chapter 1

Introduction

Environmental issues are often caused by burning of fossil fuels and production of toxic chemicals when released into the air, water or soil. These are byproducts of economic growth, which can be an important factor for development. However, the environmental issues created from these byproducts can cause socio-economic challenges, undermining the economic growth they create.

Sustainable development integrates development and environment, where global inequality, poverty and climate change can be dealt with at the same time. There are various paths and models for sustainable development, and there is a complexity related to society and situation. If integrated in a holistic approach, renewable energy can play a significant role for sustainable development.

According to the *Global Market Outlook* by Solar Power Europe, the cost of solar power is decreasing more rapidly than anticipated, the cost-competitiveness improving and the prices now competes with conventional power plants. The prospect for a medium scenario stipulates that global photovoltaic (PV) installed capacity will increase from 50.6 GW in 2015 toward 97.0 GW in 2020. Among this, it is estimated that utility-scale PV systems still will dominate in installed capacity, however roof-top PV systems are expected to have the highest increase. [1]

This thesis evaluates the possibility for a PV system for Streetlight, who operates a care center in the Philippines, and contribute to development of the area. This chapter will present the background for the project, the problem formulation, objectives and their approach as well as limitations with the project. Further, the timeline and structure of the thesis will be presented.

1.1 Background

The problem description for this thesis was developed by Streetlight in cooperation with Engineers Without Borders Norway (IUG) and Norconsult AS. IUG supports development through engineering expertise to Norwegian aid organisations and supported the project by funding and organising the fieldwork conducted in March 2017. Norconsult AS is one of Norway´s largest multidisciplinary consultancy companies and assisted the project with a mentor for the fieldwork as well as expertise and competence in the project process. Figure 1.1 is a photo from the fieldwork in March 2017 with the Streetlight administration.

Figure 1.1: Streetlight administration March 2017

Streetlight is a Non-Governmental Organisation (NGO) funded and supported by private and governmental actors, such as schools and enterprises. The organisation is based in Tacloban and Tagpuro, on the island Leyte in the Philippines. Streetlight is engaged in different activities to support children living on the streets, and their families with tools for a better future. Streetlight distinguishes their work in a community based and a residential care program and their operation includes orphanage, study center with after-school tutoring, technical-training center and football teams. Their operation started in Tacloban in 2006, however in November 2013 the center and Tacloban area was destroyed by typhoon Haiyan. Luckily everyone at Streetlight survived, and the center in Tacloban was rebuilt.

The municipality of Tacloban has for several years tried to relocate people living in informal settlements, to areas further north from the city. After Haiyan, this was further emphasised and homes were resettled. Due to challenges related to the resettlement, such as increased criminality rate and abuse, Streetlight decided to establish a new care center in this area in 2016. In November 2016 parts of the new care center in Tagpuro was completed.

Alongside with taking care of children, the organisation aims to be self-sufficient in the areas of drinking water, energy and food. Streetlight is located in a vulnerable environmental area and being self-sufficient is of high importance. This implies that if there is a shortage of drinking water, energy or food, the center can still continue its operation. It further implies that Streetlight can control the quality of its products, i.e that the drinking water is clean, the food is nutritious and that the energy is reliable and renewable. Streetlight wants to show the community that it is possible to be self-sufficient, and further be a role model in the community, creating knowledge and encouragement.

Streetlight is already self-sufficient with drinking water, with their own reverse osmosis system. It produces clean drinking water through a process that involves 20 steps of filtering well water. With the aim at being self-sufficient with food, aqua phonics will be implemented by the end of 2017. Aqua phonics combines aquaculture (fishfarming) and hydroponics (plants growing without soil) in a recirculating system, where plants can grow without chemical fertilisers while farming fish in high quality water.

Streetlight further desires to be self-sufficient with energy, and want to be supplied by renewable energy and minimise the consequences from today´s unreliable energy situation. It is further important for Streetlight to spend their funding on the residential and community based programs, and reduce the costs of energy. This can be achieved by a cost-effective PV system, and this thesis is the start of examining this possibility for the center in Tagpuro.

As of today, the center in Tagpuro is connected to the utility grid, however there are challenges related to blackouts and brownouts. Blackouts are defined as when the electrical power is lost, characterised by a voltage drop that is below the operational limits of the electrical equipment. Blackouts can occur due to failures related to power generation or transmission or due to planned interruption such as maintenance or load-shedding. [2]

Blackouts occur frequently according to Streetlight, and depends on the weather conditions and construction projects of the grid operator. At a meeting with the local grid operator Leyeco, March 15th 2017, it was confirmed that blackouts are scheduled in advance and that customers are notified. However, an unnotified blackout was experienced at the fieldwork, March 19th

2017, from morning until afternoon. According to Streetlight, they commonly last from 0.5-24 h. The short-lasting blackouts typically occur once a week, while the long-lasting blackouts occur once a month.

Brownouts are defined as when the voltage is lower than normal operational voltage. A brownout can be caused by overload, i.e when the demand is higher than the supply, which is most likely to occur during peak-demand periods. The brownout affect sensitive electronic equipment [2]. According to Streetlight, brownouts occur frequently and result in equipment being slowly damaged from charging when connected in the outlet.

1.2 Problem Formulation and Objectives

The problem definition is to evaluate possible PV system solutions for Streetlight´s center in Tagpuro. The problem formulation is answered by the following objectives:

1. Obtain an understanding of the climatic condition, energy situation and solar energy potential in the Philippines.
2. Examine the energy/power demand and determine the load profile of Streetlight´s center in Tagpuro.
3. Study, design and evaluate PV system solutions applicable for Streetlight´s center in Tagpuro, including an evaluation of on-grid and off-grid PV system solutions.
4. Conduct an economical evaluation of the PV system solutions.
5. Evaluate the PV system solutions in a holistic approach examining various aspects that can influence the outcome of the project.

1.3 Approach to Objectives

Objective 1
To obtain an understanding of the energy situation in the Philippines, Norconsult´s office in Manila was contacted. They provided two reports on the energy market in the Philippines prepared by Norconsult for the Royal Norwegian Embassy in Manila [3]. In addition, reports made by institutional participants were accessed online and used for this objective. The objective presents the context of the problem formulation and is presented in chapter 2.

Objective 2
The fieldwork included meetings and interviews as the approach to examine Streetlight´s operations and energy/power demand. It comprised of meeting the local grid operator and Streetlight´s administration and children. A needs assessment was conducted for this purpose. The energy demand was the basis for the load profile determination, executed with a combination of manual mapping and theoretical estimation. Microsoft Excel was used to process and structure data as a tool to obtain the load profile.

Objective 3
To study various PV system solutions applicable for Streetlight´s center in Tagpuro, two approaches were used. The first was to study literature concerning a PV system, obtained mainly through *Renewable and efficient electric power systems* [4], *Photovoltaic Systems Engineering* [5] and *Planning and Installing Photovoltaic Systems* [6]. The second approach was to conduct fieldwork to Streetlight´s center in Tagpuro. It was established contact with the main architect from Norway and architectural drawings were provided, which were validated during the fieldwork. In addition, other measures were taken of the site and will be presented in chapter 5. In order to design and evaluate different PV solutions, the software PVsyst was used. The selection of system components is based on the local suppliers.

Objective 4
The approach Levelized Cost of Energy (LCOE) and net-metering pricing policy were used to obtain an economic evaluation of the PV system solutions. LCOE is based on discounting annual or monhtly finanical flows to a common basis. The report *Kostnadsstudie, Solkraft Norge 2013* [7] is used, and the price list from the suppliers Solaric and Optimus Energy serves as a basis for the prices of the system components.

Objective 5
To evaluate the PV system in a holistic approach examining various aspects that can influence the outcome of the project, information and knowledge obtained during the project process was used. Information on PV regulations was obtained my meeting the local grid operator, and information about mitigation towards climatic challenges were obtained by meeting the administration operating a local PV plant.

1.4 Thesis Timeline

In order to carry out this master thesis efficiently, a fieldwork was conducted in March 2017. The process can roughly be divided into the three phases: Pre-fieldwork, fieldwork and post-fieldwork. An illustration of the project timeline is visualised in figure 1.2. The goal of the pre-fieldwork phase was preliminary studies. This included establishing contact with stakeholders and limit scope, researching background theory, familiarising with the specified site, as well as fieldwork- and project tool preparations. The goal of the fieldwork phase was data collection which was obtained through a loadprofile, 3D model of the PV site, meetings with stakeholders as well as preliminary technical results. The goal of the post-fieldwork phase was the technical- and economical evaluation. This was obtained by data and information processing, PV system simulations and an economical evaluation, followed by results and recommendations.

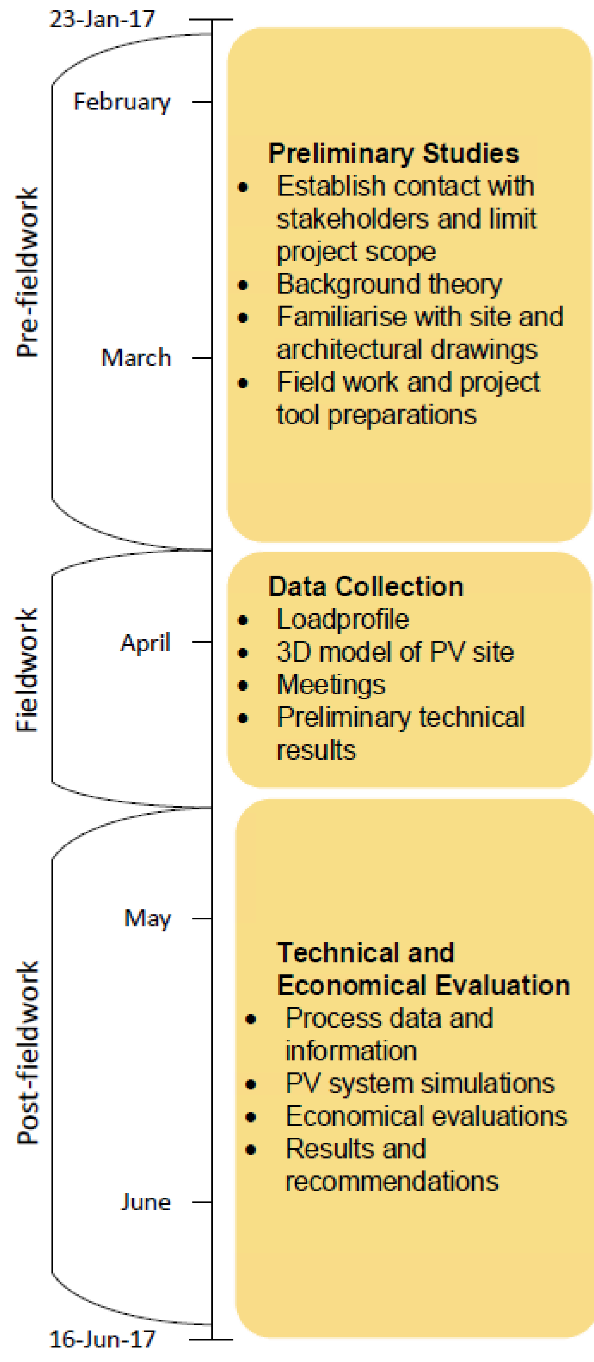


Figure 1.2: Thesis Timeline

1.5 Limitations

1. This thesis is a preparatory study that investigates the possibilities of a PV system and the possible system topologies. If the PV system is implemented, a detailed planning and design will have to be conducted by a competent adviser in the aftermath of this thesis.

2. The focus of this thesis is on a PV system to meet Streetlight´s needs and will be based on a residential PV system. The background theory comprises aspects relevant for a residential PV system, and large scale PV systems are left out of the scope.

3. Only residential roof-top PV solutions have been investigated and other design solutions have been left out of the scope. However, the roof mechanical structures are not examined, and it is not evaluated whether they can tolerate the weight of PV modules. Further, mounting equipment are not taken into account.

4. PVsyst is used as the software tool for the PV system design. An overall description of the methodology behind relevant aspects in PVsyst is evaluated and presented. It is assumed that the simulation results provided by PVsyst are valid. However, PVsyst is not examined in detail in this thesis.

5. The economical analysis will be based on the technical PV system designs. The economic analysis will support the evaluation of the most optimal PV system. However the economic analysis includes several assumptions, and serves as a guideline.

1.6 Structure of the Thesis

This chapter presented an introduction to this thesis, while the rest of the report is structured as follows:

Chapter 2 gives a description of the climatic conditions, energy situation and solar potential in the Philippines. Further, the plans of the local grid operator as well as the process for implementing a PV system in the Philippines are examined.

Chapter 3 gives an introduction to the PV technology and to the components behind PV systems. Topologies for off-grid and for grid-connected systems are then presented.

Chapter 4 presents methodology used in this thesis. It comprises of the methodology possibly used to determine the load profile, the methodology used to dimension the PV system and the methodology used for the economical analysis.

Chapter 5 presents the care center in Tagpuro and describes how the center was constructed as a model in PVsyst.

Chapter 6 describes, presents and validates the load profile determination. In addition the concept of load management is introduced.

Chapter 7 describes the simulation settings in PVsyst and simulates and proposes PV systems suitable for Streetlights needs using PVsyst. An evaluation of the PV system options are then performed.

Chapter 8 describes the input parameters to the LCOE, presents the calculated costs and gives an economic evaluation of the PV system options.

Chapter 9 discusses the PV system and the results obtained throught the objectives of this thesis.

Chapter 10 presents the conclusion of this thesis as well as further work.

Appendix A presents the acronyms used in this thesis.

Appendix B presents the architectural drawings of the center in Tagpuro.

Appendix C presents the needs assessment used to make assumptions for designing the PV system for future energy needs.

Appendix D presents the installer price list provided by Solaric and Optimus Energy.

Appendix E presents the data sheets for the modules, inverters, rectifiers and batteries used.

Chapter 2

The Philippines

The Philippines is a republic in South-East Asia, located on one of earth´s most exposed and vulnerable areas for earthquakes, volcanic eruptions and typhoons. The country has a population of over 100 million, at an area less than continental Norway. The Philippines consists of 7 107 different islands, leading to several energy infrastructural challenges. The Philippines face a growing energy demand while struggling with an energy deficit, and further less than 90 % of the population have access to electricity. The power grid is geographically divided into three main island grids: Luzon, Visayas and Mindanao as illustrated in figure 2.1. [9] [10]

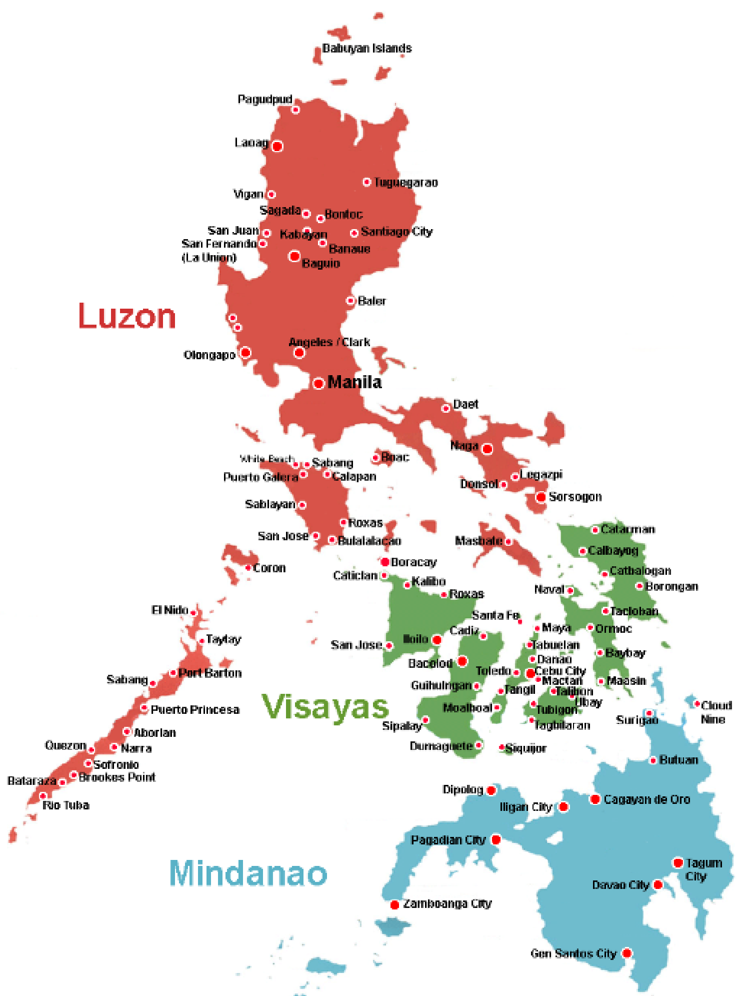


Figure 2.1: Map of Philippine´s major island groups [8]

The following sections will give an introduction to the climatic conditions, energy situation and solar potential in the Philippines. The description of the energy situation includes energy market, energy demand and supply, and energy sources. Tacloban and Tagpuro are located on the island Leyte, at the island grid Visayas. The following sections will therefore focus on these locations. The last section includes information from the local grid operator in Tacloban and Tagpuro and examines the local regulations for implementing a PV system.

2.1 Climatic Conditions

The climate in the Philippines is tropical, characterised by high temperature, high humidity and heavy rainfall. The mean annual temperature is 26.6 $^\circ C$. The coolest month is January with a mean temperature of 25.5 $^\circ C$, while the warmest month is May with a mean temperature of 28.3 $^\circ C$. Due to high temperatures and over 7 000 islands surrounded by sea, the Philippines has a high relative humidity. The monthly average varies between 71 % and 85 %, in March and September respectively. The rainfall varies with the region, depending on moisture-bearing winds and location of mountain systems. Mean annual rainfall varies from 965 - 4 064 mm, with the highest rainfall in mid-east Visayas and north Luzon and the lowest rainfall in the south region of Mindanao. [11]

The climatic conditions in the Philippines can roughly be divided into two seasons: Rainy season from June to November and dry season from December to May. The dry season can be further divided into cool dry season from December to February and hot dry season from March to May. In addition, four climatic types are defined and Tacloban belongs to type IV characterised by evenly distributed rainfall throughout the year and no dry season. [11]

Typhoons influence the climatic conditions significantly with a great impact of rainfall, humidity and cloudiness. The storms originate in the area of Caroline Islands in the Pacific Ocean, following a direction north-west. Mindanao is spared for the majority of typhoons, making southern Philippines desirable for agriculture and industrial development. On average, the Philippines receives 18-22 typhoons per year, where 1-2 are categorised as super typhoons with wind speeds greater than 62 m/s or 220 km/h [11]. The Philippine Atmospheric, Geophysical and Astronomical Service Administatrion (PAGASA) is the National Meteorological and Hydrological Services agency in the Philippines. Founded in 1972 it provides observation data on climatic conditions, especially related to tropical cyclones and tornadoes [12].

2.1.1 Mitigation Measures

Sepalco operates a 50 MW PV farm located on the island Leyte, visualised in figure 2.2. A meeting was conducted with Sepalco during the fieldwork, to learn from the measures taken towards the climatic conditions. To mitigate the destruction from typhoons the PV structures were placed 4.5 m below the ground and supported with cement. The structures were dimensioned to tolerate wind speeds up to 350 km/h. To mitigate the risks from floods the PV plant had river protection walls and canals along the PV structures for draining water. An emergency response team was constantly updated on the typhoon, flood and earthquake status for the island Leyte. Further, gnawing rats was a challenge, causing faults on DC cables. Mitigation measures such as replacement of cables and protection around DC cables had to be taken to minimise the damage.

Figure 2.2: Sepalco 50 MW PV farm. Source: Sepalco

2.2 Energy Demand and Supply

The Philippines is one of the fastest growing economies in Asia and had an economic growth of 5.8 % in 2015. The same year, energy demand increased by 6.7 % to 82 413 GWh, mainly from increased residential and commercial sectors. The power demand is expected to grow in all three regions during 2016-2025. In Luzon, the annual growth rate is expected to be 4.4 %, in Visayas 5.5 % and in Mindanao 6.9 %. To sustain such growth in the future, it is critical with a sufficient and reliable electricity supply system. However, the Philippines suffer from a deficit in power capacity reserve, which influences the power supply in terms of power outages and high power rates. [10]

2.2.1 Visayas

An illustration of the supply-demand outlook for the Visayas region is given in figure 2.3, and is based on existing, developing and planned power supply [13][1]. The blue line represents the required reserve, while the red line represents the peak demand in the region. Visayas experienced a critically short of supply in 2015 as visualised in the figure. However, during peak hours, the Luzon grid can transfer up to 150 MW available power through a HVDC interconnected submarine cable to Visayas. The supply-demand situation is improved from 2016, due to installation of a 270 MW coal plant. Between 2016 and 2021 there is projected surplus capacity to meet the required reserve. Further it is projected a supply gap of 120-570 MW from 2022 to 2025.

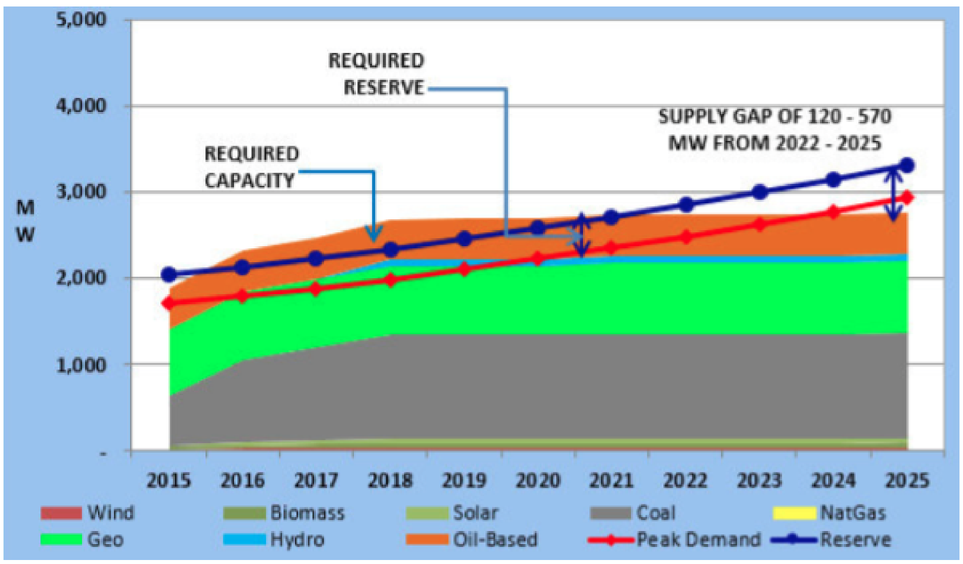


Figure 2.3: Supply-demand outlook for the Visayas region [13]

2.2.2 Typhoon Haiyan in Tacloban

Typhoon Haiyan, commonly referred to as Yolanda, caused a lack of energy for almost two months in large parts of the region of Tacloban city, after it stroke the area on November 8th 2013 [14]. 80-90 % of public facilities such as houses and commercial buildings on the island Leyte were destroyed [15], and The National Grid Corporation (NGCP) reported damage of 248 transmission towers, 276 poles and seven substations [16]. A total damage on the electricity sector was estimated to 6 830 million PhP (corresponding to 1 154 million NOK as for May 18th 2017 [17]), where 76 % comprised the distribution sector and 24 % was divided between the generation and transmission sector. Eight months after the typhoon most of the city of Tacloban had electricity, although many businesses relied on back-up generators [18].

[1] Source: Philippines Department of Energy Power Development Program, August 2015

2.3 Energy Market

The Philippine power sector experienced a restructuring in 2001, called the Electric Power Industry Reform Act (EPIRA). Prior to this, National Power Corporation (NPC), a governmental owned corporation, was responsible for developing and managing generation and transmission in the national power supply system. The restructure involved separating the industry into generation, transmission and distribution, introduce a competitive and privatised market for generation and supply, a wholesale electricity spot market, open access to distribution networks as well as an independent agency as regulator. The Department of Energy (DOE) composed the *Philippine Energy Plan 2012-2030* to encourage participation of the private sector. The restructure project was rated as successful according to Asian Development Bank's (ADB) report *Philippines: Electricity Market and Transmission Development Project* published March 2016, where the restructure improved grid reliability and reduced grid loss. [13]

The power sector in the Philippines has market-driven electricity tariffs which were the highest among the Association of Southeast Asian 5 Nations (ASEAN-5) in 2015, illustrated in figure 2.4. The rates are given in Philippine Pesos per kWh [PhP/kWh]. ASEAN-5 consist of Singapore, Thailand, Indonesia, Malaysia and Philippines. The Philippine average electricity rate was 9.00 PhP/kWh, followed by Singapore, also with market-driven tariff, at 7.50 PhP/kWh. The other ASEAN-5 members have a regulated and controlled power sector, with governmental subsidised electricity tariffs resulting in lower tariffs. [10]

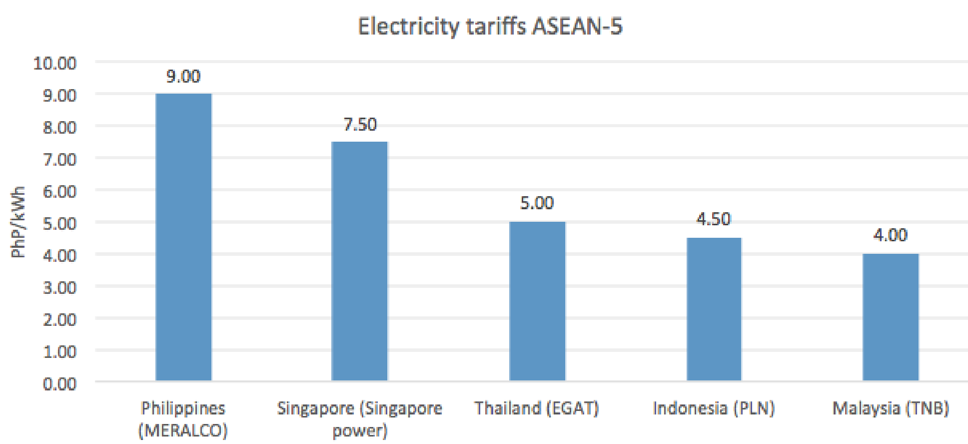


Figure 2.4: Comparison ASEAN-5´s average electricity tariffs in 2015 [10]

On the other hand, the retail rate at MERALCO, the largest power company in the Philippines, experienced a decline by almost 20 % between 2014 and 2016 due to weaker oil and coal prices. The retail rate is made up by: Generation, distribution, transmission, system loss charges, taxes and universal charges as well as Feed-In Tariff (FIT), where the largest component is generation cost, which can constitute to 50 % of the total rate. Generation cost depends on the fuel cost, and coal, oil and gas are imported at international market prices without subsidies. The retail rate is therefore among the highest in the region, even though the recent decline. The retail rate is adjusted once a month, and changes reflects variations in demand, available generation sources, fuel costs and availability of power plants. [10]

2.4 Energy Sources

The installed capacity mix in the Philippines is diverse, but the country relies mainly on coal, oil and natural gas imports. 70 % of all coal consumed is imported, mainly from Indonesia. The three regions have different power capacity profiles, as illustrated in figure 2.5. Luzon´s capacity comes mainly from coal plants, the capacity in Visayas comes mainly from geothermal and coal, while Mindanao depends mostly on hydropower. Coal accounted for 33 % of Philippines total combined capacity mix in 2016, followed by oil-based power plants and hydropower at 18 %, natural gas at 14 % and geothermal at 10 %. [10] [2]

It must be noted that installed capacity is not equivalent to produced energy. Installed capacity is the maximum output of the power plant under optimal conditions. Each power station has an installed capacity in [MW], while the energy produced over a specific time is in [MWh]. It is rarely the case that the operating conditions are optimal, the distribution of the generation mix over a year will therefore differ from the capacity mix.

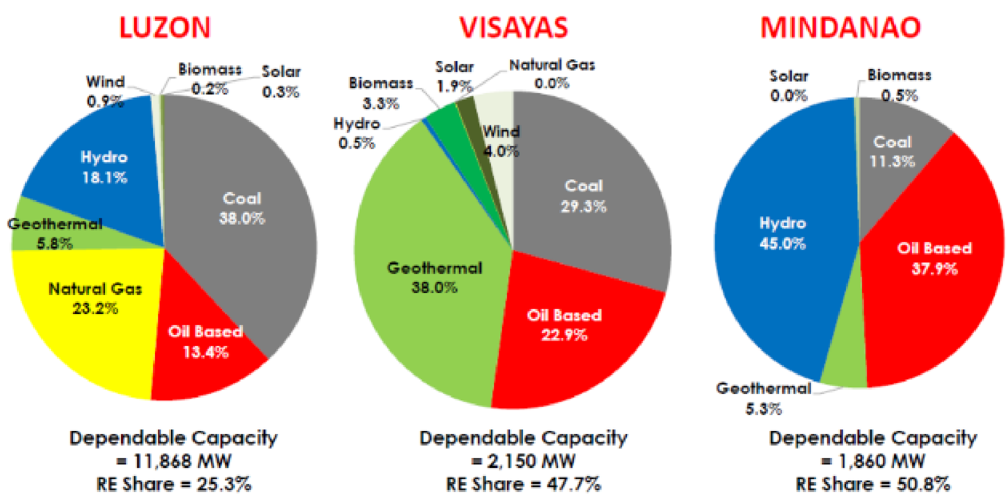


Figure 2.5: Dependable capacity mix in the Philippines major island groups in 2015 [3]

According to the *Philippine Energy plan 2012-2030* it is expected that the energy from coal will continue to grow, due to declining coal prices the last years. However, the plan targets a total 15

[2]Source: DOE Sec. Monsada, "Energy Prospects for the Philippine", EPDP Conference, January 12-13, 2016

304 MW renewable energy capacity by 2030, corresponding to 37 % of the capacity mix. Total renewable energy capacity in end-June 2016 was 6 870 MW, corresponding to less than 45 % of the 2030 target. [10]

2.4.1 Renewable Energy Act

As an instrument to reduce the Philippines´ dependence on fossil fuels, the Renewable Energy Act (REA) was initiated in 2008 by the government. REA provided many benefits for investors and developers in renewable energy and the most important benefits for small-scale systems includes [3]:

- **Net-metering:** Encourages distributed generation by allowing customers to install on-site renewable energy facility below 100 kW to generate for their own use. Surplus energy is exported to the utility and customers are only required to pay for the net energy consumption. Net-metering was the first policy mechanism that was implemented by the REA.
- **Feed-in Tariff (FIT) scheme:** Renewable energy plants are entitled a fixed rate for each kWh of energy supplied to the grid. FIT ensures a fixed price for solar energy, and provides a security for investors and producers considering solar projects in the Philippines. The FIT for solar energy is 8.69 PhP/kWh (2015) [19].
- **Green energy option for consumers:** End-users can choose to get supplied solely from renewable energy sources.
- **Transmission and distribution:** Encourages development of transmission and distribution lines in cooperation with renewable energy development plans.
- **Government subsidies:** Implemented to increase renewable energy development in rural and off-grid areas.
- **Tax- and fiscal incentives:** Provides duty free import of equipment, no income tax for seven years and reduced corporate- and realty tax.

2.5 Solar Potential

While other South-East Asian countries have embraced solar energy, the Philippines has been lagging behind, despite its large potential located along the sunbelt [20]. The installed solar power capacity in 2016 was 684 MW [10]. The annual average solar potential in the Philippines is illustrated in figure 2.6, as Direct Normal Irradiation (DNI) and Global Horizontal Irradiation

(GHI), respectively. DNI indicates direct irradiation from the direction of the sun, while GHI is the total irradiation and sum of DNI, diffuse and reflected irradiation. The difference between the various irradiation types are further explained in chapter 4.2.1. From figure 2.6 it is seen that Tacloban is located in the yellow section corresponding to DNI of about 1 300 kWh/m^2 and GHI corresponding to about 1 800 kWh/m^2. To compare these numbers, Oslo has an annual average DNI of 900 kWh/m^2 and GHI of 1 000 kWh/m^2 [21]. According to National Renewable Energy Laboratory, Philippine average solar irradiation correspond to 161.7 W/m^2, which has a potential to generate 4.5-5.5 kWh/m^2 solar energy per day [20].

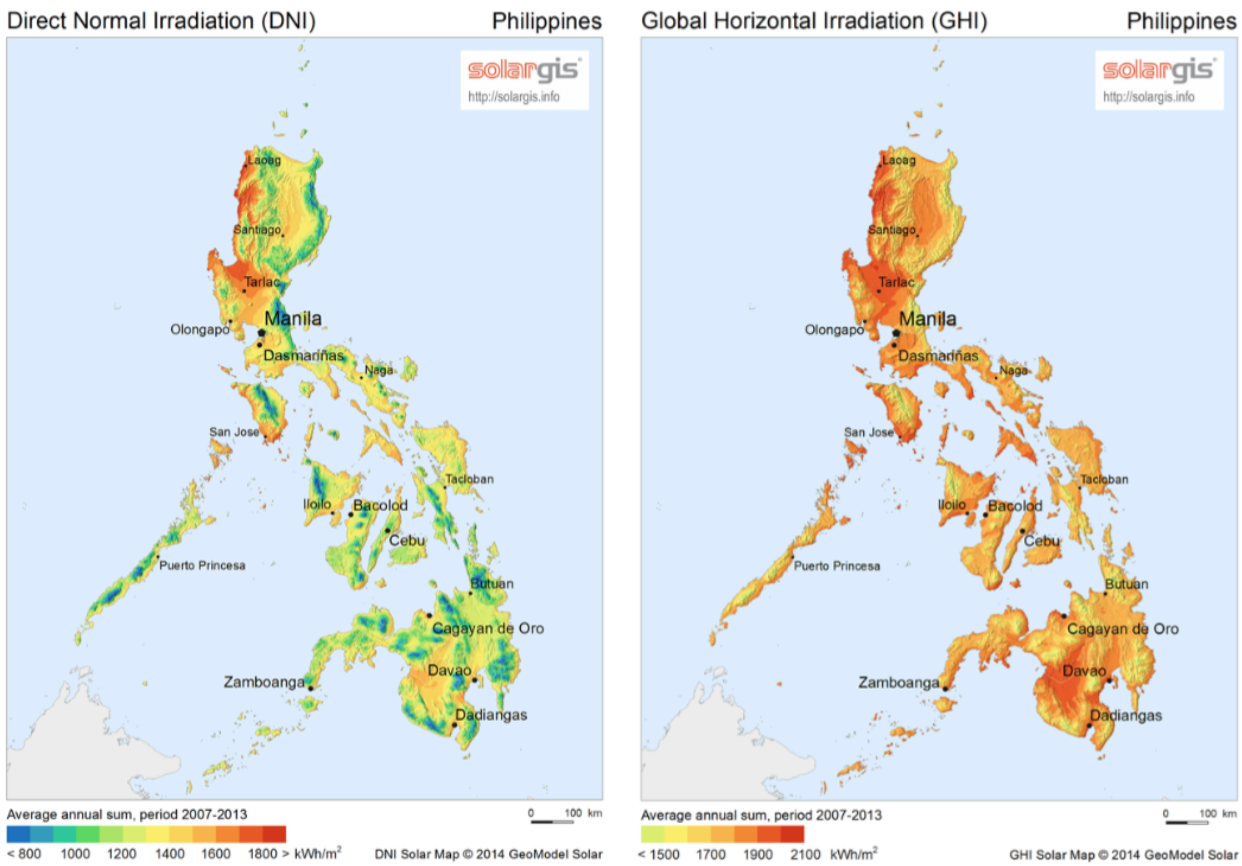


Figure 2.6: Direct normal and global horizontal irradiation in the Philippines [21]

To compare the performance of different PV systems, the Performance Ratio (PR) can be used. PR is a measure of the installation quality and is defined as $PR = \frac{Y_f}{Y_r}$ [6], where Y_f is the actual energy output [kWh/year] including losses and Y_r is the nominal energy output [kWh/year]. The PR is thereby an indicator of the system´s actual output compared to an ideal system without losses. The loss can comprise of increased operating temperature, mismatch of system components and incomplete utilisation of irradiation. Specific production is another measure to compare PV system performance. The specific production is the annual energy output [kWh] per nominal power [kW_p] installed, which corresponds to the operational hours at nominal effect, commonly referred to as full-load hours.

ADB´s Asia Solar Energy Initiative (ASEI) aims to increase solar energy investments in the region so that developing countries can benefit from solar energy. In 2012, ADB implemented its own PV system on the roof at the headquarter located close to Manila, Philippines. The main purpose of this project was to demonstrate that PV technology is accessible. In the first year of operation the system had a specific production of 1103 kWh/kW_p, while the PR was 63.0 % [22]. In comparison, the specific production in Norway is between 700-950 kWh/kW_p/year, depending on the location and the PV system design. However, the performance ratio can be higher in Norway due to the lower temperatures, and a PR value of 80 % can be obtained [7].

2.6 Local Grid Operator in Tacloban

Leyeco is the local grid operator in Tacloban and Tagpuro. During the fieldwork it was arranged a meeting with one of their electrical engineers, Gil Caidic, in order to get insight to the local regulations for implementing a PV system. As of March 2017 Leyeco had only one residential customer with net-metering pricing scheme. In order to obtain the net-metering scheme, the customer must apply to the Energy Regulatory Commission (ERC). FIT has not been implemented yet, and there are no near future plans for doing so.

Leyeco face challenges related to operating and maintaining the grid in an area constantly exposed to typhoons and tropical storms. The grid operator takes measures in order to minimise the climatic damage, and the highest quality of materials, than can withstand maximum stress, are purchased. In the future it is desired to construct more underground cables rather than overhead lines.

There is a direct link between high electricity rates and blackouts from damaged overhead lines after typhoons. According to Leyeco, 30-40 % of the blackouts and brownouts are related to grid maintenance. The Transmission System Operator (TSO) is still upgrading power lines after the damages from typhoon Haiyan in 2013 and operated with temporary power lines in the aftermath of the storm up until the date of the fieldwork (March 2017).

Currently, the main upgrading project for Leyeco is the implementation of a new sub-station in Northern Tacloban, in the village next to Tagpuro. This is due to the resettlement of people from Tacloban to the areas north of the city. The area has been low populated and hence, the electrical grid infrastructure is not capable to provide a stable and reliable power supply to the increasing population. The new sub-station will be a feed-in point at TSO voltage level and is expected to reduce the transmission loss between Tacloban and Tagpuro significantly.

2.6.1 The Process for Implementing a PV System

In order to implement a residential grid-connected PV system in Tagpuro, measures have to be taken towards system parameters, system protection operation and maintenance, net metering and testing as well as commissioning. This section will explain these measures based on information provided by Leyeco found in [23], if not other sources are cited.

The Renewable system must be compliant with the standards in the Philippine Electrical Code (PEC), Philippine Distribution Code (PDC), Distribution Services, Open Access Rules (DSOAR) and Net-Metering Interconnection Standards. The standards and regulations provide technical guidance in order to secure a reliable and safe power system.

System Parameters

The Distribution Utility (DU) require that the PV system, if the residential generation system cause interference, problems or reach unacceptable limits to the DU, will be disconnected and remain disconnected until the conditions are corrected. The DU require that the voltage- and frequency level is the same as the DU level. Further, the power factor should be limited to less than 85 % in the Point of Common Coupling (PCC). Regarding power quality the PV system can not inject DC currents greater than 0.5 % of the rated load current in the PCC and the flicker can not exceed 1.0 unit for short-term and 0.8 unit for long term. The harmonics measure THD [3] should be lower than 5 % during normal operating conditions.

System Protection

Independent of whether the interconnection is in operation, the Qualified End user (QE) is responsible of providing sufficient protection of the PV system, operating under all conditions. The conditions include system faults, equipment failure, voltage or frequency variations exceeding acceptable limits and lightning or switching surges.

To provide system protection the PV system must provide a synchronising device that monitors and controls that voltage, frequency and power factor are within their limits. Further, the system should detect islanding and disconnect within 2 s from the islanding formation. The system should also disconnect from the DU system when the system is down. The protective control devices include a disconnect device that should be visible by the DU and within 10 feet from PCC, as well as protective relays. The system grounding should be in accordance to PEC and integrated with DU system grounding.

[3] THD is a measure for harmonics defined in [24] as the ratio of the RMS value of the sum of the squared individual harmonic amplitudes to the RMS value of the fundamental frequency of a complex waveform

Operation and Maintenance

The QE needs to inform the DU whether it will isolate or synchronise the residential generation system. During the event when there are no power from the DU, the residential generation system must disconnect from DU. QE should maintain its system and interconnection point with DU, in accordance with regulations and approved by the DU.

Net-Metering

Net-metering applies for PV installations below 100 kW, both three-phase and single-phase which are grid-connected and operate in synchronisation with the DU. The Net-metering agreement is between the DU and the QE and the agreement must be submitted to the Energy Regulatory Commission (ERC), Department of Energy (DOE) and National Renewable Energy Board (NREB) within 5 days from execution.

The PV system should be equipped with a meter that can measure the energy flow in both directions. This can either be obtained through a bi-directional meter or two uni-directional meters. The meter must be installed in an accessible and visible area for reading and testing both for QE and DU. The metering service provider is responsible for the design, installation, operation and maintenance of the meter in accordance with section 2.11 in DSOAR.

Testing and Commissioning

A commissioning test shall be conducted after the interconnection system is installed. It shall include verification and inspections, production test (response to abnormal- voltage and frequency and synchronisation), unintentional islanding functionality test and cease-to-energise functionality test. The DU has the right to witness the testing and QE must have the equipment required to perform the test.

Chapter 3

Photovoltaic Systems

"I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that"

Thomas Edison [25]

The following sections will present PV system theory. First, an introduction to PV technology and various components will be given, followed by a presentation of grid-connected systems and stand-alone systems. The chapter is based on *Renewable and Efficient Electric Power Systems* [4], if not other sources are cited.

3.1 PV Cell, Module and Array

A PV system consists of modules with PV cells connected in series. The modules are commonly categorised by their cell type; Mono-crystalline, polycrystalline and thin-film module. Crystalline modules are typically deployed when no requirements to the shape and size of the modules are specified [6]. Modules are connected in series into a string, while strings are connected in parallel into an array. Figure 3.1 visualise the distinction between the PV cell, module and array.

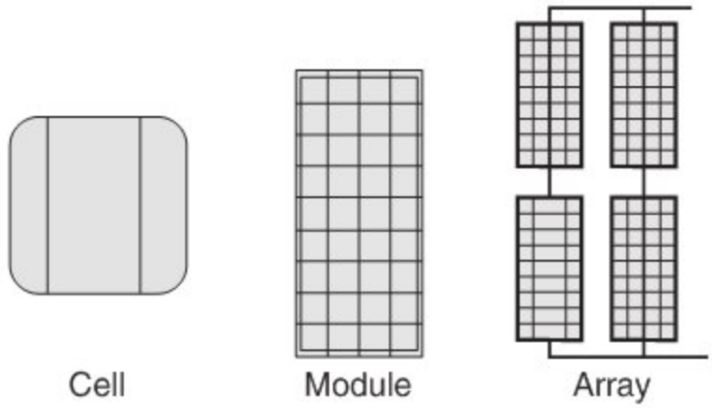


Figure 3.1: PV cell, module and array [4]

The PV cell can be modelled as a p-n junction diode, where hole-electron pairs are created when the cell is exposed to photons with energy exceeding the band gap energy. The equivalent circuit representing the PV cell is shown in figure 3.2. R_P describes the leakage current of the cell, and is represented as the parallel resistance. R_S is the series resistance of the cell, and describes the voltage drop that occurs when the charge carriers move from the semiconductor to the load that is represented by RL. In the ideal case $R_P = \infty$ while $R_S = 0$.

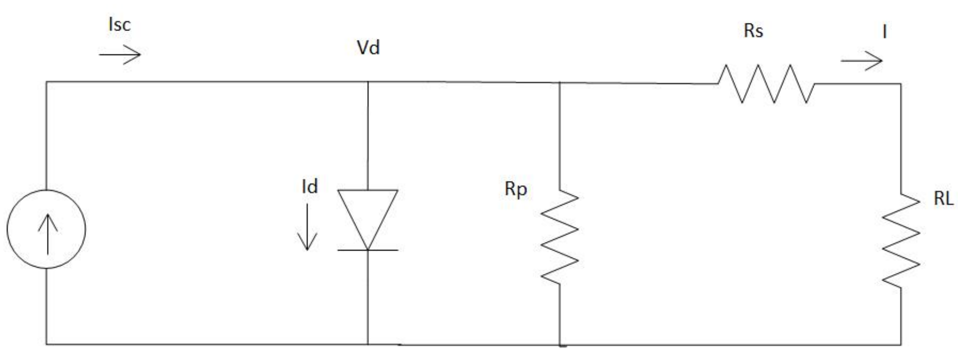


Figure 3.2: Equivalent scheme of a PV cell

3.2 The I-V Curve of the PV Cell

The equivalent scheme presented in figure 3.2 is used to obtain the I-V curve of the PV cell. The current in the diode I_d is described by the Shockley diode equation presented in equation 3.1.

$$I_d = I_0(e^{\frac{qV_d}{kT}} - 1) \tag{3.1}$$

where V_d is the voltage across the diode, while I_0 is the reverse saturation current that flows in the opposite direction of I_d. Further q is the electron charge, K the Boltzman constant and T the temperature in Kelvin. Examining the equivalent circuit in figure 3.2, and using equation 3.1 the current, I, can be described by equation 3.2, for the ideal case.

$$I = I_{SC} - I_d = I_{SC} - I_0(e^{\frac{qV_d}{kT}} - 1) \tag{3.2}$$

It is thereby seen that when it is dark, and $I_{SC} = 0$, the current in the load equals the current in the diode, but with the opposite sign. When $I = 0$, the open circuit voltage, V_{OC}, can be obtained by solving equation 3.2 for V_d. The I-V curve for the PV cell is visualised in figure 3.3, distinguishing between the PV cell being in light and dark surroundings.

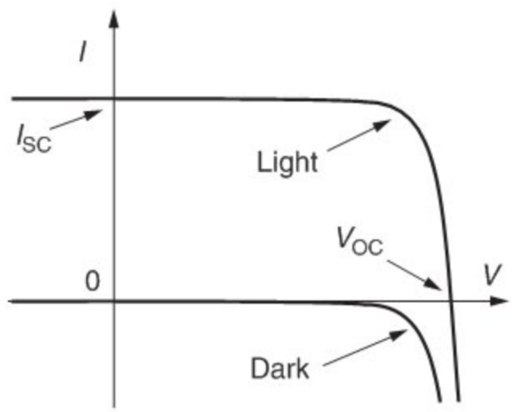


Figure 3.3: I-V curve of the PV cell [4]

3.2.1 From Cells to Module and Array

Typical configurations include 36, 72, 96 or 128 PV cells located in series in a module. The 36-cell module is often used for 12 V battery charging. Increasing cells per module, reduces the number of modules and interconnections needed to obtain a given voltage, and is an advantage in large-scale systems. With n number of series cells in the module, the module voltage V_{module} is calculated as presented in equation 3.3.

$$V_{module} = n(V_d - IR_s) \tag{3.3}$$

Modules are arranged in series to build up the desired voltage, and in parallel strings to build up desired current, to obtain desired power. The combination of modules forms an array and the I-V curve of the array with parallel and series modules are illustrated in figure 3.4.

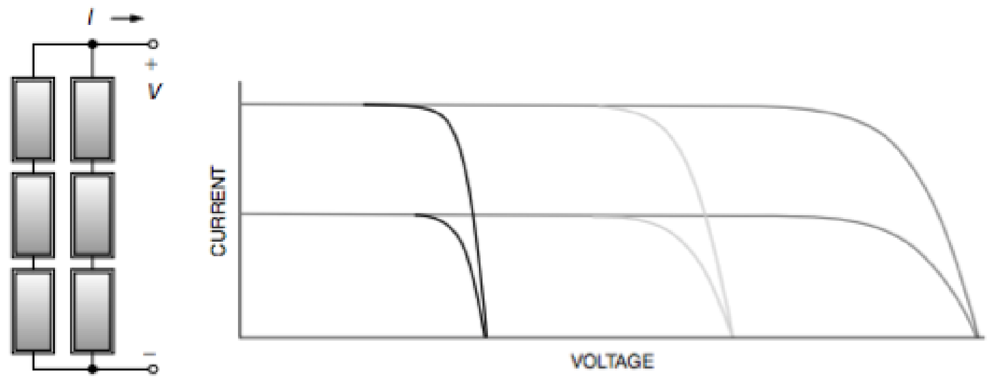


Figure 3.4: I-V curve of the PV array with parallel and series connected modules [4]

3.3 Efficiency and MPPT of PV array

The point at the I-V curve that obtain the highest power output is called Maximum Power Point (MPP). The efficiency, η, of the PV cell is described by the power at MPP as seen in equation 3.4.

$$\eta = \frac{P_{MPP}}{A \cdot S} \tag{3.4}$$

P_{MPP} is power at the maximum power point [kW], A is the area of the cell [m^2], and S is the solar irradiation [kW/m^2]. The efficiency, η, can also describe the module or array, by using P_{MPP} and area of the module or array.

To operate the module, string or array at the optimal point of the I-V curve considering maximum power output, Maximum Power Point Tracking (MPPT) can be incorporated into the system. MPPT regulates the voltage to the level of the highest operating power. This can be a cost-efficient solution when the I-V characteristics of the load deports from the MPPT of the source. MPPT can be achieved by the use of DC-DC converters, which regulates the DC output voltage to a desired level. The MPPT can also be incorporated into the inverter.

3.4 Temperature and Irradiance Effect

The I-V curve is sensitive to irradiation and to the temperature of the PV cell, and the MPP will change according to climatic conditions. When the temperature decreases, V_{OC} increase, and the PV system can therefore obtain higher power in colder days, considering the same irradiation. I_{SC} increases with irradiation, leading to increased power output. The characteristics of the I-V curve to different cell temperatures and different irradiance levels are visualised in figure 3.5. In the figure the cell temperature varies at a constant irradiance of 1 kW/m^2, irradiance varies at a constant cell temperature of 25 °C and Air-Mass (AM) is 1.5. This corresponds to Standard Test Conditions (STC), which are ideal conditions under PV laboratory testing and is a benchmark to compare different module types from different manufacturers.

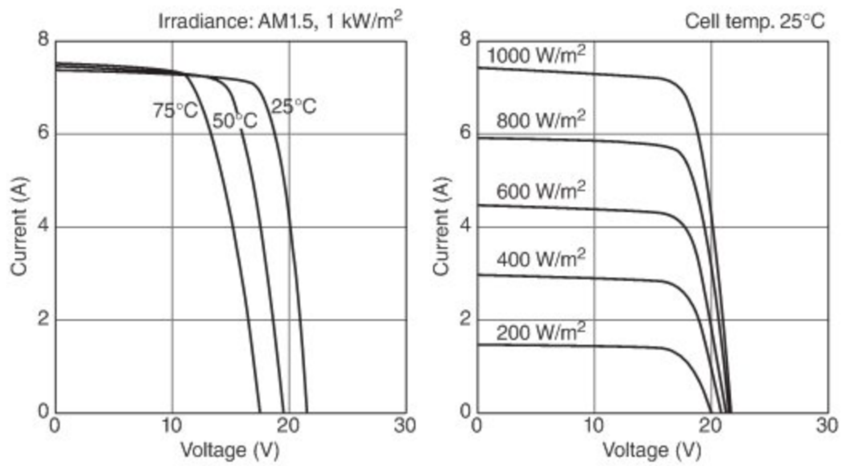


Figure 3.5: I-V curve of the PV array under various cell temperature and irradiance levels [4]

3.5 Shading Effect

In addition to the influence from irradiation and temperature, the I-V curve is also dependant on shading, and shade on one cell can reduce the power output of the module to a great extent. When a cell is shaded, the current produced in the cell is $I_{SC} = 0$, and the diode is reversed biased so that $I_d = 0$. The entire current must therefore flow through both the resistances, R_P and R_S, and a voltage drop occurs.

Shading reduces the output voltage of the module, and in addition shading can cause "hot spots". This occur when the current from the other cells pass through the shaded cell, and the current flow is converted into heat. Hot spots can be prevented by integrating bypass diodes across each cell, each module or across one string. The current will then be diverted past the shaded solar cells. The bypass diodes will also reduce the power loss that results from shading. The effect of shading on the I-V curve, both with and without bypass diodes, are shown in figure 3.6, where the bypass diode is connected across each module.

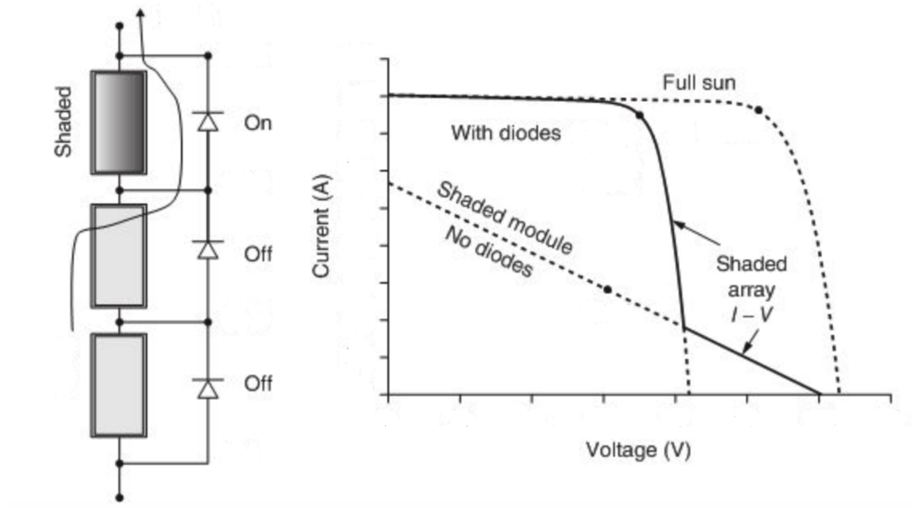


Figure 3.6: I-V curve of the PV array with shading effect, with and without bypass diodes [4]

The interconnection of the modules also influence the effect from shading. Depending on the shading conditions, modules can be mounted vertically or horizontally to minimise shading loss. Vertical mounting is the most common topology. Connection of the modules in series or parallel will also affect the shading loss. Parallel configurations can perform better regarding shading loss due to lower currents in each module that allow lower power loss. With series connected modules the current through each module will be higher, causing a higher power loss when one module is shaded. However, series connected modules are simpler and more cost-effective, so if it is possible to have an unshaded system, series connected modules are the preferred alternative. [6]

3.6 Inverter

For small PV systems it can be efficient to operate with DC loads instead of AC loads. In that case, only a DC-DC converter is necessary. However, when the system is grid-connected or operates with AC loads, an inverter is required to transform DC power to AC power. The inverter is often referred to as a DC-AC converter, since it can also operate as a rectifier transforming from AC to DC when this is required from the system.

The choice of inverter depends on whether it is part of a grid-connected or stand-alone system. Common for both applications is that the inverter should adjust the voltage and frequency to the value of the system. When the inverter is applied in a grid-connected system it also needs to comply with the requirements of the grid, while when it is applied in a stand-alone system its main function is to enable a variety of loads. [6]

The power produced by the PV array and the chosen system concept, as will be examined in section 3.7, determines the power rating of the inverter. The inverter is commonly designed to have a nominal power in the range of ± 20 % of the PV array output power, to consider local conditions such as irradiation and orientation of the array. [6]

The overall aim of sizing the inverter is that all operating points of the PV array is within the operating range of the inverter. When sizing the inverter it is important to consider the irradiance and temperature of the location. The voltage of the inverter depends on the temperature, therefore the minimum and maximum temperature of the PV system surroundings are used to determine the voltage sizing as illustrated in figure 3.7. [6]

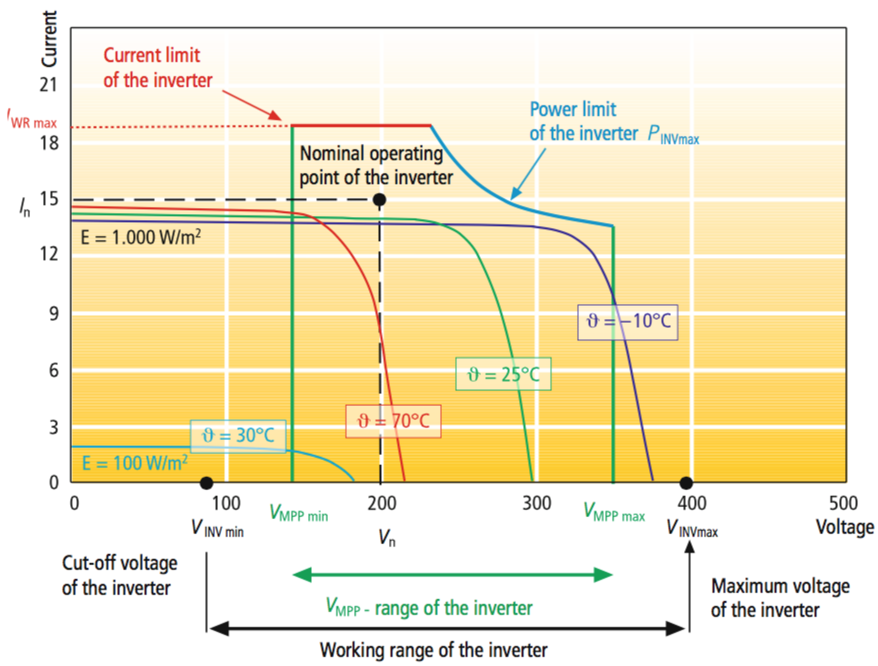


Figure 3.7: The I-V curves of the array and the operating range of the inverter [6]

3.7 System Concepts of Modules and Inverters

The topology of how modules are connected together with the DC-DC converter and/or the DC-AC inverter comprises the system concept. It may be one central converter for the PV array, one converter per string, or one converter per module. The suitable system concept depends on the application. In the following, different system concepts relevant for small-scale PV systems are described based on the source *Planning and Installing Photovoltaic Systems* [6].

3.7.1 Central Inverter Concept

In the central inverter concept there is only one inverter for the whole array. The low voltage concept and the high voltage concept are part of the central inverter concept. In the low voltage concept, only a few modules are connected in series into a string, causing low voltage obtained for the system. Short strings result in reduced shading effect compared to longer strings, since the module with the most shading in a string determines the string current. Furthermore, the high resulting currents require large cable cross-sections to reduce the ohmic losses and are a major drawback with this concept. In addition, lower voltages and higher currents cause the inverter efficiency to decrease. Therefore the application is not common, but can be found on buildings and as custom-made systems. The concept is visualised in figure 3.8.

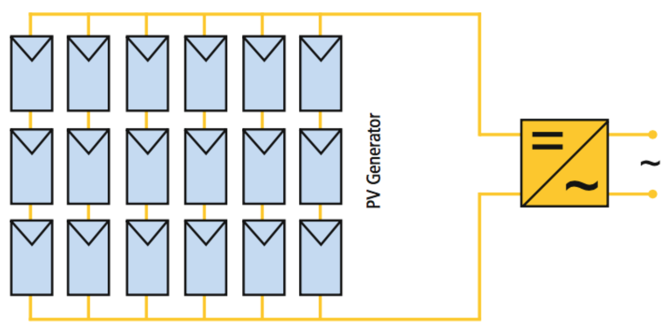


Figure 3.8: Low voltage central inverter concept [6]

To obtain higher output voltage, several modules are connected into the string. The disadvantage with this concept is the increased shading effect. However, currents are reduced so that smaller cable cross-sections can be used, and the ohmic losses in the system are reduced. The concept is commonly employed in medium or large-scale PV arrays.

3.7.2 String Inverter Concept

In the string inverter concept the inverter is connected to each string. This enables various oriented strings to adapt to the irradiance conditions and improve the power output, compared to having one central inverter. Due to the fact that the module with least irradiance determine the string current, only modules with approximately equal shading condition should be connected into one string. Hence, it is beneficial with shorter strings for shading-exposed areas to limit the power loss. The string inverter concept is easy to up-scale compared to the central inverter concept. The string inverter concept is visualised in figure 3.9 with only one string and one string inverter.

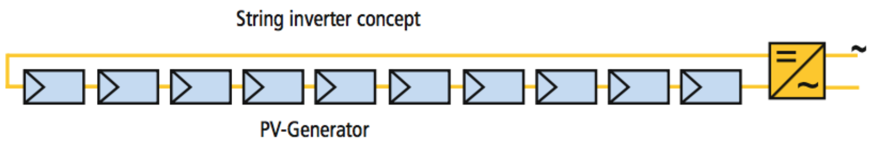


Figure 3.9: String inverter concept [6]

3.7.3 Multiple MPP Regulator Concept

In this concept the DC-DC converter is located in each string separated from the DC-AC converter that is centralised as visualised in figure 3.10. This concept is effective when power production in each string varies, i.e if the modules are irradiated differently or if the strings contain a different number of modules. The DC-DC converter will find the MPP for each string, which can give a higher power output compared to having one MPP for the whole array. The concept is similar to the string converter concept, but with lower costs since only one DC-AC converter is required for the PV array.

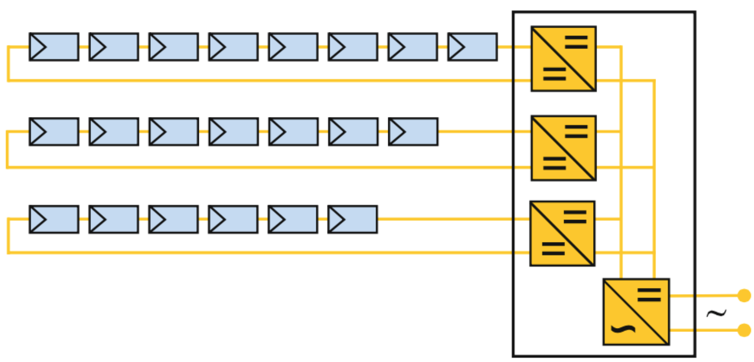


Figure 3.10: Multiple MPP regulator concept [6]

3.7.4 Module Inverter Concept

The module inverter concept, also named microinverter, is a concept rarely used, but can be viewed as the most optimal concept in terms of MPPT. In this concept each module has its own inverter, producing AC power, and therefore also called AC modules. The module inverter concept is also easily up-scaled since the inverter is within the module and the size of the inverter does not need to change with the connection of more modules. Further the concept eliminates the risk of the string being affected if one module is performing poorly, however it is an expensive system concept. The module inverter concept is visualised in figure 3.11.

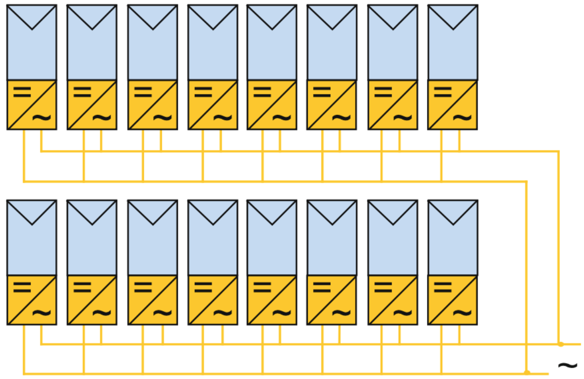


Figure 3.11: Module inverter concept [6]

3.8 Batteries

The power from the PV array is often not required in the amount - or at the time it is generated. Batteries can be used to store energy from the PV array and provide power when needed, for both stand-alone and grid-connected PV-systems. Batteries are the most common technology for storing electrical energy today and there has been recent technological advancements and cost reductions in Electrical Energy Storage (EES) [26]. The two main types of batteries are the conventional lead-acid battery, and the emerging lithium-ion battery.

The overall efficiency of a lead-acid battery is commonly 65-90 %. Its performance is affected by the temperature of operation, number of cycles and State of Charge (SOC) [26]. The ohmic losses in the battery are proportional to the square of the current, and therefore high charging- or discharging current reduces efficiency and lifetime. A deep-charging lead-acid battery can be discharged at 80 % of its capacity, although this would lower lifetime and number of cycles. The lead-acid battery can last for 10 years with a daily 25 % discharge or less.

The lithium-ion battery has higher efficiency and energy density and has replaced the lead-acid battery in several applications [26]. The lithium-ion battery has an efficiency of 85-95 % and is less sensitive to number of cycles and rate of charge/discharge. It can be discharged at 80-100 % of its capacity without significant influence on battery lifetime and weighs about one third of the of the lead-acid. Due to the fact that lithium-ion is a newer technology, it costs up to four times as much as the lead-acid battery. However, battery technology is constantly evolving and the price is expected to decrease in near future. When examining the total life-cycle cost for the two battery types, the lithium-ion life-cycle cost is only slightly above the flooded lead-acid. [27]

The battery should be dimensioned according to the load of the system. Further, autonomous days, i.e how many days the battery should be able to supply the customer when there is no irradiation, is an essential factor when sizing the battery [5]. In addition to demand and autonomous days, it is important to coordinate the battery sizing with the power production from the PV array. An oversized battery will increase system costs and reduce battery lifetime, since the power charging the battery is not sufficient to supply the currents for a complete chemical conversion. An undersized battery will not fulfil the customer requirements for electricity during no PV generation.

Batteries are connected in series and parallel to obtain the voltage and ampere-hour rating needed for the PV system. Batteries connected in parallel obtain the voltage of the weakest battery and can therefore be inefficient. Series connected batteries obtain higher voltage and lower current, and are preferable due to reduced power losses. However, if one battery in the string is performing poorly, it will affect the whole string and therefore two parallel strings are common in order to provide uninterrupted power.

3.9 System Topologies for On-grid and Off-grid PV Systems

PV systems can either be disconnected or connected to the utility grid, and system topologies for both systems will be examined in this section. Further an evaluation of batteries and generators to the system solutions will be given.

A simplified DC-coupled on-grid PV system is illustrated in figure 3.12. The PV array produce DC power that is fed into a DC-DC converter to obtain MPPT. An inverter converts DC power into AC, and controls the voltage and frequency to meet the requirements of the grid. The DC-DC converter together with the DC-AC converter is commonly referred to as Power-Conditioning Unit (PCU).

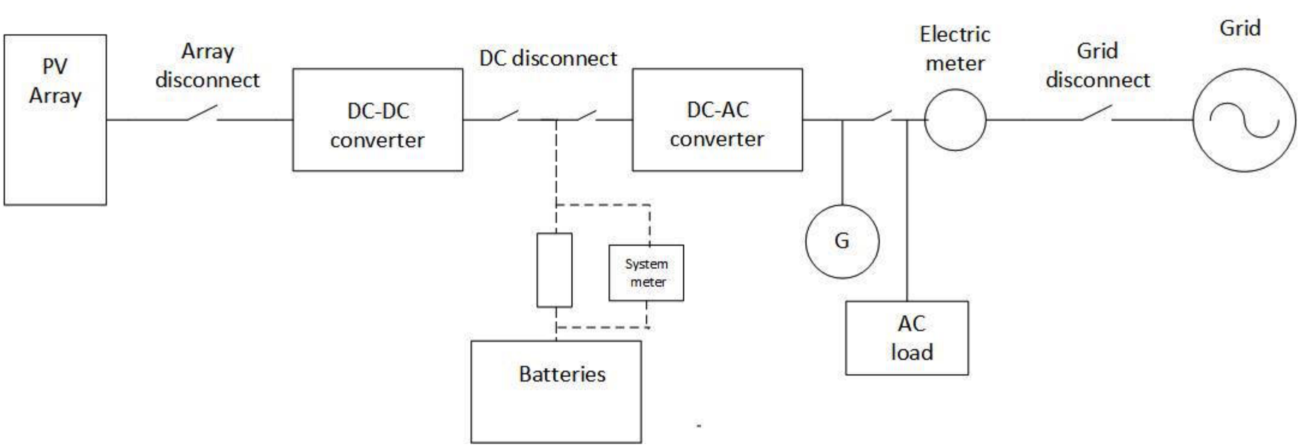


Figure 3.12: Diagram of a DC-coupled on-grid PV system

An alternative to connecting the PV array to a PCU, is to connect each module individually to a PCU, as described in section 3.7.4. This alternative can be advantageous in terms of maintenance, since one module can shut down, be removed or replaced without affecting the other modules. Regarding safety concerns, the configuration can be advantageous since the array can be connected with AC disconnectors that disconnect during the zero-crossing of the AC current. DC disconnectors, as the array disconnector viewed in figure 3.12, are considered less safe since they can not switch instantaneously and this can cause an arc. The function of the array disconnector is to protect the DC cables and the DC-DC converter from overload [6].

A disconnector is also located between the PCU and the grid, to disconnect the PV system if a fault occurs in the grid or in the PV system. The PV array is further commonly protected from lightning strikes through surge arresters located between the PV array and the array disconnector. Due to the chance of faults or disconnections, a battery or a generator can be implemented when the customer is in need of uninterrupted power during grid outages.

Figure 3.13 illustrates a simplified diagram for a DC-coupled off-grid PV system with its main components. The PV array supplies power to the DC-DC converter for MPPT, which is part of a controller connected to the battery and to DC loads. The controller also includes a charge and load controller. The charge controller breaks the current when the battery is fully charged, while the load controller disconnects the battery from the DC load when the voltage is below an acceptable level. The system meter can provide information about the SOC of the battery, and of the battery voltage and current flow.

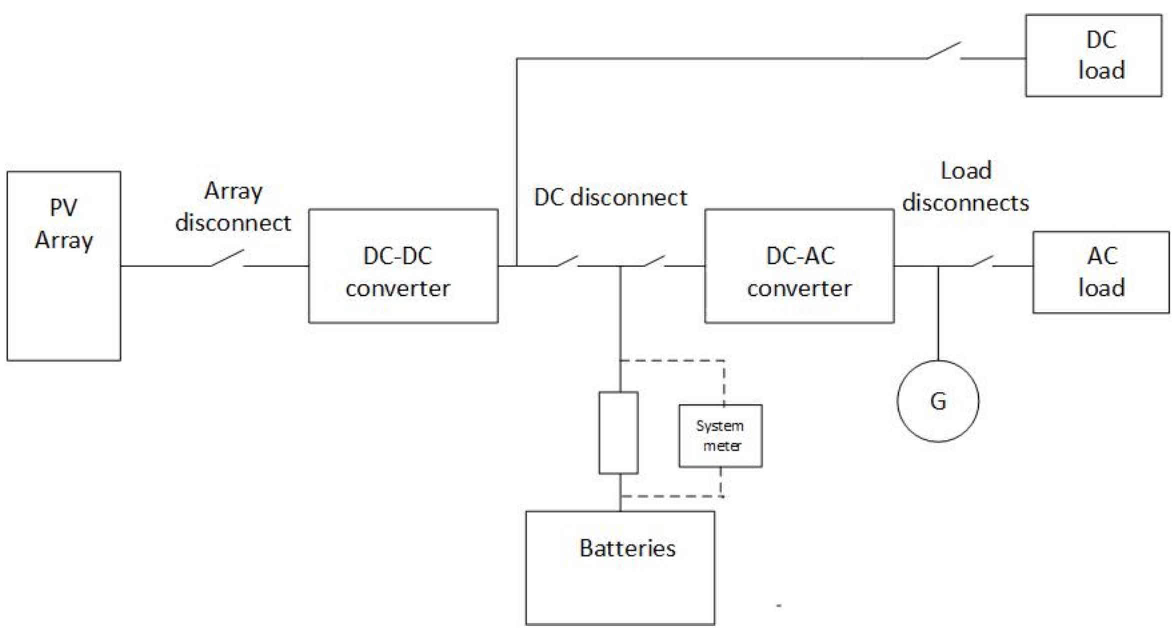


Figure 3.13: Diagram of a DC-coupled off-grid PV system

Further, the DC-AC converter is connected to the AC load. It can be efficient to operate with DC loads instead of AC loads for smaller systems, to avoid having a DC-AC converter. Another possibility is to operate with both DC and AC loads as presented in figure 3.13. In this configuration the DC-AC converter size and losses can be decreased. The choice of loads represents a difference from the on-grid system that are normally limited to AC loads [5]. The DC-AC converter can also be connected to the generator if there is need for power back-up. It should be emphasised that the converter should be bidirectional to allow the backup generator to charge the batteries.

Another option is an off-grid AC-coupled system as illustrated in figure 3.14. The main difference from the DC-coupled diagram in figure 3.13 is that the DC-DC converter is replaced by a DC-AC converter, and thereby an AC-DC converter is located before the connection to the battery. The advantage with the AC-coupled system is flexibility and the system can easily be expanded. The generating units are combined on the AC bus, enabling power generators of different kinds to be connected. This system topology is therefore also feasible for hybrid systems [28]. However, this system topology does not enable the use of DC loads.

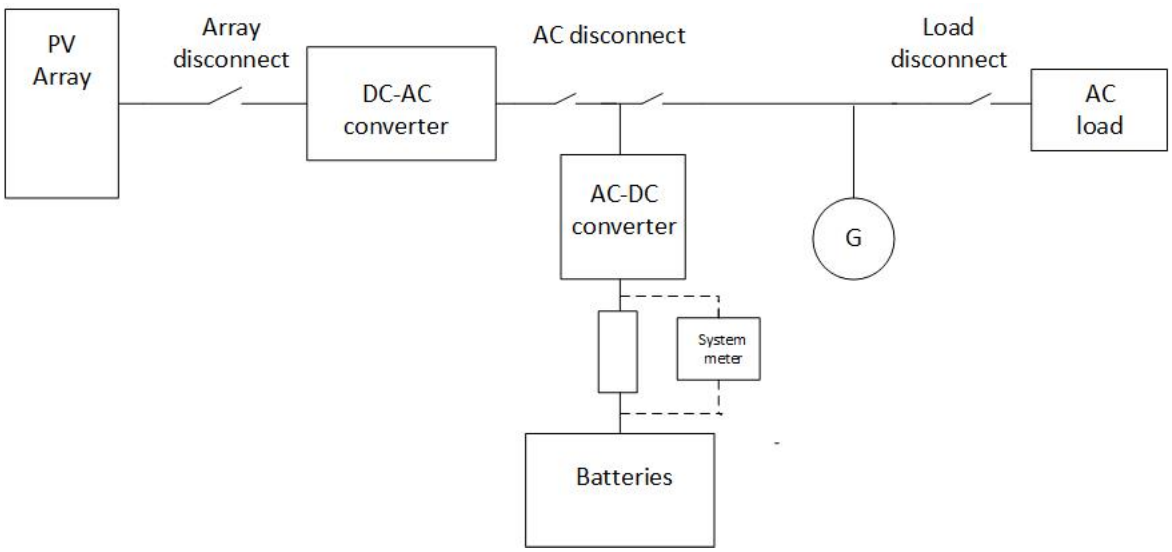


Figure 3.14: Diagram of a AC-coupled off-grid PV system

3.9.1 Battery and Generator

The simplest on-grid PV system designs are without battery. However, if the utility grid is unreliable or unstable, the system can be designed with a battery to provide energy during blackouts. A battery can only be excluded in very small off-grid systems, for instance for a fan or a water pumping system without need of constant supply. However, the most common off-grid designs require a battery. The battery is designed larger for an off-grid system than for an on-grid system. In the on-grid system the battery is commonly designed for the time the utility grid is expected to be unavailable, while in the off-grid system the battery is commonly designed for the number of days the PV array does not provide energy. The battery will thereby be more costly and will also take more space compared to the on-grid topology with battery. [5]

PV systems with batteries can be divided into AC-coupled systems and DC-coupled systems. In the AC-coupled topology the battery is located after the load together with a battery converter. An AC-coupled system is common when the battery is installed in the aftermath of the rest of the system installation, and also when the PV array is part of a hybrid source with either wind or hydro-power. It has higher efficiency than the DC-coupled system, since the power from the PV array is directly converted to AC power, rather than storing the energy in a battery as an intermediate stop. However, this solution is more expensive than the DC-coupled system. [5]

An alternative to energy storage in batteries, is supplying energy from other sources at times of power outages. This is commonly achieved by fuel-driven generators, fueled by diesel, gasoline, natural gas, propane or bio-diesel [29]. It can be a cost-effective solution to install a generator instead of a battery, or together with a battery and then not having to oversize the battery. An off-grid solution with a battery and a generator is a common topology since there is no back up from the utility grid. However, if the customer requires constant uninterrupted power supply, an on-grid system with both battery and generator can be a solution. This is a common topology for hospitals and other institutions where the consequence of power outage is critical.

Chapter 4

Methodology

In order to design an optimal residential PV system, it is required to obtain a predefined load profile. The PV system is dimensioned according to the load profile, and meteorological data, orientation and shading have a significant impact on the PV system performance. An economical analysis can validate the feasibility of the PV system design. This chapter presents the methodology for determining the load profile, dimensioning the PV system and the economical analysis.

4.1 Determining the Load Profile

A load profile is an illustration of the power [W] versus time in hours in a day, week, month or year. A daily load profile for a residential consumer has usually two periods of peak loads, in early morning around 6:00 - 9:00 and in the afternoon and evening around 17:00 - 21:00. There are various methods for determining a load profile and two common methods are theoretical estimation and measuring.

When a load profile is constructed the average power $P_{average}$ can be found by equation 4.1, with T being the hours the average is obtained for. The total energy demand, E_{Total}, of the same period T, can be calculated from equation 4.2.

$$P_{average} = \frac{1}{T}\int_0^T P \cdot dt \tag{4.1}$$

$$E_{Total} = \int_0^T P_{average} \cdot dt \tag{4.2}$$

4.1.1 Theoretical Estimation

A theoretical estimation of a residential load profile can be obtained by mapping all electrical components, their power ratings in [W] and daily electricity use. This method can be effective if the load profile should be designed for future energy needs. A needs assessment can be conducted by interviewing the users and assumptions may be considered based on similar cases. To validate the theoretical estimation a similar case can be used to verify the estimation. This may be obtained through electricity bills, where the monthly energy demand is determined. However, it does not validate a daily load profile, only annual load demand.

4.1.2 Measuring

Another method to determine the load profile is to measure the power consumption. For an annual load profile, the measurements should be conducted continuously for a whole year. Monthly measurements with seasonal variations, day and night variations, weekday and weekend variations are also good estimates. A challenge is often related to available time for measuring the consumption over a year or several months [6].

Another challenge is related to safety conditions and practical connection of the voltage and current probes. This is due to the fact that the fuse box and cables may be located in an inaccessible environment. It has to be ensured that measuring equipment is placed in a safe environment, inaccessible for intruders and at adequate height to not be a risk for children or others. A risk assessment prior to conducting measurements is important to evaluate all possible risk factors and to mitigate consequences.

Measuring Equipment

To measure the power consumption, the meters OWL and Elitepro XC Portable Energy Data Logger was tested. The two energy loggers can obtain a daily load profile and operates with two different principles. The OWL meter measures current and assumes a constant predefined voltage level, in order to obtain power consumption in [kW]. It is unable to measure voltage, which is a disadvantage in situations with varying voltage levels. Elitepro XC Portable Energy Data Logger is a more comprehensive instrument. It is able to measure current and voltage for both single-phase and three-phase systems to obtain precise power measurements [kW]. In addition, it can measure reactive power [kVAR], apparent power [kVA] and power factor [30].

4.2 Dimensioning the PV System

It is important to have a good understanding of the customer expectations and needs in order to dimension a PV system. An on-site visit can enable the assessment of the basic conditions for the PV system. However, a tool to assist the PV system design is essential to process the obtained data and to obtain an optimal solution. A number of different PV simulation software packages exist, and the most common are Polysun, PV*SOL, Solar Pro, Greenius and PVsyst [6]. PVsyst is a broadly used software package that industry use when designing PV systems today. It is a comprehensive tool, offering advanced shadow analysis based on three-dimensional (3D) site simulations and a great variety of manufacturers for PV modules, inverters and batteries. It was decided to use PVsyst version 6.52 premium education for further evaluation.

PVsyst addresses the type of PV system, whether the system should be designed grid-connected or stand-alone. The main difference between these two options is that the stand-alone system enables to select a battery coordinated with the load demand of the user. The grid-connected system does not provide the possibility to select a battery. In addition, the grid-connected system enables the load demand of the user to be defined after a proposed PV system has been created. The steps in developing a PV system in PVsyst are:

1. Create a project: Specify geographical location and import meteorological data.
2. Define a system variant: Define PV module orientation, required PV production or available area and select system components. The first simulation can be performed and is a rough estimate.
3. Define a more detailed variant by adding far and near shading and specific loss parameters etc. New simulations can be performed.

The following will describe theory and methodology for dimensioning an optimal PV system solution. First, a general description of theoretical input data of important parameters and background information will be given, followed by a specific section of how PVsyst interpret these parameters. In the following sections, *Renewable and Efficient Electric Power Systems* and PVsyst tutorial as well as the "help" function in PVsyst are used, if not other sources are cited.

4.2.1 Meteorological Data

Meteorological data as input for PV project assessment is essential and as a minimum it consists of data on solar irradiation and temperature. Temperature is an important factor to include when dimensioning the PV system and estimating performance. As cell temperature increases, V_{OC} decreases while I_{SC} increases slightly, as described in section 3.4.

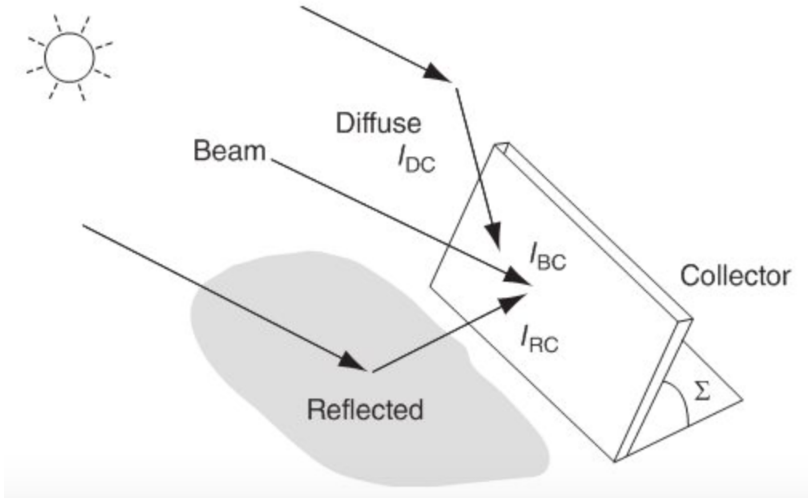


Figure 4.1: Beam-, diffuse- and reflected radiation reaching a collector surface [4]

Solar irradiation is divided into beam radiation, diffuse radiation and albedo (reflected) radiation as illustrated in figure 4.1. The beam radiation is the direct radiation from the sun to the collector. The diffuse radiation is the radiation after the beam radiation have collided with molecules in the sky, while albedo radiation is the reflected beam radiation from the ground, that reaches the collector surface. The energy produced by the PV array depends on the irradiation it collects, based on the portion of irradiation reaching the surface of the earth, I_B. The equations for beam radiation on the earth surface, I_B, beam radiation on collector surface, I_{BC}, diffuse radiation on collector surface, I_{DC} and reflected radiation on collector surface, I_{RC} are given in the equations 4.3, 4.4, 4.5 and 4.6. The denomination is $[W/m^2]$.

$$I_B = A \cdot e^{-km} \tag{4.3}$$

$$I_{BC} = I_B \cdot cos\,\theta \tag{4.4}$$

$$I_{DC} = I_B \cdot C \cdot \left(\frac{1 + cos\,\Sigma}{2}\right) \tag{4.5}$$

$$I_{RC} = I_B \cdot \rho \cdot (C + sin\,\beta) \cdot \left(\frac{1 - cos\,\Sigma}{2}\right) \tag{4.6}$$

A is apparent extraterrestrial flux $[W/m^2]$, k is optical depth and m is air mass ratio. θ is the incidence angle, a function of collector orientation and altitude and azimuth angles of the sun at particular times. The altitude and azimuth will be explained in section 4.2.2. C is a sky diffuse factor and Σ is the collector tilt angle. ρ is the ground reflectance, also called albedo factor and β is the sun altitude angle. Total irradiation on the collector surface, I_C, is the sum of beam, diffuse and reflected radiation on the collector, $I_C = I_{BC} + I_{DC} + I_{RC}$.

Equation 4.3, 4.4, 4.5 and 4.6 are based on clear-sky radiation, which has limited practical value. The determination of irradiation that will be seen on a collector under normal skies is therefore of importance. Different approaches can be used to determine the collector irradiation based on measured solar irradiation, one approach using hourly meteorological data and one using monthly average meteorological data will be presented.

Approach 1: Hourly Meteorological Data

The first approach is useful when the meteorological data is provided as hourly data. It is based on a Typical Meteorological Year (TMY), which is location-specified hourly data on irradiation and weather. The method converts Direct Normal (DNI), Diffuse Horizontal (DHI), and Global Horizontal Irradiation (GHI) data into hourly collector irradiation. The previously presented equations for I_{BC}, I_{DC} and I_{RC} are then expanded and expressed as the following presented in equation 4.7, 4.8 and 4.9.

$$I_{BC} = DNI \cdot cos\,\theta \tag{4.7}$$

$$I_{DC} = DHI \cdot \left(\frac{1 + cos\,\Sigma}{2}\right) \tag{4.8}$$

$$I_{RC} = GHI \cdot \rho \cdot \left(\frac{1 - cos\,\Sigma}{2}\right) \tag{4.9}$$

The total irradiation on the collector surface is $I_C = I_{BC} + I_{DC} + I_{RC}$.

Approach 2: Average Monthly Meteorological Data

The second approach is useful when the meteorological data is provided as monthly data of solar insolation. Solar insolation has the denomination [Wh/m^2] and is irradiation over a given time. The monthly measured horizontal insolation, $\bar{I}_H$ is decomposed into diffuse, $\bar{I}_{DH}$ and direct beam insolation, $\bar{I}_{BH}$. The denomination is in average and therefore represented with bars. The previously presented equations for I_{BC}, I_{DC} and I_{RC} are then expanded and expressed as presented in equation 4.10, 4.11 and 4.13.

$$I_{BC} = I_{BH} \cdot \left(\frac{cos\,\theta}{sin\,\beta} \right) \tag{4.10}$$

where $I_{BH} = I_B \sin\ \beta$. An average value of I_{BC} can be constructed in the Liu and Jordan procedure, which is a procedure suitable to estimate beam radiation on a tilted surface with an azimuth angle less than 15 ° [31]. This is done by averaging the value $cos\,\theta$ over the hours of the day in which the sun is in front of the collector, and averaging the value of $sin\,\beta$ over the hours of the day when the sun is above the horizon.

$$\bar{I}_{DC} = \bar{I}_{DH} \cdot \left(\frac{1 + cos\,\Sigma}{2} \right) \tag{4.11}$$

The Liu and Jordan correlation for the horizontal diffuse fraction can then be used to obtain $\bar{I}_{DH}$:

$$\bar{I}_{DH} = \bar{I}_H \cdot \left(1.390 - 4.027 K_T + 5.531 K_T^2 - 3.108 K_T^3 \right) \tag{4.12}$$

K_T is the clearness index being the ratio between the average horizontal insolation $\bar{I}_H$ and the average extraterrestrial insolation on a horizontal surface above the site and just outside the atmosphere, I_0.

$$\bar{I}_{RC} = \rho \cdot \bar{I}_H \cdot \left(\frac{1 - cos\,\Sigma}{2} \right) \tag{4.13}$$

The total insolation striking the collector is $\bar{I}_C = \bar{I}_{BC} + \bar{I}_{DC} + \bar{I}_{RC}$.

PVsyst - Meteorological Data

Meteorological data in PVsyst can be obtained through databases or self-recorded measurements with monthly or hourly data. The databases provide data either from ground metering stations or from satellites. The two most common databases where access is free are Meteonorm and National Aeronautics and Space Administration - Surface Meteorological and Solar Energy Programme (NASA-SSE). Monthly data include the parameters: GHI and ambient temperature. Optional parameters include DHI and wind velocity. Hourly data include the parameters: GHI, DHI diffuse and ambient temperature. Wind velocity is included if available.

Both Meteonorm and NASA-SSE provides average monthly meteorological data. Meteonorm includes irradiance, temperature and wind velocity from ground stations over the world. For specified sites with coordinates, data is obtained by interpolation of the three nearest stations or nearest latitude station. NASA-SSE includes GHI and temperature data provided by satellite data. Satellite data are considered to be the average for one cell area corresponding to 111x111 km^2. Since PVsyst requires meteorological data as hourly input, the monthly data (*.SIT file) are converted to hourly data (*.MET file), called synthetic data generation.

When hourly irradiation data is obtained, PVsyst use a transposition model to calculate the incident irradiance on the tilted collector plane. The irradiation on a tilted plane towards the sun result in higher values than the horizontal irradiation, because a tilted plane utilise the solar irradiation more effectively, except when located at equator. PVsyst offers two different models that can perform these calculations, Perez and Hays model. The two models differ from each other when calculating the diffuse irradiation component. The default model in PVsyst is Perez.

In addition to meteorological database, PVsyst requires to select an albedo value. Albedo is the reflected irradiance by a surface and the albedo coefficient is determined based on the type of surface. The albedo value is equivalent to ρ in equation 4.6. PVsyst suggests different values for albedo factors shown in table 4.1, with the default value of 0.2.

Table 4.1: Albedo values for different environments in PVsyst

Environment	**Albedo value**
Urban environment	0.14-0.22
Grass	0.15-0.25
Fresh grass	0.26
Fresh snow	0.82
Wet asphalt	0.18

PVsyst - Temperature

As mentioned, ambient temperature is integrated in the meteorological database, either in monthly or hourly data. Hourly temperature data are synthetically constructed and the daily temperature profile correspond to global irradiance profile. The daily temperature behaves as a sinusoidal curve, with an amplitude related to daily global irradiance with a phase shift of 2-3 h. The correlations between amplitude and phase shift was established by the Swiss meteo data, and PVsyst accept that this typology can be generalised to other locations in the world. However, PVsyst emphasises that the synthetic temperature data are not reliable enough to be suitable for building heating or cooling studies.

There are four important temperature settings which are reference temperatures for array design with respect to inverter input voltage. The temperatures can be adjusted according to the specified site, and default values are based on European climate. The four temperature settings and their default values are: Lower temperature for absolute voltage limit (-10 °C), winter operating temperature for VmppMax design (20 °C), usual operating temperature under 1 000 W/m

(50 °C) and summer operating temperature for VmppMin design (60 °C).

Batteries are sensitive to temperature and the effects can be seen in battery ageing and in the SOC. A temperature increase of 10 °C divides static battery lifetime by a factor of 2. The battery operating temperature in PVsyst is 20 °C fixed as default, but can be selected as monthly specified, external ambient or average between ambient and fixed temperature in PVsyst in stand-alone projects. PVsyst emphasises that the determination of SOC from battery voltage and temperature is difficult and unreliable. The real and accurate battery capacity is unknown and is depending on: Charge/discharge of instantaneous current, temperature, age and battery history and gassing current. PVsyst allows to choose whether simulations should be performed according to SOC thresholds or voltage thresholds, default is SOC.

4.2.2 Orientation

Orientation of both the sun and the PV array has to be evaluated and considered in order to design an optimal PV solution. In the following, the position of the sun will be described, followed by the PV array position according to the sun.

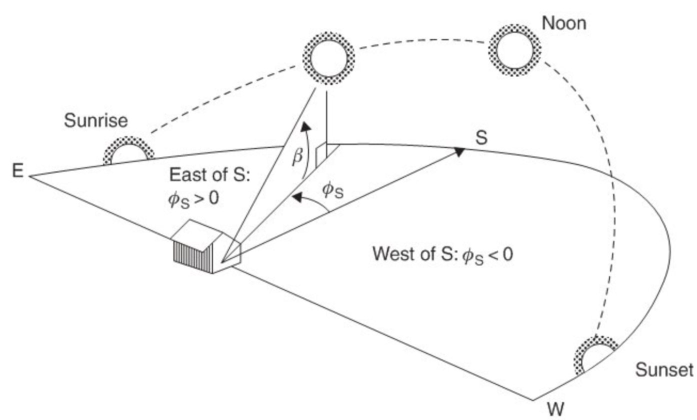


Figure 4.2: The solar position defined by the altitude and azimuth angle [4]

Solar Position

Solar position at any time of the day can be described by two angles, the altitude angle, β, and the azimuth angle, ϕ as illustrated in figure 4.2 and presented in equation 4.14 and 4.15. The altitude angle is the angle between the local horizon and the sun, while the azimuth angle is the angle in the same plane from the sun to a reference point. The reference point is the south in the northern hemisphere, and the north in the southern hemisphere. This is because the azimuth angle is by convention defined positive before solar noon.

$$sin\,\beta = cos\,L \cdot cos\,\delta \cdot cos\,H + sin\,L \cdot sin\,\delta \tag{4.14}$$

$$sin\,\phi_s = \frac{cos\,\delta \cdot sin\,H}{cos\,\beta} \tag{4.15}$$

L is latitude, δ is solar declination related to the time of year and H is hour-angle, which is the number of degrees the earth must rotate before the sun is directly over the local meridian.

PVsyst - Solar Position

PVsyst provides sun-path diagrams for the selected meteorological database as visualised in figure 4.3. It shows the latitude and longitude in degrees, as well as altitude in meter for the specified location. The x-axis is the solar altitude, also called solar height, while the y-axis is the azimuth angle of the sun in rectangular coordinates. The diagram illustrates which months have the longest distribution of sun. PVsyst give the option to view the diagram in legal time or solar time, as well as polar coordinates.

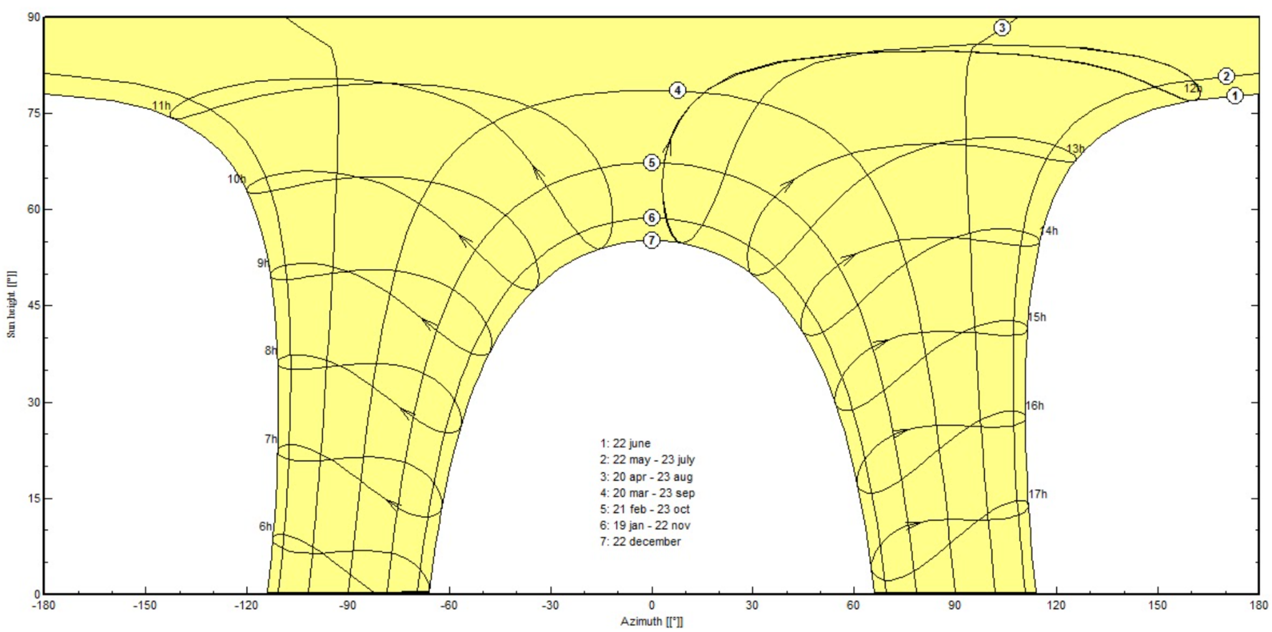


Figure 4.3: Sun-path diagram

PV Orientation

Altitude and azimuth angles are not only applicable for the solar position, they are also essential for determining location of the PV array and obstacles that may cause shading on the PV modules. Collector azimuth, denoted as ϕ_c, is the angle between the perpendicular from the PV location and south-direction.

The position of the sun is used to find the optimum tilt angle, $\sum$, of the PV array. The local latitude, L, is used as a rule of thumb for this purpose. When the collector is tilted at the angle equal to latitude and facing the equator, the sun will be directly facing the collector when the sun is at equinox [1]. If the system should be designed to emphasise winter collection, the tilt angle should be higher than L, and if summer collection should be emphasised, the angle should be lower than L. This is illustrated in figure 4.4.

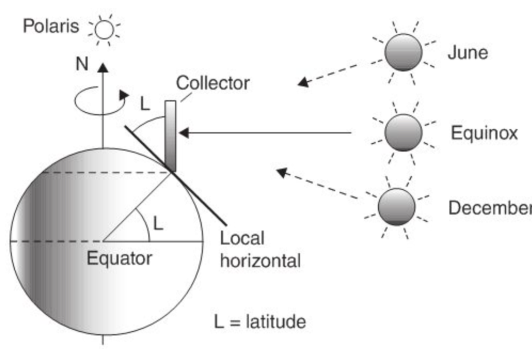


Figure 4.4: The latitude used to find the tilt angle of the collector [4]

PVsyst - PV Orientation

Orientation is the first to be selected when defining a system variant in PVsyst. The choices are based on whether the PV plane has a fixed tilt or a tracking system, and one or several PV orientations. For each plane, a tilt angle $\sum$ and azimuth ϕ_c has to be selected.

PVsyst has tools for optimising orientation to illustrate how much the user can gain if the system is optimally oriented. The optimisation depends on the PV system: For grid-connected systems, the energy is sold to the grid so the user would want to maximise annual energy production. For stand-alone systems, the solar yield for sizing the system can be according to seasonal variations, for instance winter months.

For fixed tilted planes, information on transposition factor, loss in % with respect to optimum and available irradiation on the plane can be viewed. Graphs of the transposition factor as a

[1] Defined as 12 h daytime and 12 h darkness, occurring at March and September 21st

function of plane tilt and azimuth views whether the plane is tilted optimally. The transposition factor is calculated through Hay´s or Perez model. It is the ratio of the incident irradiation on the PV plane and the horizontal irradiation, which illustrates the gain or loss from tilting the collector.

4.2.3 Shading Impact

The orientation of the sun is also important when designing the PV system in order to prevent shading impact. Shading can be divided into temporary shading or shading resulting from location, building or by the system itself [6]. Temporary shading is commonly caused by leaves, dust, snow and bird droppings, but can also come from other types of soiling, depending on the location of the PV system. If it rains regularly and the array has a tilt angle, the array can be self-cleaning. However, in dry areas, regular and manual cleaning is important [6].

Neighbouring buildings and trees are common causes for shadings resulting from the location. It can be caused by antennas, chimneys and building structures. The modules can also cause shading to each other, and sufficient space between the modules is therefore important. Losses caused by shadings are highest when the shade is darkest, i.e when the shadow-casting object is close, and these objects should have special attention when preventing shading. [6]

PVsyst - Shading

Temporary shading is not taken into account in PVsyst. However, shading caused by location, buildings or by the system itself is divided into near shadings and horizon shadings in PVsyst. Horizon shadings are shadings caused by the horizon where the distance of the shading object is typically 10 times the PV system size. This shade affects the whole array. When considering horizon shading, a horizon line is drawn in the sun-path diagram visualised in figure 4.3, called a horizon profile which is a defined curve set of height (azimuth) points. PVsyst determines when the sun is beyond the horizon line and the far shading operate as either on or off at a given time.

Near shadings are caused by near objects. Contradictory to the horizon shadings, the near shading can affect only parts of the array. The implementation of objects from near shadings in PVsyst are described in detail in chapter 5. The near shading can be implemented as "linear shading" or "according to module strings", in PVsyst. Linear shading considers only the shaded area, whereas according to module strings considers the position of the strings. PVsyst assumes linear shading in the stand-alone system design.

4.3 Economical Analysis

The method Levelized Cost of Energy (LCOE) is a commonly used method to measure overall competitiveness for different power generating technologies. It is used to evaluate whether a residential PV system is economical favourable compared to grid power. The LCOE is a present worth analysis where all future costs are converted into an equivalent net-present value (NPV) by discounting annual or monthly financial flows to a common basis, considering the time value of money. It represents a cost per kWh of building and operating a PV system over a given financial lifetime, considering the system expected lifetime costs. LCOE takes into account investment costs, annual costs as well as PV production over the system lifetime. It also include a specified return of investment over a financial lifetime. Net-metering is included in the annual costs for the grid-connected system. [7] [4]

4.3.1 LCOE

The formula for LCOE is presented in equation 4.16 [7], where I_0 corresponds to total investment costs, AC is annual costs, AEP is annual PV energy production and LF is annual system loss factor in %. The discount rate is d, the economic life time is predefined as i and n is year number.

$$LCOE = \frac{I_0 + \sum_{n=1}^{i} \frac{AC}{(1+d)^n}}{\sum_{n=1}^{i} \frac{AEP \cdot (1-LF)^n}{(1+d)^n}} \tag{4.16}$$

For an off-grid PV system AC includes operation and maintenance costs, as well as additional fuel costs for a back-up generator. For an on-grid PV system AC includes operation and maintenance costs and the revenues or costs from net-metering. If there are need for reinvestments of any system components during the economic lifetime n, the present value of total investment cost I_0 includes the reinvestment cost I_R presented in equation 4.17.

$$I_R = \frac{I_{R,m}}{(1+d)^m} \tag{4.17}$$

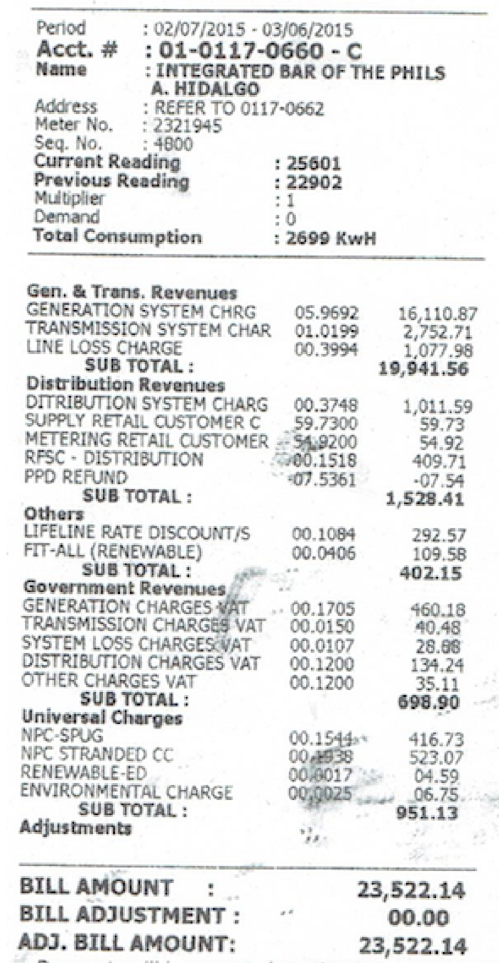
$I_{R,m}$ is the investment cost in the year of reinvestment and m is the year of the reinvestment. If the lifetime of the reinvested component exceeds the economic lifetime, the remaining value has to be taken into account and equation 4.18 has to be applied to the reinvestment. The lifetime of the reinvested component is l.

$$I_{RR} = I_R \cdot \frac{d}{1-(1+d)^{-(m+l)}} \cdot \frac{1-(1+d)^{(i-m)}}{d} \tag{4.18}$$

LCOE can be conducted either as a real or nominal computation. When a real LCOE is conducted the discount rate is corrected for inflation, which is not taken into account in the nominal computation. However, the inflation can be unpredictable and therefore the nominal LCOE can be just as useful. [5] [32]

4.3.2 Net-Metering

For on-grid PV systems net-metering revenues or costs are accounted for in AC, in equation 4.16. To compare a situation with and without a PV system, it is relevant to evaluate how much the exported PV energy reduces the total annual energy bill. The PV energy exported to the grid receives the net-metering pricing scheme. The energy bill includes fixed and variable components as visualised in figure 4.5. Fixed variable costs correspond to system costs including transmission- and distribution costs, governmental charges such as Value Added Tax (VAT) and other charges such as environmental- and renewable energy charge. The variable costs correspond to the generation costs. It is assumed that Streetlight receive the generation costs [PhP/kWh] for the exported PV energy to the grid. It is assumed that imported energy will be calculated as if the PV system was not present.


Period : 02/07/2015 - 03/06/2015
Acct. # : 01-0117-0660 - C
Name : INTEGRATED BAR OF THE PHILS A. HIDALGO
Address : REFER TO 0117-0662
Meter No. : 2321945
Seq. No. : 4800
Current Reading : 25601
Previous Reading : 22902
Multiplier : 1
Demand : 0
Total Consumption : 2699 KwH

Gen. & Trans. Revenues		
GENERATION SYSTEM CHRG	05.9692	16,110.87
TRANSMISSION SYSTEM CHAR	01.0199	2,752.71
LINE LOSS CHARGE	00.3994	1,077.98
SUB TOTAL :		**19,941.56**
Distribution Revenues		
DITRIBUTION SYSTEM CHARG	00.3748	1,011.59
SUPPLY RETAIL CUSTOMER C	59.7300	59.73
METERING RETAIL CUSTOMER	54.9200	54.92
RFSC - DISTRIBUTION	00.1518	409.71
PPD REFUND	-07.5361	-07.54
SUB TOTAL :		**1,528.41**
Others		
LIFELINE RATE DISCOUNT/S	00.1084	292.57
FIT-ALL (RENEWABLE)	00.0406	109.58
SUB TOTAL :		**402.15**
Government Revenues		
GENERATION CHARGES VAT	00.1705	460.18
TRANSMISSION CHARGES VAT	00.0150	40.48
SYSTEM LOSS CHARGES VAT	00.0107	28.88
DISTRIBUTION CHARGES VAT	00.1200	134.24
OTHER CHARGES VAT	00.1200	35.11
SUB TOTAL :		**698.90**
Universal Charges		
NPC-SPUG	00.1544	416.73
NPC STRANDED CC	00.1938	523.07
RENEWABLE-ED	00.0017	04.59
ENVIRONMENTAL CHARGE	00.0025	06.75
SUB TOTAL :		**951.13**
Adjustments		

BILL AMOUNT : 23,522.14
BILL ADJUSTMENT : 00.00
ADJ. BILL AMOUNT: 23,522.14

Figure 4.5: Copy of one electricity bill for Streetlight´s center in Tacloban

Chapter 5

Streetlight in Tagpuro

"We change the world for one child at the time"

Streetlight

An important part of the fieldwork was the determination of the site and the buildings to find the possible location of the modules. This was obtained through site visits where all buildings and nearby shading objects were mapped. The center was constructed as a 3D model in the "Near shadings" section in PVsyst, and the next sections will describe how the data was implemented and how the measures were completed. This chapter will present the site at the Tagpuro center, the localisation of PV modules and a visual shading analysis.

5.1 The Center

Architectural drawings of the center in Tagpuro were provided by Streetlight prior to the fieldwork and used in this project. The main architect behind the center is Alexander Furunes and the center was built through a participatory design process with the local community. The buildings were also built by careful consideration of the environmental challenges the area is facing.

An overview of the center in Tagpuro is given in figure 5.1. The overview is consistent with the buildings that were at the site, besides having one extra orphanage that was not built and neither is planned being built in near future. At the time of the fieldwork there were four buildings at the site: An orphanage, a study center, an office and the Johannesen residence. The Technical Training Center was under construction, with a plan to be completed in June 2017. This building was provided by the charity organisation named Consuelo, who are in charge of both the construction of the building and a rooftop off-grid PV system. The Johannesen residence is a private building and not owned by Streetlight. These buildings will therefore be left out of the evaluation for locating modules, but will be included in the 3D model to examine any shading they may cause. Further module and inverter manufactures for the Technical Training Center are considered in chapter 7.

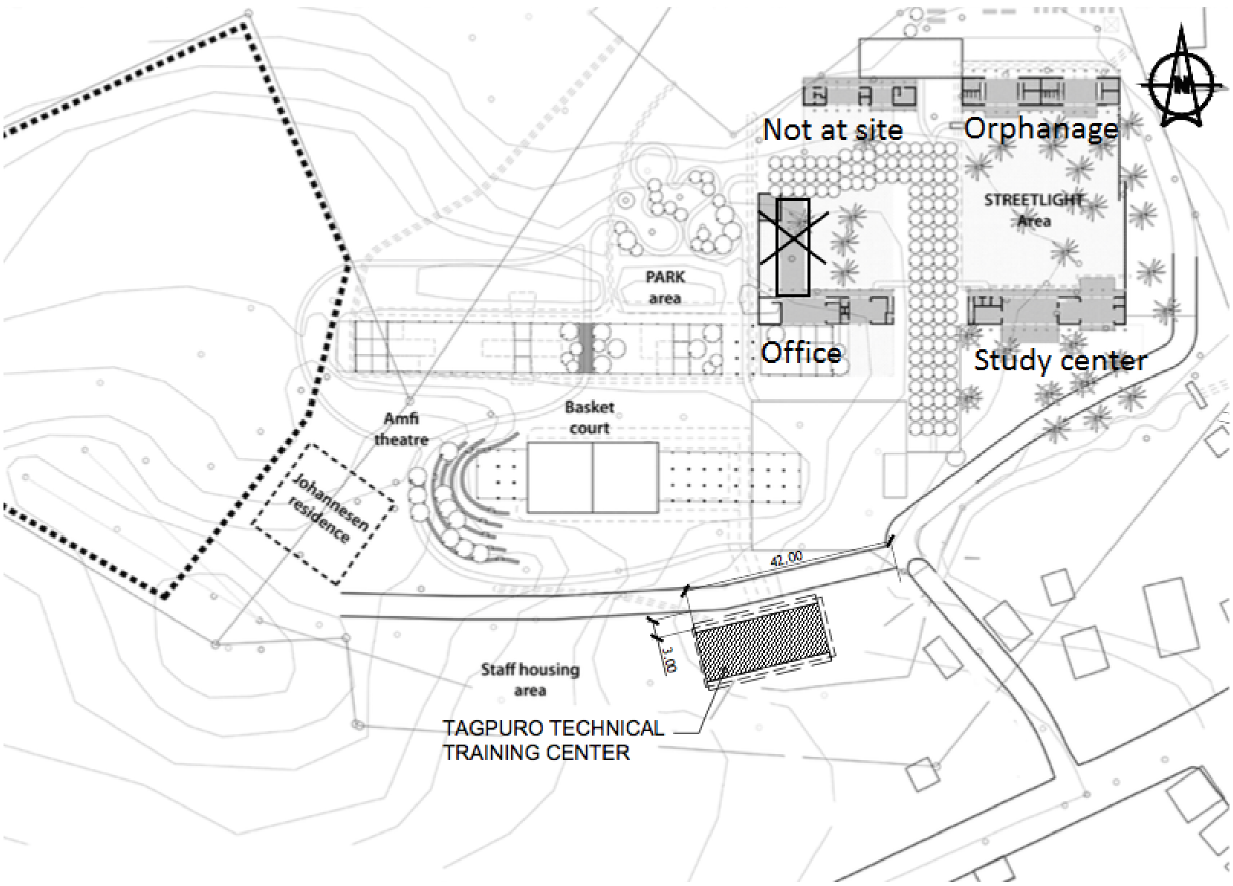


Figure 5.1: Overview of the center in Tagpuro

This thesis will be investigating how the orphanage, study center and the office at the site in Tagpuro can implement a PV system. The buildings are named in figure 5.1 and will be referred to as Orphange, Study Center and Office for the purpose of this thesis. At the time of the fieldwork in March 2017, the Orphanage housed 5 children, while 40 children were using the Study Center. However, in the future perspective the Orphanage will have capacity for 35 children, while the Study Center has capacity for 75 children. The Office is not in operation yet, but it is expected to have a capacity up to 20 employees, both for administration and social workers.

5.2 The Buildings

Figure 5.2 and figure 5.3 visualise the Office and the Study Center respectively, and are pictures taken from the south side of both buildings at the fieldwork.

Figure 5.2: The south side of the Orphanage

When constructing the Office and the Orphanage in PVsyst, measures from the architectural drawings presented in Appendix B were used and verified at the site visit. For the Study Center there were no architectural drawings available. It was assumed to have the same height as the lower roof of the Orphanage, which was 4.3 m. This was chosen because the other measures such as the width of building, the gable eaves (i.e the length of the roof out from the building structure) and the lateral eaves (i.e the width of the roof out from the building structure) were identical to the Orphanage.

Figure 5.3: The south side of the Study Center

Figure 5.4 visualises the three buildings designed in PVsyst. The Office and the Orphanage have an upper floor that is located on parts of the main structure. In PVsyst two houses were designed, the first one for the ground floor and the second for the upper floor. The z-axis of the second house was set to the same value as the height of the first floor.

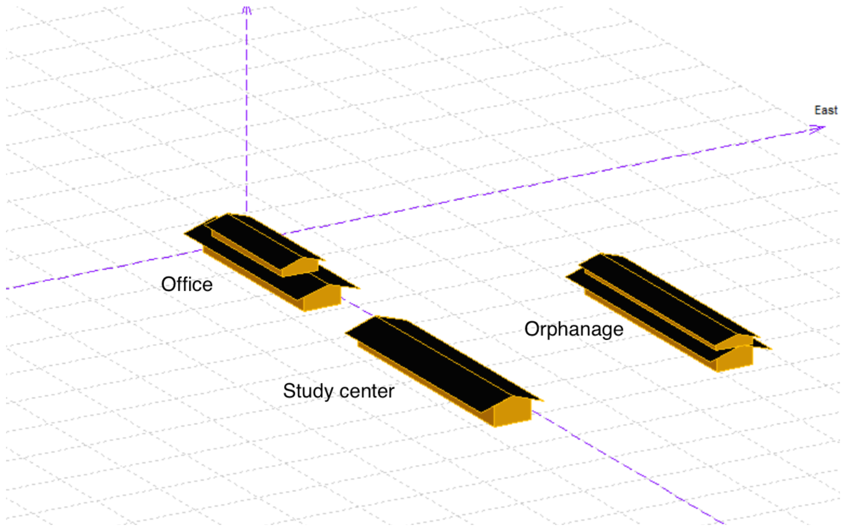


Figure 5.4: The buildings that will be evaluated for a PV system in PVsyst

Measures in the architectural drawings in Appendix B were used to design the Technical Training Center. To locate the Technical Training Center, the overview drawing presented in figure 5.1 was used. There were no architectural drawings provided for the Johannesen residence. Due to this, and the fact that the building is located far from the buildings evaluated for a PV system, the distance to the other buildings were determined based on a visual estimate. The house was set to 10x10 m, with a flat roof, and with a height of 5 m. Figure 5.5 visualises the 3D model of the site with all buildings included.

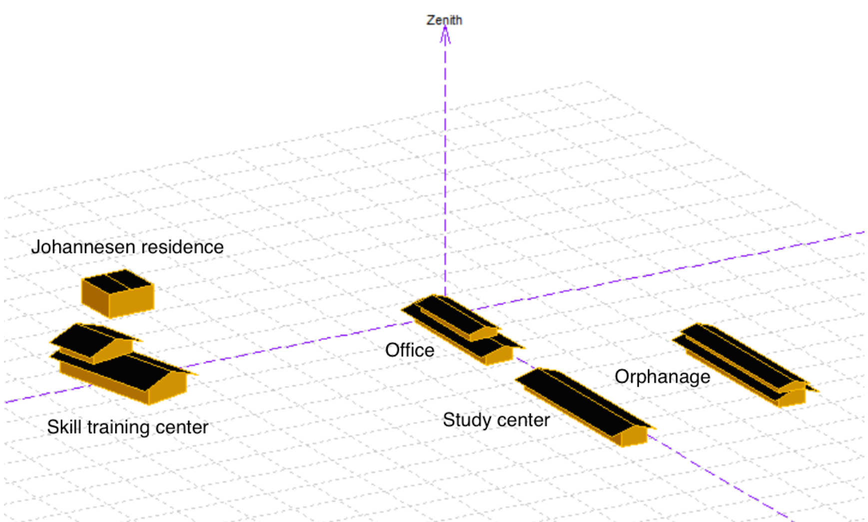


Figure 5.5: The buildings at the center in Tagpuro

5.3 Positioning of Trees

The site is surrounded by high palm trees, mahogany trees and some other trees. It is crucial to locate these in order to evaluate the resulting shading on the modules. The trees were located by measuring the distance from the closest building to the tree, as visualised in the working sketch presented in figure 5.6.

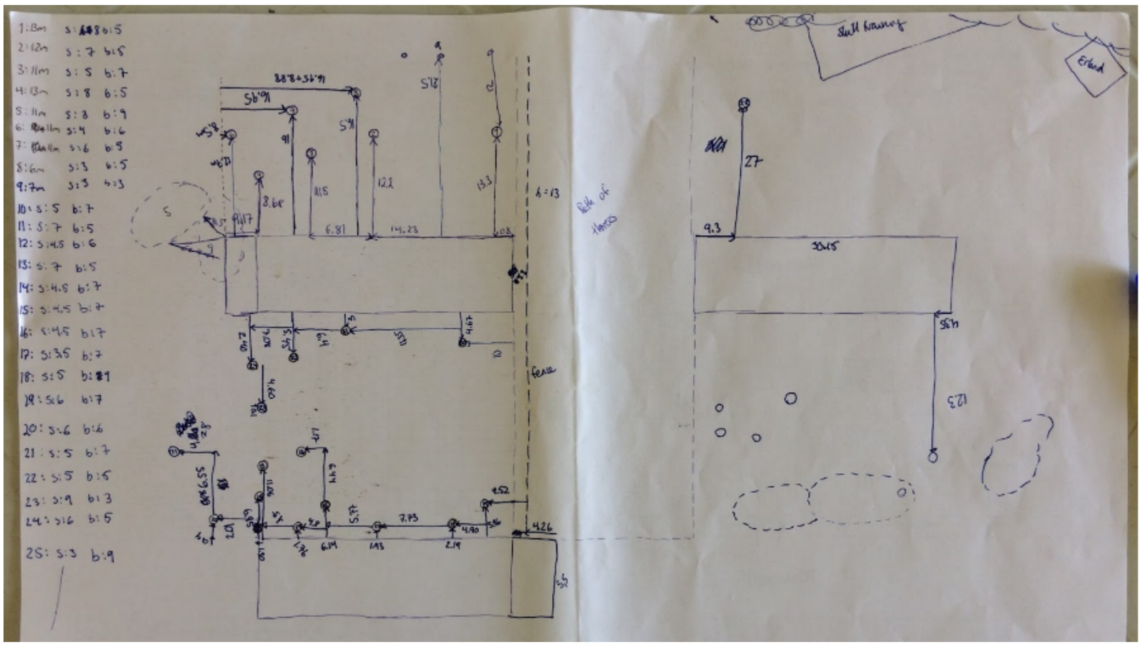


Figure 5.6: Working sketch used for measurements of heights and positioning trees

In addition to the position, the height was roughly measured by visual estimate and the shape taken into account. When estimating the height two variables were used, the trunk of the tree and the distance from the lowest leaf to the highest leaf. This was interpreted into PVsyst by setting the trunk to the “trunk height”, while the distance from blade to blade were divided into “Medium-point-height”, “Medium height” and “Low part height” and configured into the shape of the tree. The “medium diameter” were also adjusted according to the shape of a tree. The trunk diameter was set to 0.5 m for all the palm trees. The other trees such as the mahogany trees had a shorter trunk and a longer distance from blade to blade, the shape of those trees were adjusted. Figure 5.7 visualises this explanation.

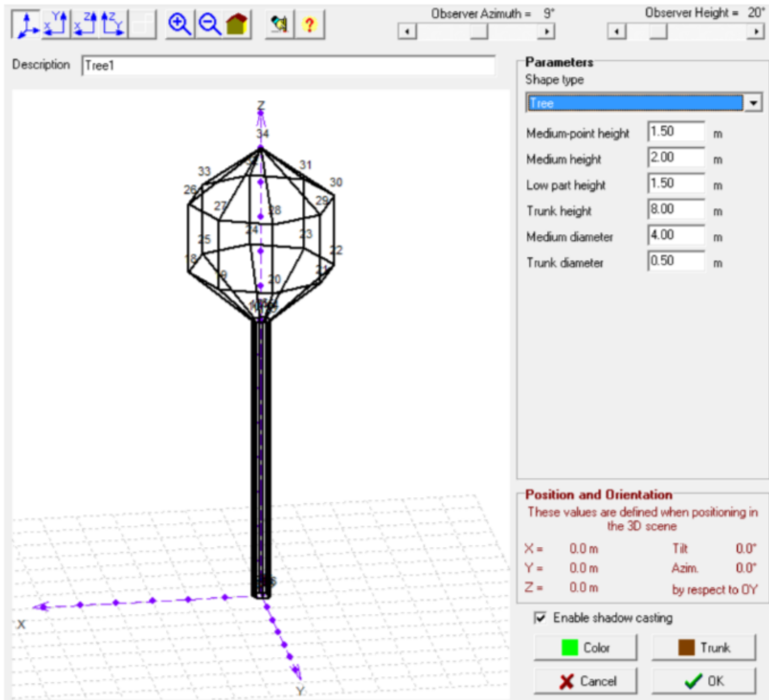


Figure 5.7: A palm tree dimensioned in PVsyst

There is a large path of mahogany trees located between the Office and the Study Center. They were also positioned according to the path of trees in the sketch in figure 5.6. They were all measured by visual estimation to have a height of 13 m. Figure 5.8 visualises the buildings and the trees when positioned in PVsyst.

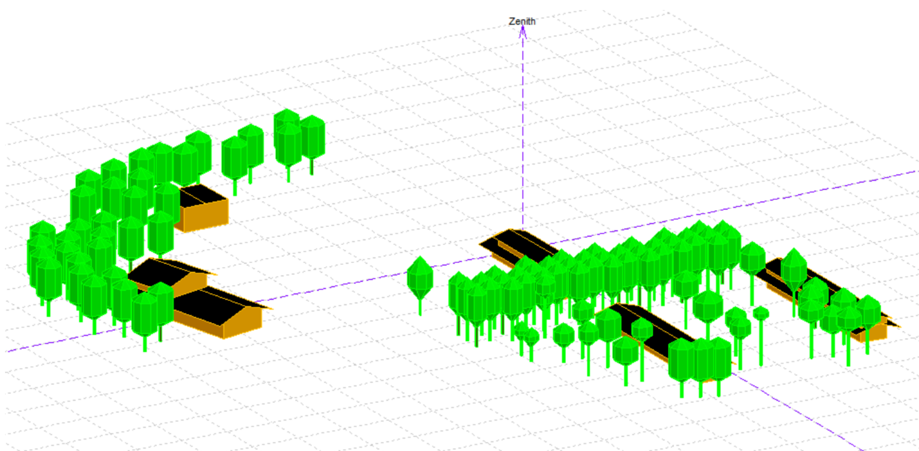


Figure 5.8: The buildings including trees at the center in Tagpuro

5.4 Inserting Elevation

The terrain in the area is flat and there are not any near hills that will influence the system to a great extent. However, there are some small heights in the terrain that were taken into account by visual estimate. The Johannesen residence and the trees in the surrounding area were located 4 m up, and the Office 0.5 m up from reference at 0. The Technical Training Center and the trees located around the Technical Training Center were also lifted 0.5 m. The other buildings and trees are located at the reference of 0.

5.5 Locating PV Modules

In the "Near shading" section in PVsyst the modules are placed according to the available area for the modules. They are then adjusted in the section "System" in PVsyst, to be dimensioned according the the system load. The length of the module JA Solar 290 W_p used, as will be described in chapter 7, is 1.65 m while the width is 0.99 m. The area between the modules is set to a fixed value of 0.02 m in PVsyst.

The area used for modules is the maximum available area on the roof, taking into account the length and the width of the modules and the area between them. Only the roof that is facing the sun is used for the PV design, which is the south-facing roof because it will result in highest energy yield. Table 5.1 summarises the information used to determine the area used for the localisation of the modules, and the maximum number of modules that can be located. The Study Center, Orphanage and Office can locate 88, 66 and 36 modules respectively. This was calculated by assuming vertical position.

Table 5.1: Available area and number of modules at the Study Center, Orphanage and Office

	Study center	**Orphanage**	**Office**
Length [m]	37.50	37.64	20.84
Length used [m]	36.74	36.74	20.04
Number of modules in length	22	22	12
Width [m]	4.95	3.56	3.56
Width used [m]	4.04	3.03	3.03
Number of modules in width	4	3	3
Area [m^2]	185.30	134.00	74.19
Area used [m^2]	148.58	111.43	60.78
Number of modules	**88**	**66**	**36**

5.6 Orientation of the 3D Model

The Study Center, the Orphanage and the Office are located in parallel to each other and will therefore have the same orientation towards the sun. A compass was used to determine the azimuth of the buildings. The compass was placed at the Study Center, facing the north. The compass showed that the building was placed 14 ° towards east. This was transformed to an azimuth of +14 ° in PVsyst.

5.7 3D Model of Tagpuro Center

The complete 3D model of the center in Tagpuro with maximum number of modules at each south oriented top roof is visualised in figure 5.9.

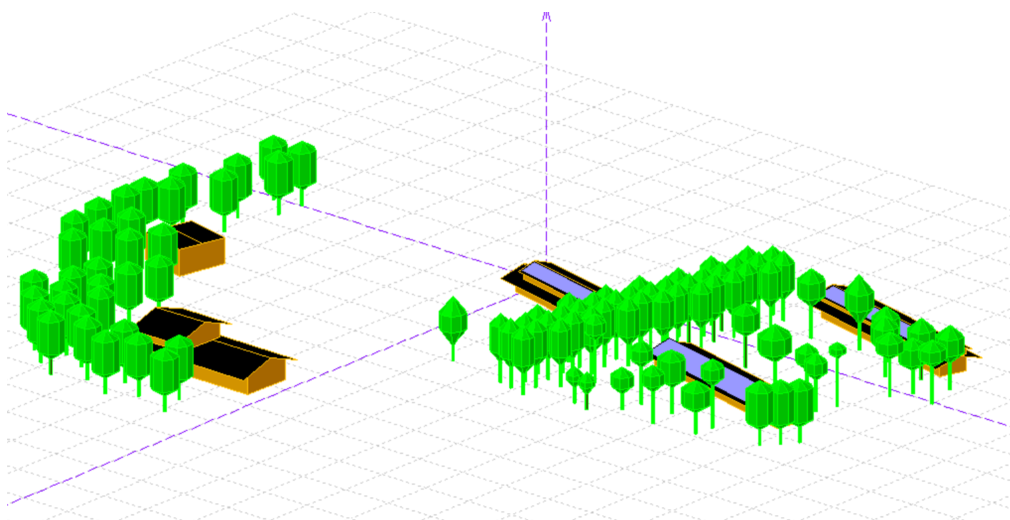


Figure 5.9: 3D model of the center in Tagpuro composed in PVsyst

5.7.1 Shading Analysis

PVsyst provides a shading analysis to visualise the shading on the PV modules from sunrise to sunset. It was found that the Orphanage is most exposed to shading from trees. An illustration of the shading analysis is presented in figure 5.10, where the figure to the left is in the morning, and the figure to the right is in the afternoon, both resulting in shading (black colour) at the Orphanage.

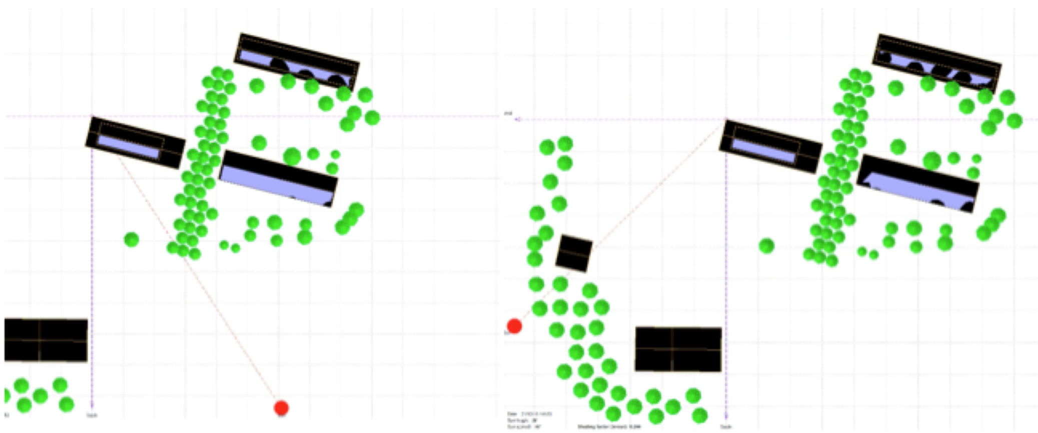


Figure 5.10: Illustration of the shading analysis in PVsyst

The sun-path diagram including iso-shading curves for the center in Tagpuro is presented in figure 5.11. It visualises that the sun height (altitude) is highest in June, and lowest in December, number 1 and 7 respectively. The x-axis represents the azimuth angle. The iso-shading curves represent the shading distribution according to the season and the time of day during the year. Based on these curves, it is desirable with a positive value of azimuth, corresponding to a South-East direction for the location. The loss factor applies to the beam component reaching the PV plane. The highest loss factor is in December.

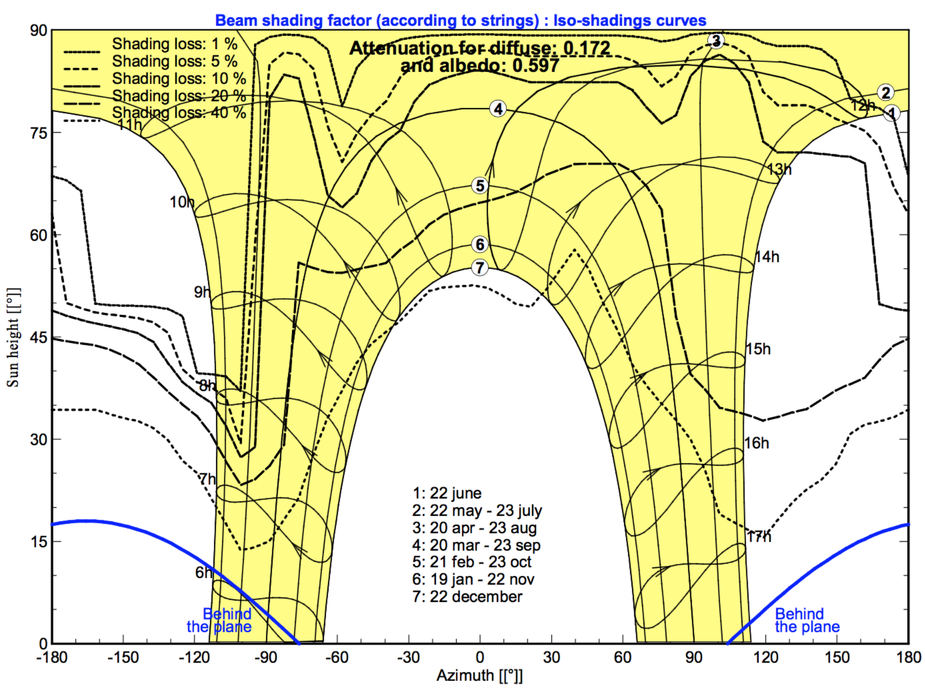


Figure 5.11: Sun-path diagram Tagpuro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Chapter 6

Load Profile Determination

This chapter presents the load profile obtained during the fieldwork in Tagpuro, which was constructed in Microsoft Excel. To determine the load profile the two methods explained in chapter 4 were prepared for. At the fieldwork, it was found that the center in Tagpuro was not in full operation. It was established that the PV system should be designed for future energy demand in a 1-2 year perspective, a time perspective where the operation is foreseen to stabilise, subject to unforeseen changes that can occur. Based on this information, it was decided to only use theoretical estimation as the approach to determine the load profile. This was done both by manual mapping of existing electrical equipment, interviews and discussion with the Streetlight administration, as well as teachers, houseparents and children. A needs assessment questionnaire was performed and included in Appendix C.

This chapter will present the mapping of electrical components and their energy use including power consumption from water consumption. Further, the critical load is determined. The daily load profiles including total load and critical load are presented. The total load demand will be validated with the demand in Tacloban, based on electricity bills. Finally, load management applicable to Streetlight is presented.

6.1 Electrical Components, Power and Time of Consumption

The electrical components at each building, quantity and their power ratings were mapped. The results, in addition to interviewing the users on the current and future energy use, is given in figure 6.1, 6.2 and 6.3. The yellow rows correspond to the assumed components based on the future estimates, and the green rows correspond to observed components. The power ratings are a combination of observed rating of the current equipment and typical ratings of similar components that Streetlight use.

When the mapping was completed, it was also determined the times for which the components were in use for Monday-Friday, Saturday and Sunday. This was based on a combination of current and future energy use. The time of consumption were determined on an hourly basis and the time intervals are visualised in the blue area.

				Time of consumtion		
Room	Equipment	Quantity	Power [kW]	Monday-Friday	Saturday	Sunday
Guard station	Light	1	0,020	08-18		
	Water boiler	1	1,500	08-09,12-13,15-16		
Multi-purpose room	Light	2	0,030	17-22		
Pantry	Light	4	0,084	08-17		
	Water boiler	1	1,500	08-09,12-13,15-16		
	Sink	1				
Toilet	Light	1	0,020	08-17		
	Sink	1				
	Toilet	1				
CEO's/upstairs 1	Light	5	0,100	08-17		
	Emergency light	1	0,002			
	Aircon 1.5 HP	1	1,119	08-17		
General managers room/upstairs 2	Light	5	0,100	08-17		
	Emergency light	1	0,002			
	Aircon 1.5 HP	1	1,119	08-17		
Office/main room	Light	6	0,090	08-17		
	Aircon 4.5 HP	1	3,356	08-17		
	Computers	16	0,720	08-17		
Board/meeting room	Light	4	0,084	08-17		
	Light	1	0,020	08-17		
Indoor outdoor garden	Light	2	0,040	15-17		
Storage	No access	1	0,020			
Outdoor lighting	Luminous light	14	0,112	18-05	18-05	18-05
	Light bulb	1	0,020	18-05	18-05	18-05

Figure 6.1: Electrical components, power and time of consumption at the Office

The Office is only in operation on weekdays from 08:00-17:00, hence most of the energy use is during this time period as presented in figure 6.1. The times of consumption were conducted based on interviews with the administration. It must be noted that the water boiler will not be used constantly for the whole hour when in use, from 08:00-09:00, 12:00-13:00 and 15:00-16:00, but only a few minutes. However, it was chosen to use a resolution of hourly estimates and not minutes for the load profile, and the water boiler was therefore included for one hour to illustrate the maximum power consumption.

The electrical components, power and time of consumption at the Orphanage are presented in figure 6.2. The time intervals were conducted based on the current situation, as provided by Nanai Rosie and Mary living there. The Orphanage will be in operation every day.

				Time of consumtion		
Room	Equipment	Quantity	Power [kW]	Monday-Friday	Saturday	Sunday
Living area	TV	2	0,400	12-14	10-19	10-19
	Sound system	2	1,020			
	Light	12	0,180	17-20	17-20	17-20
	Emergency light	2	0,004			
House parents room	Light	2	0,042	04-23	04-23	04-23
	Printer	2	0,032	08-09		
House parents bedroom	Light	4	0,084	04-05, 23-24	04-05, 23-24	04-05, 23-24
	Electric fan	2	0,120	05-17	05-17	05-17
	Iron	1	1,000		08-10	08-10
	Iron	1	1,200		08-10	08-10
	Iron	1	1,000			
	Emergency light	2	0,004			
Dorm	Emergency light	2	0,004			
	Light	4	0,080	05-07,17-20	06-08,17-20	06-08,17-20
	Electric fan	2	0,120	17-05	17-05	17-05
	Radio	2	0,006	17-20	06-20	06-20
Kitchen	Sink	1				
	Refrigerator	1	0,100	00-24	00-24	00-24
	Refrigerator	1	0,120	00-24	00-24	00-24
	Water supplier	1	0,595	00-24	00-24	00-24
	Freezer	1	0,175	00-24	00-24	00-24
Bathroom	Toilet	4				
	Shower	4				
	Light	4	0,084	04-07,18-23	06-08,18-23	06-08,18-23
	Sink	4				
Outdoor light	Light	13	0,273	18-05	18-05	18-05

Figure 6.2: Electrical components, power and time of consumption at the Orphanage

The power and time of consumption for the electrical equipment at the Study Center are presented in figure 6.3. The time intervals were conducted based on both future and current situation, as provided by tutor Bernard. The Study Center is mainly in operation in weekdays afternoon and full day at Saturdays.

				Time of consumtion		
Room	Equipment	Quantity	Power [kW]	Monday-Friday	Saturday	Sunday
Outdoor room	Light	6	0,090	18-05	18-05	18-05
Music room	Light	2	0,030	16-21	08-20	
	Electric fan	1	0,070	16-21	08-20	
Tutor room	Light	4	0,060	13-17		
	Toilet	1		13-17		
	Sink	1				
	Small light	1	0,060	13-17		
	Computer	1	0,045	13-17		
	Aircon 1.5 HP	1	1,119	13-17		
Library	Light	2	0,030	16-21	08-20	
	TV	1	0,120	16-21	08-20	
Study room	Light	6	0,090	16-21	08-20	
	Water supplier	1	0,595	00-24	00-24	00-24
	Computer	5	0,225	16-21	08-20	
	Emergency light	2	0,004			
Toilet (from outside)	Toilet	2		16-21		
	Light	2	0,040	16-21	08-20	
	Sink	2		16-21	08-20	
Outdoor light	Light	18	0,378	18-05	18-05	18-05
Pantry	Light	2	0,030	15-19		
	sink	1		15-19		

Figure 6.3: Electrical components, power and time of consumption at the Study Center

There will be several outside lights at the site, both for safety reasons and for outside activity reasons such as football field. At the time of the fieldwork there were only lights located between the Study Center and the Orphanage. These lights are estimated to be on when it is dark, between 18:00-05:00 at the time of year with minimum sun in the Philippines [33]. The consumption times for lights are therefore an overestimate, however the range only varied by one hour for the time of year with maximum sun. The outside lights and the consumption times are presented in figure 6.4.

				Time of consumtion		
Location Outdoor light	Equipment	Quantity	Power [kW]	Monday-Friday	Saturday	Sunday
Behind orphanage	Light	2	0,200	18-05	18-05	18-05
Between study center and orphanage	Lightbulbs	72	0,288	18-05	18-05	18-05
Outdoor entrance	Light	5	0,500	18-05	18-05	18-05
Walkway	Lightbulbs	40	0,160	18-05	18-05	18-05
Football field	Light	20	2,000	17-20	17-20	17-20
	Light	4	0,800	17-20	17-20	17-20

Figure 6.4: Outside lighting, power and time of consumption

6.1.1 Power and Time of Consumption from Water Use

The above tables include the water consuming equipment, however the power and time of consumption of the water consuming equipment will be presented in this section. In order to evaluate this contribution, there were several factors considered:

- Water pump capacity
- Water tank capacity
- Approximate water use per capita for the Philippines

During the fieldwork, it was found that the pump capacity is 2 × 40 l/min at 2 × 746 W (2 × 1 HP) and that the water tank capacity in Tagpuro is 2 × 5 000 l, when the center is completed. The approximate water use per capita for the Philippines is 186 l/capita/day according to the *Statistical Yearbook for Asia and the Pacific* from 2014 by the United Nations [34]. The water consumption distribution is presented in figure 6.5 and is based on a report from Philippine Institute for Development Studies. The distribution is based on data from 1983-1998, where the water consumption per Filipino was estimated to 170 l/day. The latest data from 2014 is used in the following, although it is assumed that the same distribution for water consumption in 1998 applies for today [35].

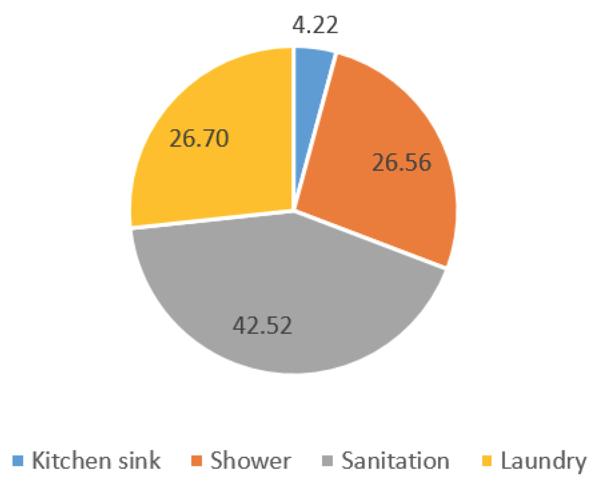

Figure 6.5: Water distribution in % per Filipino per day

The distribution of water consumption is divided into kitchen sink, shower, sanitation and laundry. 42.52 % of the water use is due to sanitation, 26.70 % is due to laundry, 26.56 % is due to shower and 4.22 % is due to kitchen use. To determine the total water use, and hence water pump consumption, it was estimated how many people and the percentage of the total water use each person use during one day at the Tagpuro center.

The water consumption between Monday and Friday is assumed according to the following: For the Orphanage, it was assumed that each person out of 32 people use 80 % of their daily water consumption at the center in Tagpuro. The rest of the consumption is assumed to be in school or elsewhere. For the Office, it was assumed that each person out of 16 use 30 % of their daily water consumption at the center. For the Study Center, it was assumed that 71 people use 20 % of their daily water consumption at the center. This corresponds to a total of 8 296 l/day of water consumption for the Orphanage, Study Center and Office.

To determine the load profile including power consumption from water use, it was important to calculate the time the pump needed to fill the water tank. The total water use of 8 296 l/day was therefore divided by the pump capacity to find the filling time. The pump operation is activated by a water level floater which starts to fill up the tank when the water level is at 2 500 l. An additional 796 l/day (from 8 296 - (10 000- 2 500)) is therefore added, corresponding to additional time. This time is added to the actual filling time of the 10 000 l tanks.

In order to fill the 10 000 l tanks for the water consumption Monday-Friday, the water pump has to operate for 1.8 h. The pump operation time is assumed between the times at 11:00 and 13:00 when PV production is maximum. In several systems with pumps, the pump is adjusted to the time of the load, however it was chosen to preset the time the water tanks are filled. The time of consumption for the pump on Monday-Friday has been rounded up to two hours, and preset from 11:00-13:00.

The water consumption on Saturday is assumed according to 100 % daily water consumption of the 32 people at the Orphanage and 50 % daily water consumption of 36 people at the Study Center. This corresponds to 9 300 l. The water consumption on Sunday is assumed to be 100 % daily water consumption of the 32 people at the Orphanage, corresponding to 5 952 l. To determine the time of consumption from water use, the same principle applies to the pump operation on Saturdays and Sundays. On Saturday the water consumption is assumed to be highest, so the pump has to operate for 2.3 h, which is preset between 11:00-14:00. For Sundays, the water pump has to operate for 1.2 h to cover the water consumption, which is be preset between 11:00-13:00.

6.2 Determining Critical Load

Streetlight categorises three important loads that are prioritised and supplied during outages in order for them to maintain their operation. The critical loads are defined as:

1. Lighting
2. Freezers, refrigerators and water suppliers
3. Computers

It is especially critical with outdoor lighting for safety concerns in the evenings and night time. Freezers and refrigerators are critical to ensure that food are not decomposed. It is also assumed that the water supplier, which cools drinking water, is a critical load. Computers are important for the administrative work and used in the day-time. The computers does not require power constantly, but they require power for charging the battery full at least once a day. In Tacloban, there is a back-up supply which automatically starts to operate these critical loads during outages. The critical load profile is illustrated combined with the load profile for Monday-Friday, Saturday and Sunday.

6.3 Daily Load Profile

All electrical components are assumed to operate at rated power at the time of consumption when interpreted into the load profile. The daily load profile including power consumption from water use combined with additional 10 % uncertainty, is presented in figure 6.6, 6.7 and 6.8. The uncertainty includes consumption from socket/outlets such as cell-phone chargers and other smaller applications not taken into account in the mapping. The uncertainty is further evaluated to 10 % to take into account underestimates of the usage of applications already considered.

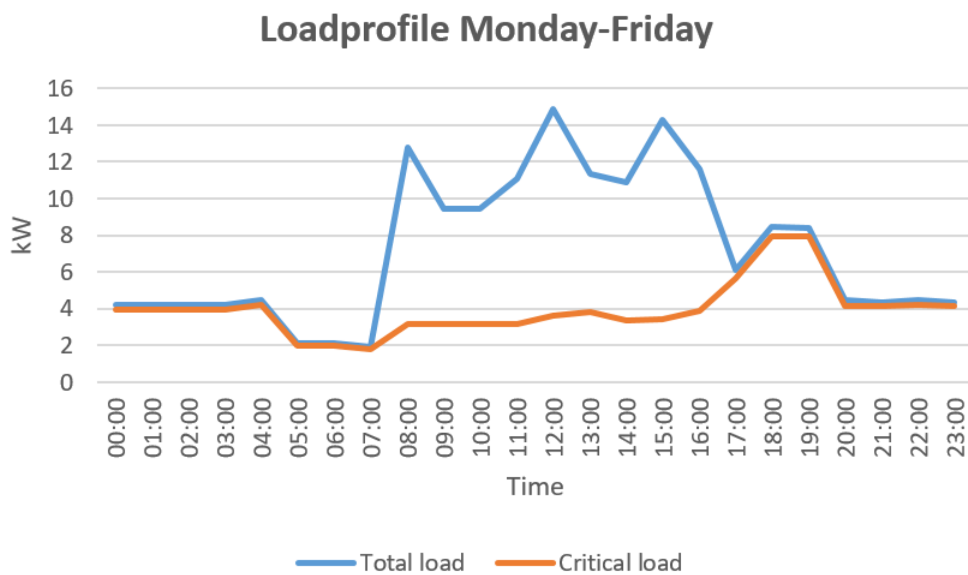

Figure 6.6: Load profile at Tagpuro center Monday-Friday including water pump and 10 % uncertainty

Figure 6.6 illustrates the load at weekdays Monday-Friday. The load profile is characterised by high load between 08:00 and 17:00 due to the operation of the Office. The three peak loads of 13-15 kW during the day is due to the water boiler. The lowest load is 2 kW which are after the night lights have turned off and before people arrive at the Office. By using equation 4.1 with T being the hours in one weekday, the average load on weekdays is 7.25 kW. The critical load is highest in the evening when lights are turned on.

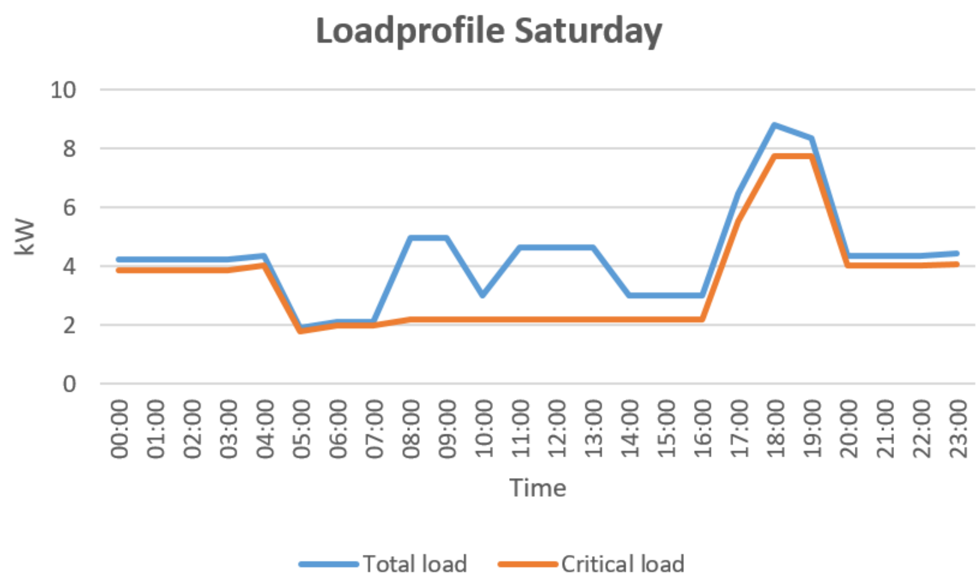

Figure 6.7: Load profile at Tagpuro center Saturday including water pump and 10 % uncertainty

Figure 6.7 illustrates the load on Saturdays. In general, the load demand is low compared to the Monday-Friday profile. The load is lowest during early mornings at only 2 kW due to low activity and night-lights turned off. The load increases during the day as activity increases. In the evening, the lights at the football field are turned on, resulting in the peak of almost 9 kW between 16:00 and 20:00. The average load on Saturdays is 4.35 kW.

The load demand for Tagpuro is lowest on Sundays due to low activity, illustrated in figure 6.8. The peak of 7.5 kW in the evening is due to lights at the football field. The average load on Sundays is only 3.29 kW.

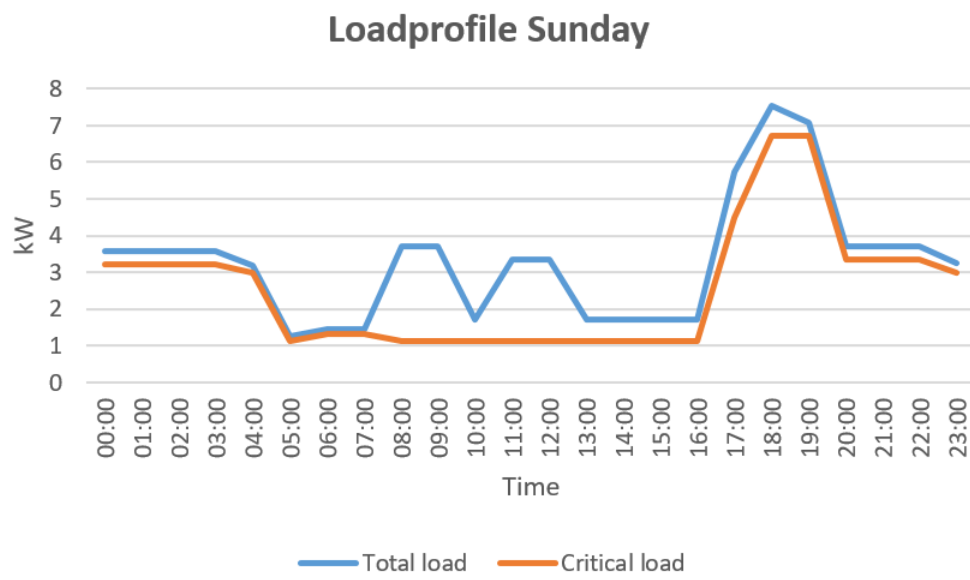

Figure 6.8: Load profile at Tagpuro center Sunday including water pump and 10 % uncertainty

The Monday-Friday, Saturday and Sunday load profiles are added into one weekly load profile that are assumed constant for the whole year. By using equation 4.1 with T being the hours in a week it is found that $P_{average}$ is 6.27 kW. By using equation 4.2 with T being the hours in a year, the annual energy demand E_{Total} is 54.94 MWh. The critical annual energy demand is 32.22 MWh.

6.4 Validation of Annual Load Demand

A validation of the load profile could include to measure the load consumption at the center in Tacloban, that has an approximate similar consumption as Tagpuro will have. However, it was concluded not to proceed with this for safety reasons. It was challenging to locate the energy meter in an environment inaccessible for intruders. In addition, it was considered a risk with the practical connection of voltage and current probes. In order to validate the total annual load demand, electricity bills from Tacloban for 2016 was used.

In 2016 the center in Tacloban consisted of a study center with 50 students, a skill-training building with 35 students and an office with 6 employees. The operational hours for the buildings and electrical equipment were assumed to be the same as in Tagpuro. In addition, the energy consumption included volunteers dorm with 8 people, a residential facility with 4 people, a guards-house with 2 people and a maintenance house with 7 people. The energy consumption in Tacloban in 2016 also included the reverse osmosis system for drinking water. However, there were not an orphanage in Tacloban as there will be in Tagpuro.

Monthly electricity bills were provided from February to August. These were used to find an average of the energy used for the other months. The energy consumption for Tacloban in 2016 is presented in table 6.1. The total energy demand of the center in Tacloban was found to be 55.96 MWh. This corresponds to the theoretical total energy demand estimated to be 54.94 MWh for the center in Tagpuro. The total costs [PhP] for the energy consumption is used further in chapter 8.

Table 6.1: Energy consumption from electricity bills for Tacloban 2016

Month	**Energy [kWh]**	**Total costs [PhP]**
Jan	4 663	36 976
Feb	4 515	37 751
March	4 258	35 802
April	4 771	38 954
May	4 837	38 070
June	4 648	35 632
July	4 393	33 502
Aug	5 221	39 121
Sept	4 663	36 976
Oct	4 663	36 976
Nov	4 663	36 976
Dec	4 663	36 976
Total	**55 959**	**443 713**

6.5 Load Management

Streetlight can manage the load to obtain a situation where the power and consumption times are optimised according to the supply, referred to as the term load management. It requires that the loads adjust rapidly according the the solar conditions and hence PV production. This can be achieved manually by using the power demanding apparatus when there are maximum production from the sun. Another possibility is to utilise an automatic home load management system with wired or wireless communication between the different apparatus and the PV system. The communication system transmits the information to a common processor that will resend command signals to either turn off or on apparatus and optimise the loads according to the solar production and predefined requirements from the user [36].

In addition, Streetlight can use energy saving apparatus to obtain a lower energy consumption. The load profile reviewed that there are lights on during the night, when there are no PV production. If all of these were energy-efficient lights they could consume only 1/5 of the energy that conventional lighting consume [6]. It is beneficial that PV systems utilise the opportunity of energy saving apparatus as well as manual or automatic load management.

Chapter 7

PV System Design and Simulation Results

This chapter presents the different simulation cases and results given by PVsyst where the main goal is to find the optimal PV system solutions. An introduction to the selected system components and simulation settings in PVsyst will first be presented, followed by a preliminary case. The preliminary simulations are divided into two sub-cases. First, an assessment and comparison of three different meteorological databases will be presented. The matching of inverter and modules, string design, one-line diagram, resulting loss diagram, energy production and the Input/Output diagram will be presented and examined in this sub-case of the preliminary case. In the second sub-case, the impact from near shading at the PV site will be evaluated.

Based on results from the preliminary case an on-grid and an off-grid case is performed. For the on-grid case, the roof area is the important dimension criteria, and the PV system will exchange energy with the grid. The economical evaluation in chapter 8 will evaluate which roof area is the most economically optimal solution. For the off-grid case, the load demand is the important dimension criteria, and a battery will store energy and provide energy when necessary.

- **Preliminary Case: On-Grid All Buildings**
  - Meteorological Databases
  - Shading Impact
- **On-Grid Case**
- **Off-Grid Case**

7.1 System Components

PVsyst offers a number of different manufacturers for PV modules, inverters and batteries available to select when constructing a PV system. The datasheets for the selected PV module, inverter, rectifier and battery are presented in appendix E. It must be noted that the selection of PV system components is not the main focus in this thesis and a different combination of components may be just as feasible as the presented system solutions. Nevertheless, the assessment is based on the available information and a minor mapping of available suppliers that operate in the Philippines. The Technical Training Center in Tagpuro will have a PV system installed from the supplier Solaric. Fortunately, it was possible to get hold of the dealers pricelist from December 2016 with manufacturers and models that Solaric supply. This serves as the basis for the selection of PV modules and inverters.

The on-grid simulation cases apply the system topology presented in figure 3.12 and "Grid-connected" mode in PVsyst, whereas the off-grid simulation cases apply the system topology presented in figure 3.14 and "Stand-alone" mode in PVsyst. Both the on-grid and off-grid solutions assume one inverter per string i.e string inverter concept as presented in section 3.7.2.

Module and Inverter

Solaric provides four types of PV modules as presented in the dealers pricelist in appendix D. Amongst these, the most cost-effective (PhP/W_p) module is JA Solar 290 W_p. This is the same module type that will be installed at the Technical Training Center in Tagpuro. The JA Solar 290 W_p module was available in PVsyst and simulations have been conducted with these modules for all cases. Solaric provided the inverter Thinkpower which was also available in PVsyst. Three different models were available: 1.5 kW, 2.2 kW and 3.0 kW and the matching between modules and inverters is based on the three models.

The PV system in the "Grid-Connected" mode can be organised by several sub-arrays in PVsyst. One sub-array consists of one type of PV module with x number in series connected to one inverter type, both selected from the database. PVsyst give warnings if the array power exceeds the inverter power or if the inverter is oversized. The optimal combination of modules, strings and inverters is a result of trial and error in order to maximise number of modules located at the available roof area. Sub-arrays are not an option in the "Stand-Alone" mode. Neither is it possible to adjust specific strings to each building roof, as it is for the grid-connected mode. However, the same matching of modules and inverters as for the grid-connected system is assumed to be installed and the matching of inverter and modules in the off-grid cases are only performed for simulation purpose.

Battery and Rectifier

A battery can only be selected in PVsyst for the off-grid simulations. PVsyst only offers a few manufacturers on batteries and none of the battery types from Solaric were an option. After research it was concluded to use batteries from Exide Classic, which are offered in the Philippines [37] [38]. The largest battery named OPzS Solar 4600, of 3 450 Ah nominal capacity and 2 V, was selected, with 24 batteries in series, obtaining 48 V. The voltage was set to 48 V since the system voltage for modest loads is commonly 12, 24 and 48 V [4]. The number of parallel connections varies in the simulations to obtain the desired storage capacity. The off-grid topology requires an additional rectifier before the battery and the selected rectifier is Sunny Island 8.0 provided by SMA. However, this was not possible to select in PVsyst.

7.2 Simulation Settings

The simulation settings in PVsyst that apply to all cases will be briefly presented in the following sections. Other simulation settings are left at default values.

Meteorological Database and Solar Irradiation

The meteorological databases in the simulation cases are either from Meteonorm or NASA-SSE. As mentioned in section 4.2.1, Meteonorm is based on ground data whereas NASA-SSE is based on satellite data. The Tagpuro site has been included by adding the coordinates 11.34° N latitude, 124.95° E longitude and altitude of 12 m a.s.l.

For Meteonorm, the synthetic data generation is obtained by interpolation between the three nearest stations, taking altitude and region typology into account. According to PVsyst, there are two Meteonorm stations located in the Philippines. One is in Calapan (roughly 483 km from Tagpuro[1]) and one is in Manila (roughly 577 km from Tagpuro), both North-West from the site in Tagpuro. It is assumed that PVsyst performs synthetic data generation based on these two stations and one additional station from a neighbouring country at approximately same latitude. For NASA-SSE, the meteorological data is valid within the boundaries of 11 - 12 °N and 124 - 125 °E.

[1]Based on a straight line distance from Google Maps

Temperature and Albedo

The lower temperature for absolute voltage limit, which is the minimum ambient temperature at the PV site was changed. It was -10 °C at default value for Europe and changed to +20 °C, based on a minimum temperature for Tacloban at +22 °C [39]. The albedo value was left unchanged at 0.2 for grass surface.

Orientation

The orientation of the buildings was assessed during the fieldwork and all buildings had the same orientation with tilt angle of 18 ° and azimuth angle of 14 °.

Shading

The near shading was determined in the 3D model of the site presented in chapter 5. Shading was additionally taken into account by implementing near shading "according to module strings". The horizon shading was not considered, since the elevation at the site was insignificant and there were no nearby hills.

Users Needs

PVsyst allows to upload a self-composed load profile. The load profile from chapter 6 was restructured in order for PVsyst to read it as an input .csv file. The load profile was structured with hourly load data for one year.

7.3 Preliminary Case - Meteorological Databases

The preliminary simulations was conducted in the "Grid-connected" mode. The available south oriented top roof at all buildings were utilised in the simulations, as previously visualised in figure 5.9.

7.3.1 Meteonorm - Tagpuro

The first simulation was conducted with Meteonorm database, where the meteorological data was obtained by interpolating data from the three nearest databases to the center in Tagpuro. Wind velocity is taken into account in the Meteonorm database and is 1.1 m/s on average over the year. This simulation is later referred to as the Base Case.

Matching Inverter and Modules

The Office, Orphanage and the Study Center have an available area to place 36, 66 and 88 modules respectively at the south oriented top roof. The matching of the modules and inverters for the Office in PVsyst is visualised in figure 7.1.

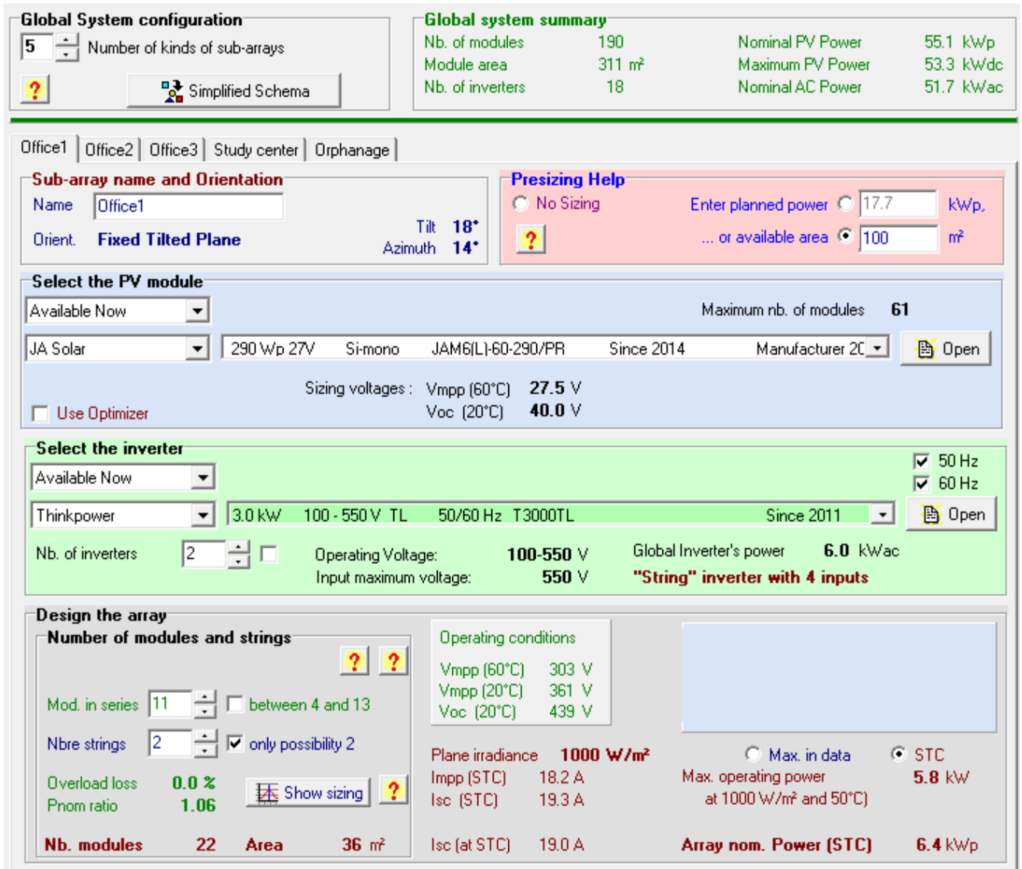

Figure 7.1: Matching inverters and modules Office On-grid

The matching of modules and inverters, named system configuration, is presented in table 7.1. The Office is divided into three sub-arrays with 2 × 3.0 kW, 1 × 2.2 kW and 1 × 1.5 kW inverters, with 11, 8 and 6 modules in series respectively. Both the Study Center and the Orphanage consists of one sub-array each with 8 × 3.0 kW and 6 × 3.0 kW inverters respectively, both with 11 modules in series. The total number of modules is 190 and the total number of inverters is 18.

Table 7.1: System configuration Base Case - Modules located at all buildings

	Office			**Study Center**	**Orphanage**
Sub-array	1	2	3	1	1
Inverter type	3.0 kW	2.2 kW	1.5 kW	3.0 kW	3.0 kW
Number of inverters/strings	2	1	1	8	6
Modules in series	11	8	6	11	11
Total number of modules	22	8	6	88	66
Sum modules	**36**			**88**	**66**

One-Line Diagram

The one-line diagram in figure 7.2 represents the system topology used for the preliminary and on-grid case. The number, n, represents the number of inverters for the system configuration with modules located at all buildings.

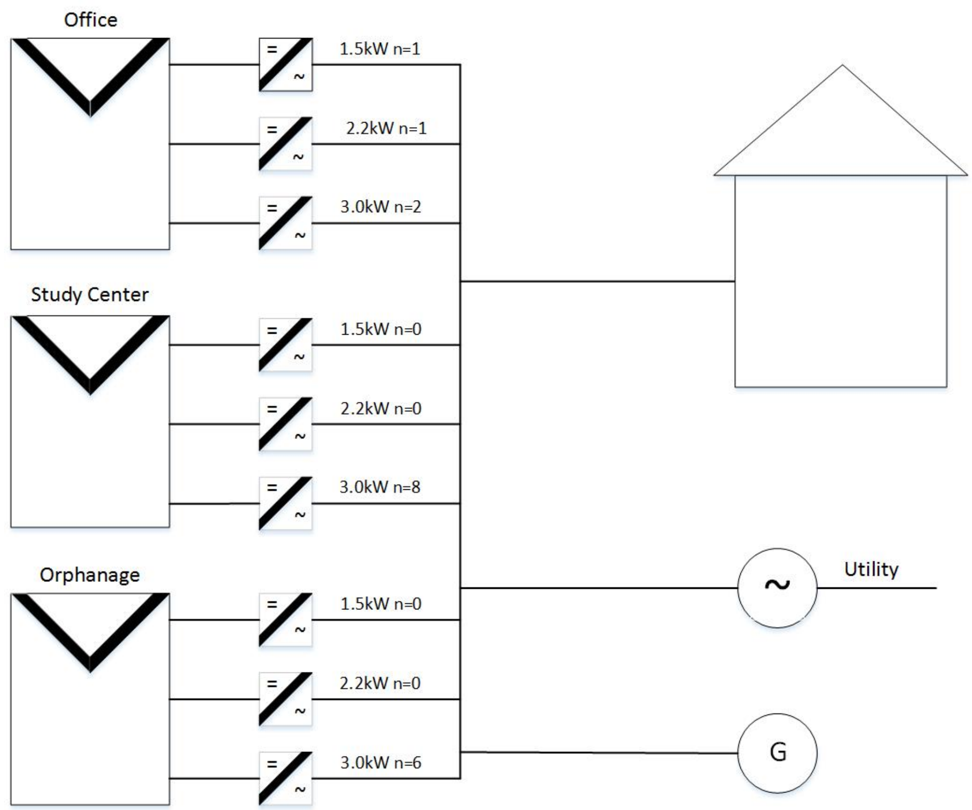

Figure 7.2: One-line diagram for the Base Case - Modules located at all buildings

String Design

The strings were placed vertically, an evaluation taken based on the shading analysis. An illustration of the string design in PVsyst is presented in figure 7.3. The small rectangle represents one module and rectangles coloured in the same colour represent one string.

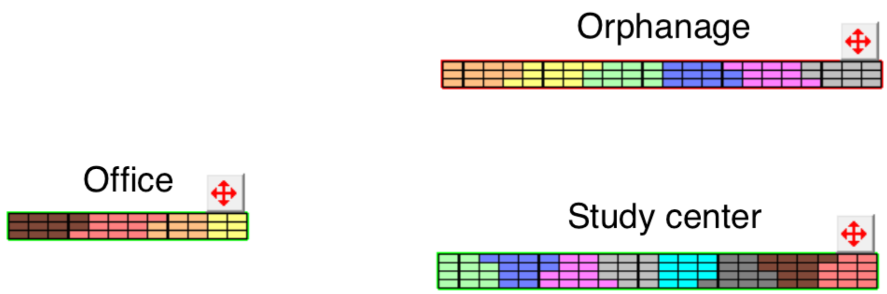

Figure 7.3: String design Base Case - Modules located at all buildings

Loss Diagram

The resulting one-year loss diagram for the Base Case is presented in figure 7.4. The total annual energy production is 60.7 MWh, divided in energy to the user at 27.7 MWh and energy to the grid at 33.0 MWh. Even though the PV system produce sufficient energy to cover the load demand of 54.9 MWh over the year, the time of available PV energy and load demand is not consistent. Therefore, 27.2 MWh is required imported from the grid.

"Horizontal global irradiation" of 1618 kWh/m^2, is visualised as the input to the system. 0.2 % is subtracted due to loss from "Global incident in coll. plane". This is the loss computed from the transposition model for the horizontal- and diffuse irradiance and is dependant on the geographical coordinates. The "Near Shadings: irradiance loss" of 13.9 % is as expected high, due to nearby objects. The "IAM factor on global" of 2.8 % is related to the tilt angle of the modules and reflections increasing with incidence angle. The tilt angle used is 18 ° while the local latitude is 11.34 °.

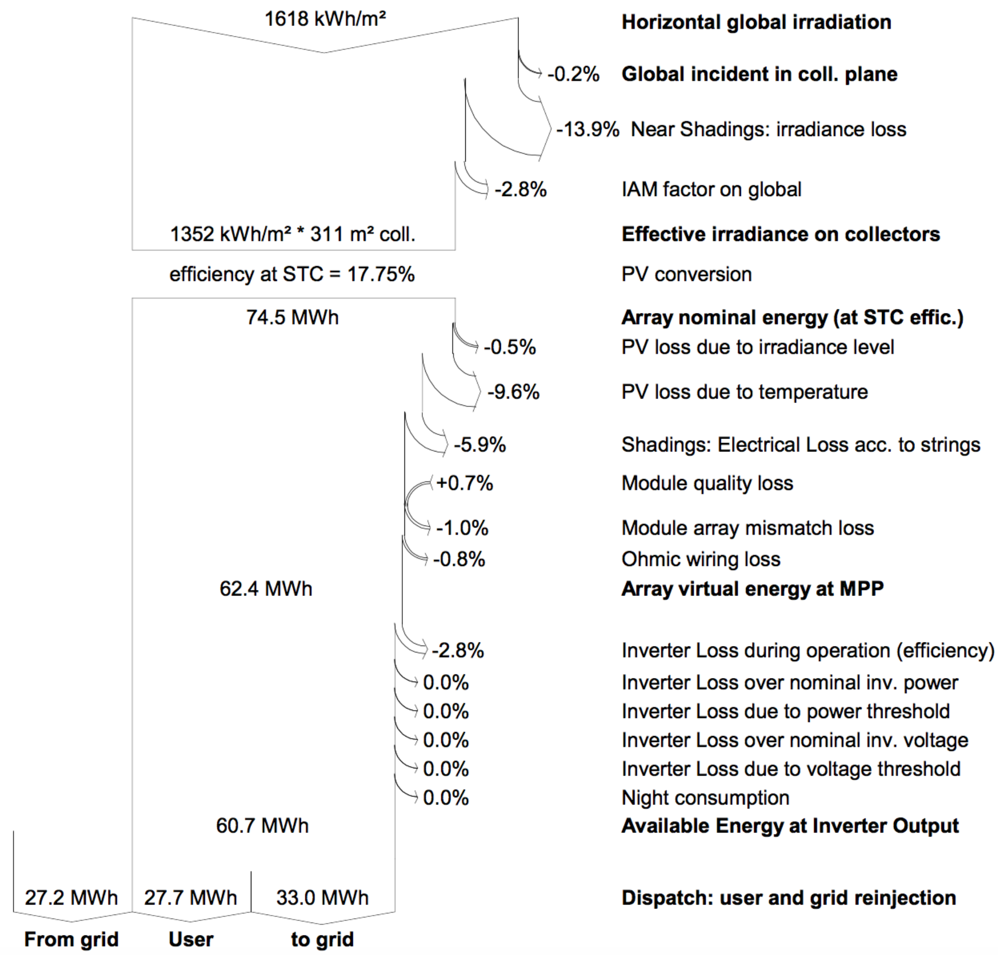

Figure 7.4: Loss diagram Base Case - Modules located at all buildings

Multiplying the irradiance with the area and the efficiency of the modules, the energy from the PV array is 74.5 MWh, corresponding to STC operating conditions. The efficiency of the module JA Solar 290 W_p is 17.75 % at STC. The "PV loss due to irradiance level" and the "PV loss due to temperature" are due to the PV system not operating at STC irradiance of 1 kW/m^2 and STC temperature of 25°C. The "PV loss due to irradiance level" is only 0.5 %, while "PV loss due to temperature" is 9.6 %. The PV performance is sensitive to temperature increase and the monthly average temperature deviates from the STC temperature, as visualised in figure 7.7.

The "Shadings: Electrical Loss according to strings" accounts for 5.9 %. This loss takes into account the location of the strings, and adds the strings that are not shaded but will be affected by shading, into the loss diagram. To decrease this loss fewer modules could be located in series. However, this could increase the number of inverters and hence, increase the price of the system. It was therefore decided to retain the number of modules in series.

The "Module quality loss" is +0.7 % and express how the module performance can change compared to the manufacturer´s specifications, i.e it is the confidence PVsyst has in the module compared to the manufacturer´s specifications. The "Module array mismatch loss" takes into account that the P_{MPP} for the whole array will deviate from the P_{MPP} for one module. This is set to a default loss of 1.0 %. "The ohmic wiring loss" express the loss in the cables between the module and the terminal of the array and is 0.8 %. Type, length and number of required cables have not been specified and the loss is assumed based on default values.

The "Inverter loss during operation (efficiency)" is 2.8 %. Norconsult AS operate with an acceptable inverter loss below 5.0 %, this is therefore regarded as a good result. The other losses related to inverters are 0.0 % and therefore not commented.

Energy Production at 01.01.90

Figure 7.5 illustrates the simulation results of energy at a given day 01.01.90 for the Base Case. The date represent a clear-sky day with maximum production. The figure illustrates that the available solar energy was 173 kWh/day, energy supplied to the user was 97.15 kWh/day and energy injected to the grid was 75.82 kWh/day. The previously presented load profile for weekdays presented in figure 6.6, matches the purple graph of energy to the user. The green graph of available solar energy is well above the energy to the user, meaning the PV system can supply additional energy to the grid on clear-sky days. The peak loads in the load profile occurred between 08:00 - 16:00, which correlates to the hours with maximum PV production on a clear-sky day.

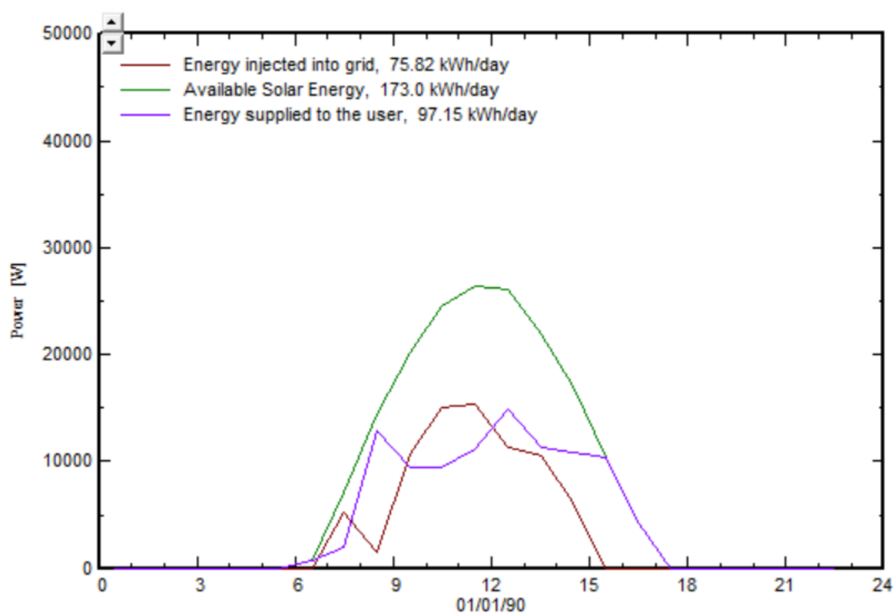

Figure 7.5: Energy production 01.01.90 Base Case - Modules located at all buildings

Input/Output Diagram

The Input/Output diagram in figure 7.6 visualise the input (x-axis) as collector irradiance level per day in [kWh/m^2/day] and output (y-axis) as the energy production per day [kWh/day]. Each point on the graph represents the PV production for one day for a year. It is desirable that the points have a linear relationship, indicating minimal system losses [40]. The coldest days represent the lowest irradiance level and lowest production. The warmest days corresponds to highest irradiance and highest production, but also highest temperature loss. The Input/Output diagram visualise that there are deviations from the linear relationship between produced energy and global incident irradiation.

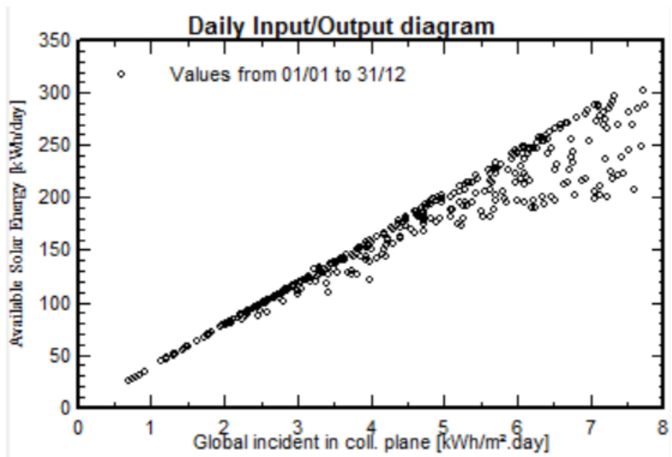

Figure 7.6: Input/Output diagram Base Case - Modules located at all buildings

7.3.2 Meteonorm - Calapan

Instead of interpolating between the three nearest stations, one ground station can be selected. The nearest Meteonorm ground station is Calapan and located 483 km North-West from Tagpuro. The average wind velocity with this database was 2.2 m/s over the year.

7.3.3 NASA-SSE - Tagpuro

In the last simulation of meteorological databases, Meteonorm was replaced with NASA-SSE to compare simulation results. The NASA-SSE is based on satellite data and wind velocity is not included.

7.3.4 Simulation Results

As visualised in the loss diagram presented in figure 7.4 the "Horizontal global irradiation" for the Meteonorm Tagpuro database was 1618 kWh/m^2. With Meteonorm Calapan database it was 1627 kWh/m^2, while for NASA-SSE database it was 1919 kWh/m^2. The graph in figure 7.7 compares the monthly difference in GHI and temperature for the three databases. It is evident that the values for GHI are highest with the NASA-SSE database, and the ambient temperature is lowest with NASA-SSE database. According to a meteorological station located in Tacloban provided from yr.no, the temperature variation is between 25.7 to 28.1 °C [41]. These values are between the Meteornorm and NASA-SSE database, underlining that Meteonorm and NASA provides a higher and a lower temperature estimate, respectively.

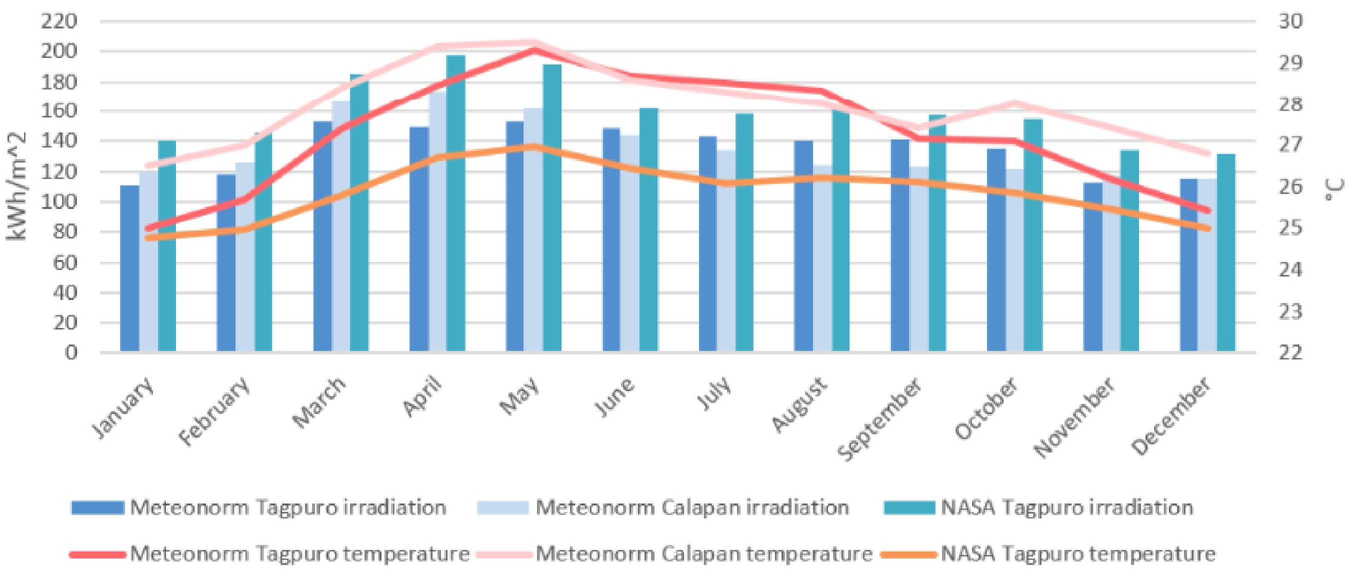

Figure 7.7: Monthly irradiation and temperature data for Meteonorm and NASA

Comparing the two different Meteonorm databases, the irradiation from Calapan varies more over the year than the irradiation obtained when interpolating with respect to Tagpuro. This result could be due to local rain season. Calapan is located at type I climate, characterised by a wet season from June to September. This correlates to the months when Calapan provide lower irradiation and temperature values. Tagpuro has, as described in section 2.1, small climatic variations over the year which correlates with the monthly irradiation provided by Meteonorm Tagpuro.

The two meteorological databases, NASA-SSE and Meteonorm Tagpuro, serves as a maximum and minimum case and will therefore be used in the following to compare meteorological databases. The main findings from the simulations are presented in table 7.2. The shading from irradiance loss correspond to "Near Shadings: irradiance loss" from the loss diagram in figure 7.4. The

Shading electrical loss correspond to the "Shadings: Electrical Loss according to strings". The Temperature loss correspond to the "PV loss due to temperature" and inverter loss correspond to "Inverter Loss during operation (efficiency)".

Table 7.2: Simulation results preliminary case - Meteorological databases

Parameter	Meteonorm Tagpuro	NASA-SSE
Performance ratio PR [%]	68.2	67.4
Installed capacity P_{nom} $[kW_p]$	55.1	55.1
Spec. prod. [kWh/kW_p/year]	1101	1311
Shading irradiance loss [%]	13.9	12.5
Shading electrical loss [%]	5.9	8.4
Temperature loss [%]	9.6	10.1
Inverter loss [%]	2.8	2.8
Energy production [MWh]	60.7	72.2
Energy to user [MWh]	27.7	28.8
Energy to grid [MWh]	33.0	43.4
Energy from grid [MWh]	27.2	26.1

The shading irradiance loss decreased from 13.9 % to 12.5 % with NASA-SSE database. This is related to the transposition models, and to NASA-SSE providing less shading. However, the shading electrical loss increased from 5.9 % to 8.4 %. The temperature loss increased slightly, from 9.6 % to 10.1 %, although NASA-SSE provides lower ambient temperatures as seen in figure 7.2. This is unexpected, however one reason could be that wind velocity is not included in the NASA-SSE database. Wind provides fluctuations and can reduce the temperature loss.

As a consequence of increased irradiance, the energy production proves to be 16 % higher with NASA-SSE. Accordingly, energy to user and energy to grid increased, whereas energy from grid decreased slightly. PR decreased from 68.2 % to 67.4 % with NASA-SSE database. Since both PV systems are identical, the installed capacity P_{nom} remains unchanged at 55.1 kW_p. The specific production increased from 1 101 to 1 311 kWh/kW_p/year. Comparing this system configuration to the rooftop PV project by ADB, presented in section 2.5, the PR was 63.0 %. The specific production of ADB´s PV system was 1 103 kWh/kW_p/year, very close to Meteonorm Tagpuro´s result.

Based on the presented results, Meteonorm Tagpuro database is the most conservative database with respect to irradiation. This will therefore be the default database in the following simulation cases. The system configuration presented in table 7.1 serve as a base case for comparison purposes.

7.4 Preliminary Case - Shading Impact

The next preliminary case investigates the impact from shading trees at the site. To examine which building has the most impact from shading, trees will be removed at the whole site, south of the Orphanage and south of the Study Center in the following simulations. From the shading analysis described in section 5.7.1 it was found that the Office was least exposed to shading and hence, the most optimal building for installing modules. The last simulation will therefore maximise the south oriented roof at the Office.

7.4.1 Impact from Trees at PV Site

To improve the shading loss from the previous simulation and to visualise the effect shading trees have on the system performance, all trees were removed in the first simulation. The site without any trees is visualised in figure 7.8.

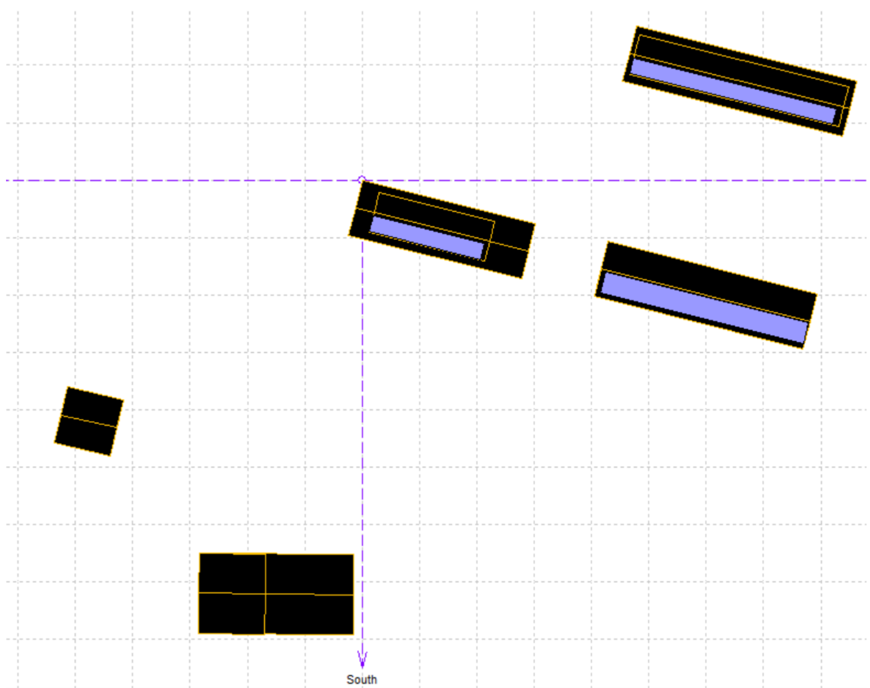

Figure 7.8: The site when all trees are removed

Input/Output Diagram

The Input/Output diagram in figure 7.9 is without any trees. Compared to figure 7.6 with trees, the figure shows a nearly linear relationship between irradiation in the collector plane and energy output, emphasising the positive impact on the losses from removing all trees at the PV site.

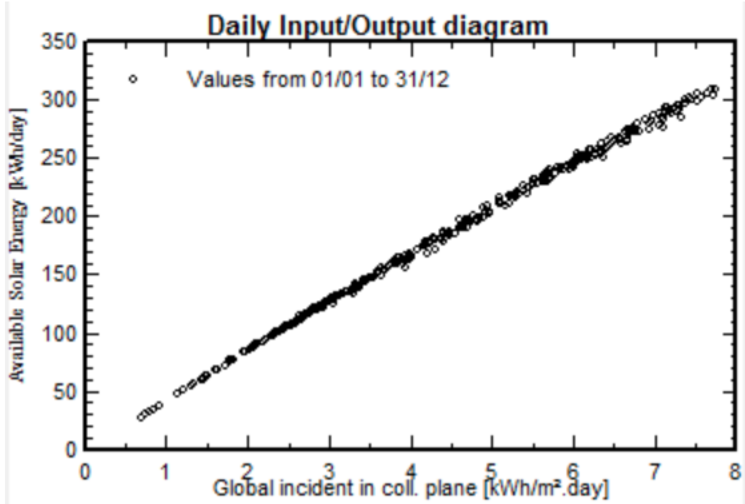

Figure 7.9: Input/Output diagram when all trees are removed

7.4.2 Impact from Trees South of the Orphanage

The trees south of the Orphanage were removed. The trees are already considered being removed by Streetlight due to the danger they pose to the surrounding buildings during a potential typhoon. At the time of the fieldwork, the trees were connected together by a wire, so that they would stabilise each other. The site is visualised without these trees in figure 7.10.

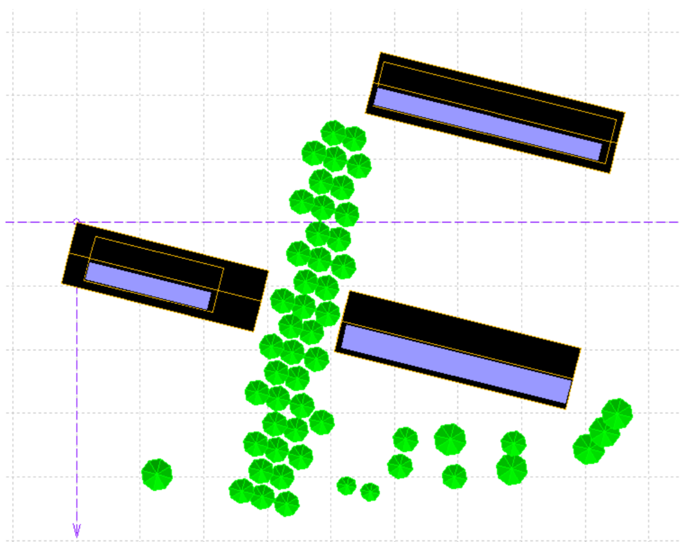

Figure 7.10: The site when trees are removed south of the Orphanage

7.4.3 Impact from Trees South of the Study Center

Next, the trees south of the Study Center were removed and is visualised in figure 7.11.

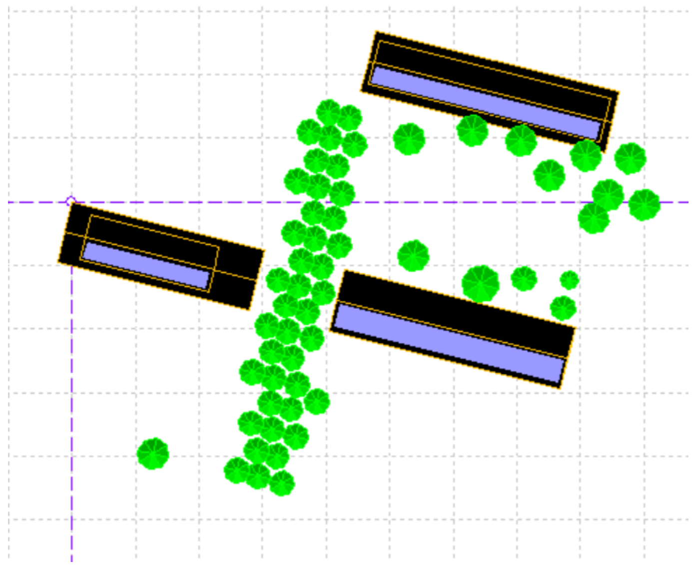

Figure 7.11: The site when trees are removed south of the Study Center

7.4.4 Modules at Study Center and Maximised Office Area

The last simulation maximises the south oriented roof areas at the two most optimal buildings, the Office and the Study Center, as illustrated in figure 7.12. The aim with this simulation is to exclude the building most affected by shade (Orphanage), and maximise the other roof areas in order to reduce system loss, but still obtain sufficient energy production.

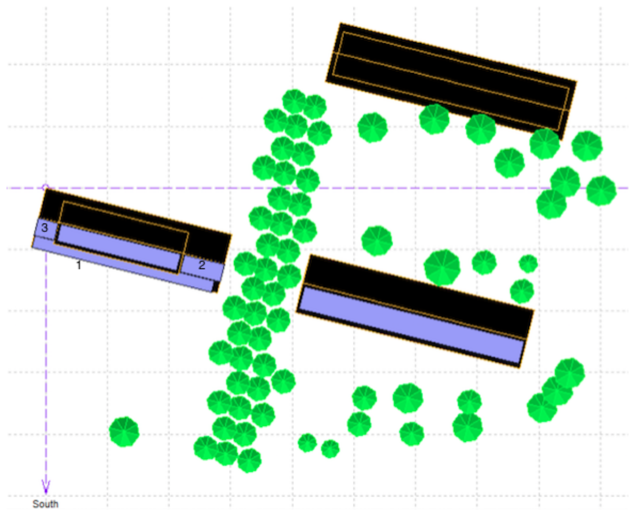

Figure 7.12: Modules located at the Study Center and maximised Office area

Matching Inverter and Modules

The total number of allowed modules is increased when utilising the lower roof at the Office. The additional lower roof 1 in table 7.3 is the rectangle at the front lower roof. The additional lower roof 2 is the small rectangle on the right side and the lower roof 3 is the left side rectangle. The calculated additional module area is 63.92 m^2, 20.60 m^2 and 12.54 m^2 respectively. This corresponds to an additional number of 54 modules in total, where 36 are located at lower roof 1, 12 are located at the lower roof 2 and 6 are located to the lower roof 3.

Table 7.3: Available area and number of modules at lower roof area Office

	Office		
Additional roof area	lower roof 1	lower roof 2	lower roof 3
Length [m]	31.18	6.80	4.14
Length used [m]	30.06	6.68	3.34
Number of modules in length	18	4	2
Width [m]	2.05	3.03	3.03
Width used [m]	2.02	3.03	3.03
Number of modules in width	2	3	3
Available area [m^2]	63.92	20.60	12.54
Area used [m^2]	60.78	20.26	10.12
Number of modules	36	12	6
Sum modules	**54**		

The same sub-array distribution as the Base Case simulation applied to the top roof at the Office and the Study Center, with a total of 22 and 88 modules respectively. The lower roof area 1, 2 and 3 was divided into two sub-arrays, corresponding to Office 4 and 5 respectively, in table 7.4. Sub-array 4 had 6 × 2.2 kW inverters and 8 modules in series, while sub-array 5 had 1 × 1.5 kW inverter and 6 modules in series. A total number of 178 modules and 19 inverters was located with this configuration.

Table 7.4: System configuration - Modules located at the Study center and maximised Office area

	Office					**Study center**
Sub-array	1	2	3	4	5	1
Inverter type	3.0 kW	2.2 kW	1.5 kW	2.2 kW	1.5 kW	3.0 kW
Number of inverters	2	1	1	6	1	8
Modules in series	11	8	6	8	6	11
Numbers of strings	2	1	1	6	1	8
Number of modules	22	8	6	48	6	88
Sum modules	**90**					**88**

String Design

An illustration of the string design for this simulation is given in figure 7.13.

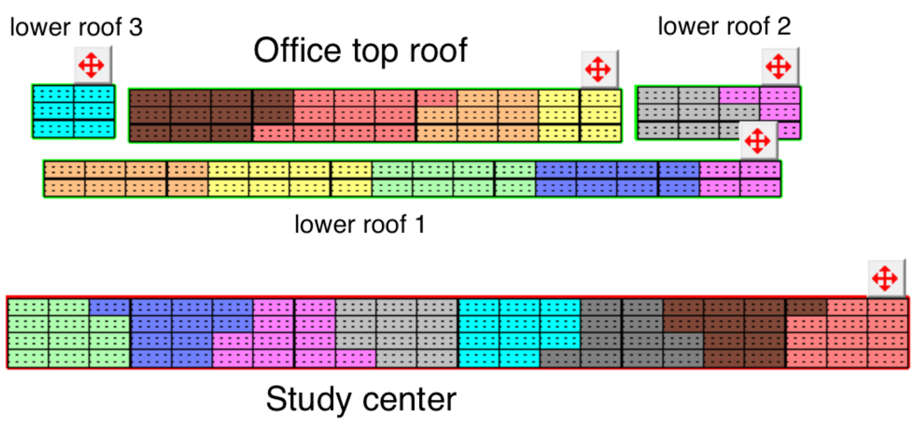

Figure 7.13: String design - Modules located at the Study Center and maximised Office area

7.4.5 Simulation Results

The main simulation results from shading impact are summarised in table 7.5. The goal with the simulation with no trees at PV site was to eliminate the shading loss, for both shading irradiance loss and shading electrical loss. The shading irradiance loss was reduced from 13.9 % to 0.4 %, while the shading electrical loss was reduced from 5.9 % to 0.1 % when removing all trees compared to the Base Case. This proves that the impact from shading trees had significant effects. As a consequence, the PR, specific production and energy production increased when removing trees at the site.

Table 7.5: Simulation results preliminary case - Shading impact

Parameter	Base Case	No Trees PV site	No Trees Orphanage	No Trees Study Center	Study Center and maximized Office
Performance ratio PR [%]	68.2	82.7	75.0	71.1	66.0
Installed capacity P_{nom} [kW_p]	55.1	55.1	55.1	55.1	51.0
Spec. Prod. [kWh/kW_p]	1101	1336	1211	1148	1067
Shading irradiance loss [%]	13.9	0.4	8.1	11.2	14.6
Shading electrical loss [%]	5.9	0.1	2.5	4.7	8.3
Temperature loss [%]	9.6	10.3	10.0	9.7	9.6
Inverter loss [%]	2.8	2.7	2.8	2.8	2.9
Energy production [MWh]	60.7	73.6	66.8	63.2	55.1
Energy to user [MWh]	27.7	29.1	28.3	28.0	27.3
Energy to grid [MWh]	33.0	44.5	38.5	35.2	27.7
Energy from grid [MWh]	27.2	25.8	26.7	26.9	27.6

The temperature loss increased from 9.6 % to 10.3 % when removing all trees. This may be due to trees causing lower operating temperature on the modules. The trees provide an important function for reducing the temperature inside the buildings. The results prove that removing trees south of the Study Center was not as effective as removing trees south of the Orphanage. This was an expected result by examining the distance from these trees to the buildings. Since the highest impact from shading trees was south of the Orphanage and these trees are already considered being removed, the following simulation results will include this case for comparison reasons.

It was expected that the last simulation when utilising the two most optimal buildings would result in improved performance, compared to the Base Case. The energy production was reduced from 60.7 MWh to 55.1 MWh, and the number of modules was reduced from 190 to 178. The PR was unexpectedly reduced from 68.2 % to 66.0 %. In addition, the shading irradiance loss increased from 13.9 % to 14.6 %. The shading electrical loss increased from 5.9 % to 8.3 %. This implies that the added lower roof area was more exposed to shade than the Orphanage. The shade could be imposed from the upper roof unto the lower roof, and the localisation of strings could in addition increase this impact.

7.5 On-Grid Case

The on-grid case is divided into two simulations to evaluate different system configurations based on the results from the preliminary case. The first simulation utilise the top roof area at the two most optimal buildings, Office and the Study Center. The second simulation utilise only the Office, which is the most optimal building for installing PV modules.

7.5.1 PV Modules Office and Study Center

The first simulation was performed with modules only at the Study Center and the Office as illustrated in figure 7.14. The goal with this simulation is to minimise the shading loss by excluding the Orphanage.

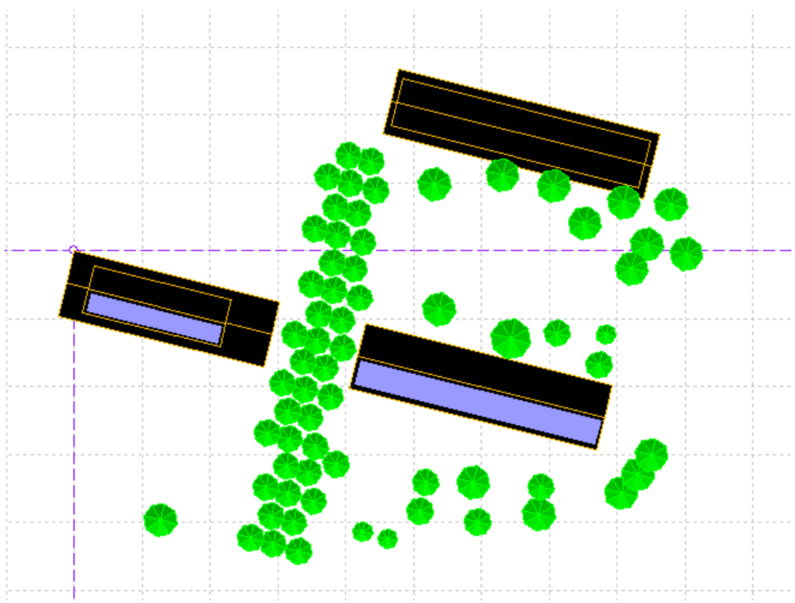

Figure 7.14: Modules located at the Office and the Study Center

Matching Inverter and Modules

The matching of inverters and modules is the same as in the Base Case, except the Orphanage is excluded. The system configuration is summarised in table 7.6. The total number of inverters with this configuration is 12 and the number of modules is 124.

Table 7.6: System configuration - Modules located at the Office and the Study Center

	Office			**Study center**
Subarrays	1	2	3	1
Inverter type	3.0 kW	2.2 kW	1.5 kW	3.0 kW
Number of inverters/strings	2	1	1	8
Modules in series	11	8	6	11
Number of modules	22	8	6	88
Sum	**36**			**88**

String Design

The string design from PVsyst is illustrated in figure 7.15.

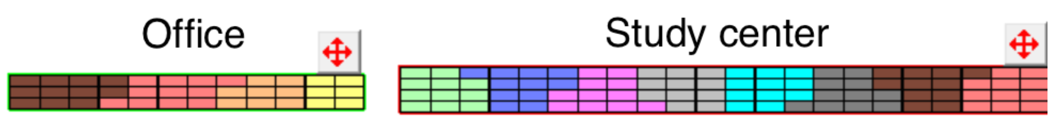

Figure 7.15: String design - Modules located at the Office and the Study Center

7.5.2 PV Modules Office

The next simulation was performed with a PV system installed only at the Office top roof. The matching of inverters and modules is identical to the system configuration in section 7.5.1, except now the Study Center is excluded. The same applies to the string design.

7.5.3 On-Grid - Simulation Results

The simulation results from the on-grid case is comparable to the Base Case and the case without trees south of the Orphanage. The results are summarised in table 7.7.

Table 7.7: Simulation results - on-grid case

	Preliminary Case		**On-Grid Case**	
Parameter	**Base Case - All buildings**	**No Trees Orphanage - All buildings**	**Office and Study Center**	**Office**
Performance ratio PR [%]	68.2	75.0	72.4	81.0
Installed capacity P_{nom} [kW_p]	55.1	55.1	36.0	10.4
Spec. Prod. [kWh/kW_p/year]	1101	1211	1170	1308
Shading irradiance loss [%]	13.9	8.1	10.7	2.4
Shading electrical loss [%]	5.9	2.5	3.4	0.4
Temperature loss [%]	9.6	10.0	9.8	10.3
Inverter loss [%]	2.8	2.8	2.8	2.8
Energy production [MWh]	60.7	66.8	42.1	13.7
Energy to user [MWh]	27.7	28.3	24.9	12.5
Energy to grid [MWh]	33.0	38.5	17.2	1.2
Energy from grid [MWh]	27.2	26.7	30.1	42.5

The PR increased from 68.2 % to 72.4 %, when locating modules at the Office and the Study Center, compared to the Base Case. The shading irradiance loss decreased from 13.9 % to 10.7 % and the shading electrical loss decreased from 5.9 % to 3.4 %. P_{nom} decreased from 55.1 kW_p to 36.0 kW_p, and as a result the energy production decreased to 42.1 MWh, unable to cover the load demand. Nevertheless, the energy production is enough to supply the annual critical load of 32.2 MWh. 17.2 MWh can be exported to the grid, whereas 30.1 MWh is imported from the grid, in order to cover the total annual load demand.

The simulation results with modules only at the Office resulted in high performance, substantiating that this is the optimal building for a PV system. PR is 81.0 % which is a significant improvement. This has correlation with the improved shading conditions at the Office, the shading irradiance loss is only 2.4 % and the shading electrical loss is only 0.4 %. Nevertheless, the temperature loss has increased slightly and is now 10.3 %, due to the fact that the Office is more exposed to irradiance. However, the specific production of 1 308 kWh/kW_p/year is the highest for all cases and indicates that the increased temperature loss is insignificant. Installed capacity P_{nom} is 10.4 kW_p and annual energy production is 13.7 MWh.

7.6 Off-Grid Case

When designing an off-grid system, the goal is to achieve a result where the missing energy is close to 0, corresponding to a match between production and demand. To reduce the missing energy two possibilities have been examined. The first increases the number of autonomous days which implies to increase the battery size. The other possibility increases the number of modules and thereby the energy production. In the first simulation modules will be placed at all buildings and in the second simulation the battery will be increased. In the last simulation the number of modules are increased, while the battery size is equal the first simulation. A back-up generator has not been specified in the system design in PVsyst and it is assumed that when missing energy > 0, a back-up generator will supply this.

7.6.1 All Buildings

As an attempt to achieve sufficient energy production, modules were located at all buildings, as previously visualised in figure 5.9. A total battery capacity of 6 900 Ah and 48 V from Exide Classic was selected after several preliminary simulations with adapting battery size to the system. The battery was dimensioned for 2 autonomous days in PVsyst, resulting in 2 parallel strings with 24 batteries in series. In the grid-connected simulation this configuration had an energy production of 60.7 MWh, however with battery storage loss and unused energy loss the energy production is expected to decrease. The off-grid configuration with modules at all buildings includes 190 modules, with 10 series-connected modules in 19 strings. The matching of inverters and modules in PVsyst is visualised in figure 7.16 and there are no selection of sub-arrays or inverters.

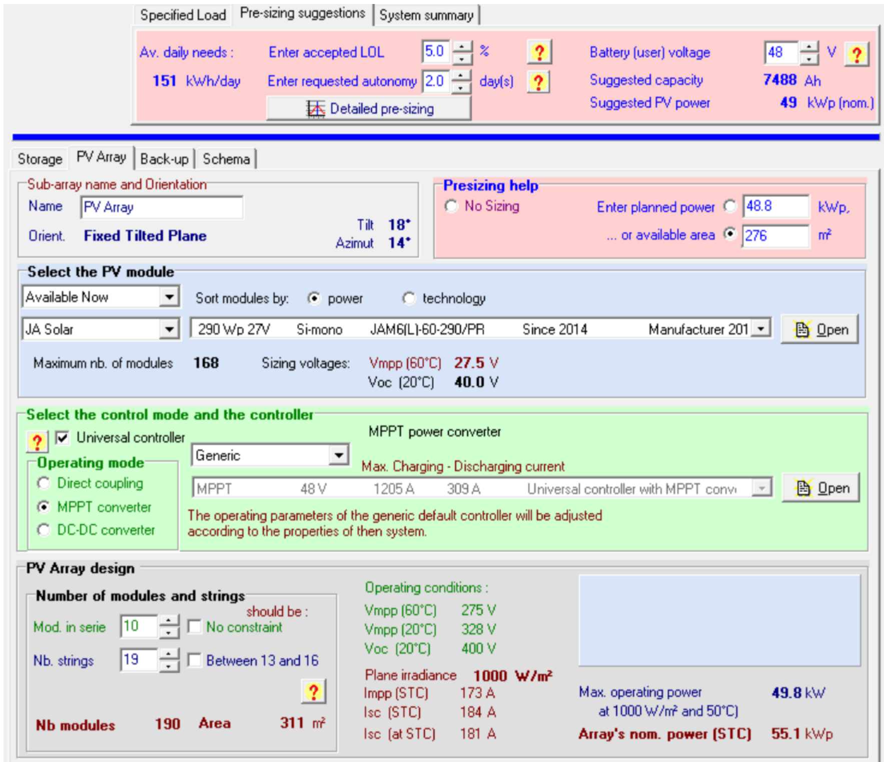

Figure 7.16: Matching inverters and modules All buildings Off-grid

One-line Diagram

The one-line diagram of the system is presented in figure 7.17. In order to find the required number of rectifiers, the total AC output power, P_{AC} = 51.7 kW, was divided by the maximum AC input power of the rectifier SMA Sunny Island, P_{rec} = 11.5 kW. This resulted in 5 rectifiers. The number was validated by dividing the total current of 224.8 A by 5, obtaining a current of 44.96 A per rectifier. The maximum AC input current of the rectifier is 50 A. Datasheet of the rectifier SMA Sunny Island is included in appendix E.

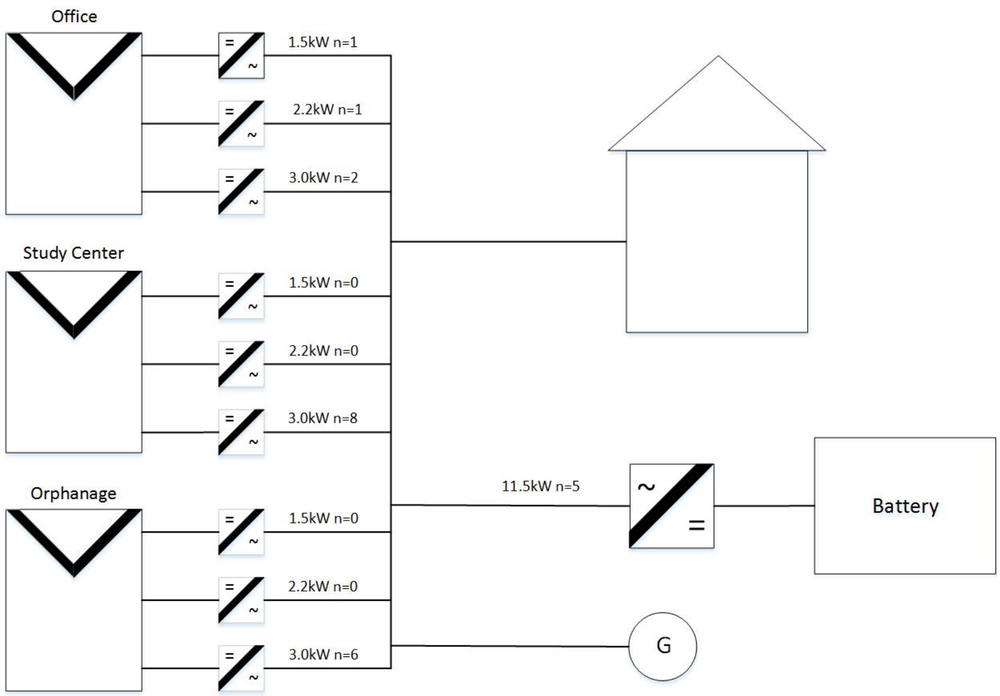

Figure 7.17: One-line diagram for the off-grid case - Modules located at all buildings

Loss Diagram

The loss diagram is presented in figure 7.18. The loss diagram for the off-grid simulation differ from the on-grid by including "Unused energy (full battery) loss", "Converter Loss during operation (efficiency)", and losses related to battery storage. Unused energy corresponds to lost energy due to a full battery at the same time as the load of the system is supplied. The converter loss is the loss in the converters connected to each string. The battery storage loss includes loss from stored energy balance, efficiency, charge/discharge current efficiency, gassing current and self-discharge current. The loss diagram for the stand-alone simulation excludes the "Inverter loss" taken into account in the grid connected simulation.

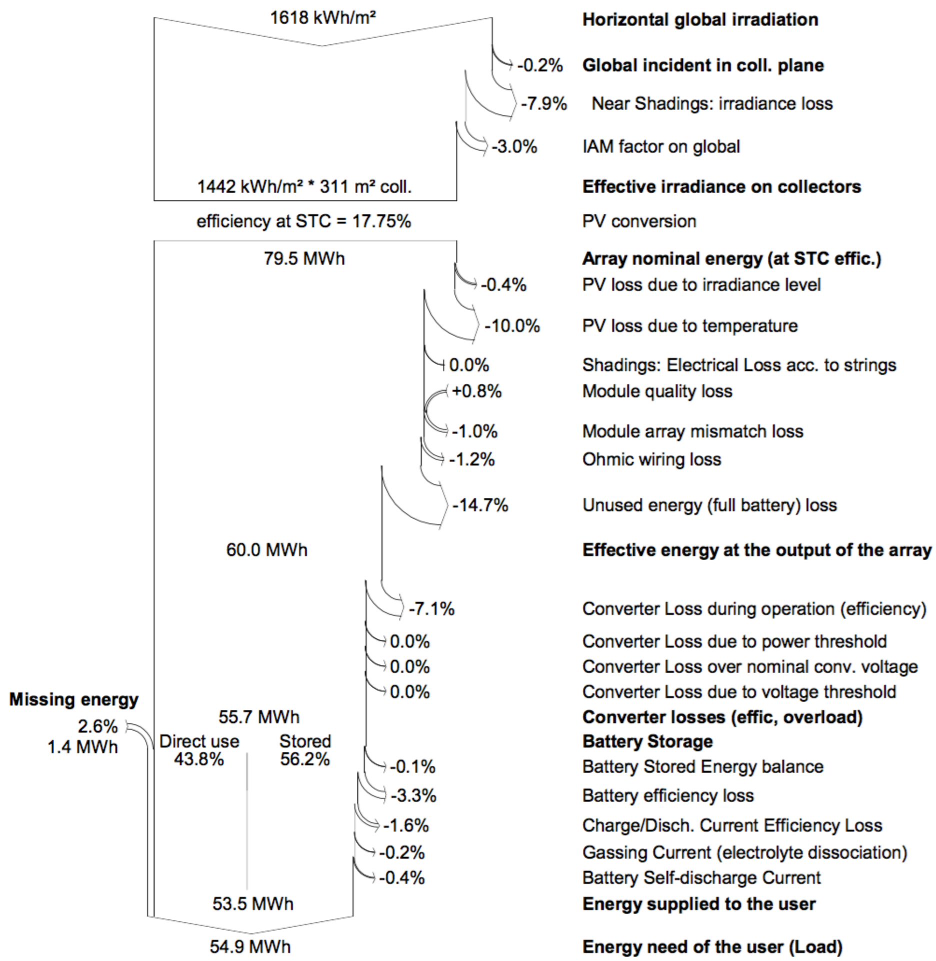

Figure 7.18: Loss diagram Off-grid - Modules located at all buildings

Increased Battery Capacity

A simulation was also conducted with an increased battery capacity, with modules at all buildings. The battery was dimensioned for 4 autonomous days in PVsyst, resulting in 4 parallel strings with 24 batteries in series. Total capacity was 13 800 Ah at 48 V. The autonomous days of 4 was found to be the least number of days to obtain missing energy of 0. The SMA rectifier Sunny Island has a battery capacity range up to 10 000 Ah. In this case the battery pack is divided in two and there are three and two rectifiers supplying each of the battery packs.

7.6.2 Modules at All Buildings and Maximised Office Area

To increase energy production the additional south oriented lower office roof was utilised. 240 modules were located and the modules were distributed in 24 strings with 10 series-connected modules each. The nominal power of this system is 66.4 kW. Dividing it by 11.5 kW, the required number of rectifiers is 6. The current of the system is 288 A and divided by 6 rectifiers this is 48 A per rectifier, which is within the maximum AC current input for SMA Sunny Island.

7.6.3 Off-grid - Simulation Results

The most important off-grid simulation results are presented in table 7.8. When locating modules at all buildings the PR of the system is 60.1 %, and increased to 61.8 % when the battery is increased. This is due to reduced total losses in the system. The unused energy loss decreased from 14.7 % to 12.3 %, whereas the converter loss was unchanged and the battery storage loss decreased from 5.6 % to 5.5 %.

Table 7.8: Simulation results off-grid case

Parameter	**All buildings**	**All buildings -increased battery capacity**	**All buildings -maximising office**
Performance ratio PR [%]	60.1	61.8	48.5
Installed capacity P_{nom} [kW_p]	55.1	55.1	69.6
Spec. Prod. [kWh/kW_p/year]	1199	1197	1113
Unused energy loss [%]	14.7	12.3	24.7
Converter loss [%]	7.1	7.1	7.1
Battery storage loss [%]	5.6	5.5	6.0
Energy production [MWh]	53.5	54.9	54.5
Direct Energy [MWh]	24.4	25.4	22.9
Stored Energy [MWh]	31.3	31.9	34.3
Missing energy [MWh]	1.4	0.0	0.4
Missing energy [%]	2.6	0.0	0.8

The energy production when locating modules at all buildings is 53.5 MWh and the missing energy 1.4 MWh (2.6 %). To reduce the missing energy the two possibilities were tested. The first increased autonomous days which implies to increase the battery capacity. The battery capacity was increased from 6 900 Ah to 13 800 Ah to obtain missing energy ≈ 0. When the battery was increased, the unused energy loss decreased from 14.7 % to 12.3 %, implying that the battery size is better configured to the PV system. However, the loss in unused energy is high in both cases. The battery capacity for obtaining missing energy ≈ 0 is large, and it could be more optimal to supply the missing energy with a generator.

The second possibility to reduce the missing energy is to increase the number of modules and thereby the energy production. Additional modules were located at the lower roof area of the Office increasing the number of modules to 240. In this simulation the missing energy was 0.8 %. However, the energy production only increased from 53.5 MWh to 54.5 MWh. This is due to the significant increase in unused energy loss from 14.7 % to 24.7 %, implying that a large part of the increased production is lost. This is because the energy will be produced at the time when the battery is already full, and at the time when the load is already supplied.

7.7 Evaluation of On-Grid and Off-Grid Cases

The on-grid and off-grid simulation results are presented in table 7.9. The green cells correspond to the PV system capable to supply the total annual load demand, while the red cells correspond to the off-grid cases where missing energy > 0 and supplied by a back-up generator. The blue cell correspond to the PV system capable of supplying annual critical load demand, while yellow cell correspond to supplying 25 % of the load demand.

Table 7.9: Simulation results on-grid and off-grid case

	On-grid			**Off-grid**		
Parameter	**Base Case - All buildings**	**Office and Study Center**	**Office**	**All buildings**	**All buildings - increased battery capacity**	**All buildings -maximising Office**
# modules	190	124	36	190	190	240
# inverters	18	12	4	18	18	25
# rectifiers	-	-	-	5	6	5
# batteries	-	-	-	48	96	48
Prod. [MWh]	60.7	42.1	13.7	53.5	54.9	54.5
Export [MWh]	33.0	17.2	1.2	-	-	-
Import [MWh]	27.2	30.1	42.5	-	-	-
Missing [MWh]	-	-	-	1.4	0.0	0.4

For the same number and location of modules, the on-grid system had a higher energy production than the off-grid system. The on-grid system with all buildings had an energy production of 60.7 MWh, compared to 53.5 MWh for the corresponding off-grid system. This is due to battery losses, both as unused energy and energy storage loss. In addition, the inverter losses in the on-grid simulations differentiates from the converter loss in the off-grid simulations.

The system configurations for the on-grid and off-grid cases varies greatly in number of modules, inverters, rectifiers and batteries and has impact on the system investment costs. The results prove that the on-grid case has the possibility to supply annual load demand, critical load demand or 25 % of annual load demand. The optimal on-grid case is a trade-off between total investment costs and energy production, including net-metering in the evaluation. The optimal off-grid case is a trade-off between battery capacity and back-up generator operating time, based on the choice of spilling renewable energy compared to utilising non-renewable energy. The economical evaluations will be considered in the following chapter 8.


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Chapter 8

Economical Evaluation of PV System Designs

This chapter presents an economical evaluation of PV system designs. The input parameters to the LCOE analysis are described, including investment costs, operation and maintenance costs, fuel costs, net-metering costs and annual energy production. LCOE from the utility grid and LCOE from PV system designs are presented. In the end a sensitivity analysis of the discount rate, battery price and the net-metering rate are conducted separately. The economical analysis is based on nominal LCOE methodology as described in section 4.3. The price lists from Solaric and Optimus Energy presented in appendix D serves as a basis for the system components, excluding battery.

The report *Kostnadsstudie, Solkraft Norge 2013* [7] provided by Multiconsult for Enova, is used as a guidance for parameters and for obtaining share of costs for mounting, monitoring and control equipment. The report analyses LCOE for PV systems installed at a single family house (7 kW_p), an industrial building (100 kW_p) and a utility scale PV system (1000 kW_p). The modules and inverters are 250 W_p from Innotech Solar and string inverters from SMA. The prices of the system materials are based on quotations from suppliers in Norway, as well as a few Swedish and Danish suppliers. In addition the PV project by ADB is used as a reference project.

8.1 Input Parameters LCOE Analysis

The input parameters for the LCOE analysis for all PV system designs are presented in table 8.1.

Table 8.1: Input Parameters LCOE

Parameter	Value
Discount rate, d [%]	10
Economical lifetime, i [years]	25
Annual system degradation, LF [%]	0.4

The discount rate takes into account risk or uncertainty of future cash flows. The greater the uncertainty, the higher the discount rate. The discount rate used in Multiconsult´s report is 5 % and based on risk-free project. According to IRENA (International Renewable Energy Agecy) a standard discount rate for renewable energy projects are 7.5 % for OECD countries and 10 % for non-OECD countries [42]. The discount rate in the ADB PV project presented in section 2.5 was 10 % [22]. In addition, Sepalco PV farm suggested that the discount rate for power plants in the Philippines should be slightly above the loan interest rate of 7-9 %. Based on this information the discount rate was selected to be 10 %.

The economic lifetime of the system is expected to be 25 years, corresponding to the linear power warranty for the module JA Solar. This is the same lifetime as the 250 W_p Innotech Solar modules in Multiconsult´s report. The annual system loss factor, LF, is assumed 0.4 % and is the linear loss factor used in Multiconsult´s report.

The lifetime of the inverters and rectifiers is estimated to be 12.5 years, based Multiconsult´s evaluation. It is common that inverters can operate as long as the modules, however it is normal to include a reinvestment due to uncertainty. Lead-acid batteries can as mentioned in section 3.8 last 10 years with a daily discharge at 25 % of its rated capacity or less. A reinvestment has therefore been included for inverters and rectifiers in year 12.5 and for batteries in year 10 and 20. The reinvestment in year 20 includes a remaining value since the battery reinvestment in year 20 will last 5 year longer than the economic lifetime i.

8.1.1 Investment Costs, I_0

Materials

The price list from Solaric presented in appendix D excludes VAT and the total system cost will also exclude VAT. The price for the inverter Thinkpower 1.5 kW, 2.2 kW, 3.0 kW is 22 000 PhP, 24 000 PhP and 27 500 PhP respectively. The cost of the JA Solar 290 W_p module is 9 500 PhP.

Based on material costs and total costs in Multiconsult´s report, the share of costs per material was calculated as presented in table 8.2. The share of costs is based on an industrial building of 100 kW_p installed capacity. The share of total cost [%] for modules and inverters, was used to determine total cost of the system materials. The mechanical and electrical mounting equipment as well as monitoring equipment were calculated from the share of total costs [%]. The calculations are based on the assumption that the share of costs for Streetlight´s PV system will be similar as the analysis conducted by Multiconsult.

Table 8.2: The share of cost per material cost based on Multiconsult´s report [7]

Type	Cost [kNOK]	Share of total costs [%]
Modules	725	58.7
Inverters	207	16.8
Mechanical mounting equipment	212	17.2
Electrical mounting equipment	50	4.0
Control system and monitoring equipment	41	3.3

Multiconsult provides the same information with share of total costs for a single family house of 7 kW_p installed capacity. The main difference from the 100 kW_p, is that module costs are reduced to 54.9 %, while inverter costs are increased to 23.1 %. However, total module- and inverter costs only increased from 75.5 % to 78.0 %. The total share of costs for the mechanical- and electrical mounting equipment as well as the control system and monitoring equipment has therefore decreased from 24.5 % to 21.9 %. This is regarded as insignificant, and the share of total costs for an industrial building is used in the following for all the PV system solutions.

The off-grid system will additionally include battery costs. The price for one Exide Classic OPzS 4600 Battery at 3 450 Ah 2 V is € 2 325.84, based on the UK supplier Shop Solar Wind [43]. May 9th 2017 this corresponded to 126 595 PhP [44]. The rectifier SMA Sunny Island can be provided by Optimus Energy, which is a supplier in the Philippines located in Cebu and Manila. The price of one rectifier (when purchasing >5 units) is 221 439 PhP.

The investment costs for the back-up generator has not been considered in this evaluation. It is likely that Streetlight will have a back-up generator in Tagpuro, independent of a PV system or not, due to the issues with frequent outages. The costs for the operation of the back-up generator have been included in the stand-alone solution when missing energy > 0 as presented in section 8.1.3. Table 8.3 presents the costs for the selected system components.

Table 8.3: Material cost per unit for system components [7]

Type	Unit Cost [kPhP]
Module JA Solar 290 W_p	9 500
Inverter Thinkpower 1.5 kW	22 000
Inverter Thinkpower 2.2 kW	24 000
Inverter Thinkpower 3.0 kW	27 500
Battery Exide Classic OPzS 4600	126 595
Rectifier SMA Sunny Island 8.0 H	221 439

Installation Costs and Other Costs

Multiconsult provides installation costs as a share of total costs, accounting for 34.5 % of material costs for the 100 kW_p system. However, this share is assumed to be significantly reduced for this project, due to reduced labour costs in the Philippines and internal labour from Streetlight used for the installation. Further it is possible that Solaric includes installation in the costs of material. In the following, it has been assumed that installation costs and other costs accounts for only 2 % of material costs. Other costs will include machinery, equipment and tools.

8.1.2 Operation and Maintenance (O&M) Costs

The PV system requires low maintenance. However, to optimise efficiency and avoid faults or down-times, there are some maintenance routines that should be executed. A table of maintenance measures and how frequent they should be carried out are presented in [6] as visualised in figure 8.1. The inverter should be checked for faults daily, while the power meter should be checked monthly. The module surface should be cleaned when dirty and ensured being properly fastened every six months. Cables should be checked for broken isolation or other damage every six months and surge arresters should be checked after thunderstorms. When in doubt, the circuit breakers and string fuses should be checked and the modules characteristic curves measured, which includes the I-V curve.

Daily	Inverter	– In operation without fault indication?
Monthly	Yield Check	– Check and note meter values regularly
Every 6 months	Module Surfaces	– If module surfaces dirty due to leaves/bird droppings/air pollution/other, clean all surfaces. – Ensure all modules still properly fastened. – Are module surfaces under tension, possibly due to bending/deformation of roof surface?
	Generator circuit boxes	– Have insects or moisture penetrated (especially outdoor) junction boxes? – Check all accessible fuses.
	Surge arresters	***Check after thunderstorms!*** – Surge arresters intact (Windows showing white or red?)
	Cables	– Check for scorching/broken isolation/other damage! (Also damage due to animal activity) – Check all connections.
Every 3-4 Years	Repetition of all measurements as at commissioning	– Examination by a specialist
	Inverters located outdoors	– Moisture penetration is possible, also where rated for outdoor installation Examination by a specialist
When in doubt	Modules	– Characteristic curve measurement, Thermographic analysis or functional analysis by expert.
	Generator circuit boxes	– Check string fuses
	AC protection devices	– Check circuit-breakers, AC fuses and RCDs

Figure 8.1: Maintenance measures [6]

The O&M costs for the industrial building is 2 % of the investment costs, I_0, according to Multiconsult. For the single family house, O&M costs are 0.5 % of the investment costs. Furthermore, in the project by ADB presented in section 2.5 the O&M cost was 1 % of the project costs. By using ADB as a reference 1 % of total investment costs has been assumed as O&M costs in the following for all PV system solutions.

8.1.3 Fuel Costs

Additional costs were added due to operation of a back-up diesel generator in the off-grid simulations with missing energy > 0. The missing energy [kWh] was multiplied with 3.6 MJ/kWh. The amount in MJ was multiplied with the heat factor [liter diesel/MJ] of diesel, which then was multiplied with the assumed diesel price of 31.2 PhP/liter [45] [46]. The costs [PhP] were divided with the efficiency of a diesel generator [5]. The parameters are listed in table 8.4.

Table 8.4: Input Parameters Fuel cost

Parameter	Value
Heat factor [liter diesel/MJ]	0.03
Price [PhP/liter diesel]	31.20
Efficiency [%]	0.80

8.1.4 Net-Metering Costs

Export and import of energy were added in the LCOE calculation for the on-grid cases. The cost of imported energy from the utility is obtained through the electricity bill from Tacloban presented in table 6.1. The annual energy cost of 443 713 PhP was divided with the annual energy consumption of 55 959 kWh. The average cost of imported energy from the utility grid was 7.93 PhP/kWh.

The electricity bill is divided into generation costs and transmission costs. In average over a year, the generation cost was found to be 5.30 PhP/kWh and transmission cost 2.63 PhP/kWh. It is assumed that when exporting PV energy to Leyeco´s utility grid, the income for Streetlight is the generation costs subtracted by the transmission costs. Therefore, the income per kWh exported PV energy is assumed to be 2.67 PhP/kWh. This is based on meeting with Leyeco and their net-metering policy document provided in [23]. The cost of imported energy was multiplied with imported energy from the utility grid, while the cost of exported PV energy was multiplied with exported energy to the utility grid. The Net-Metering (NM) is the resulting costs of imported energy minus income from exported PV energy. The NM is further referred to as NM costs since the price of exported energy is lower than the electricity price.

8.1.5 Annual Energy Production

The AEP in equation 4.16, is the annual energy consumption in the off-grid cases, to account for the generation from fuel of the back-up generator. For the on-grid cases the AEP is the energy production when producing more than annual consumption, and energy consumption when consuming more than the PV annual production.

8.2 LCOE Utility

In order to evaluate whether it is profitable to invest in a PV system, it was also conducted a LCOE for today´s situation with energy from utility. It is difficult to predict the price escalation of electricity and it is assumed that utility energy will be constant for a 25-years perspective and without considering general inflation. The LCOE is therefore equal to the average cost of imported energy from the utility grid at 7.93 PhP/kWh.

8.3 LCOE Results

The results from the on-grid and off-grid simulations as well as the LCOE results are presented in table 8.5. The investment costs are significantly higher for the off-grid cases than for the on-grid cases, as expected due to the high battery costs.

Table 8.5: LCOE results on-grid and off-grid case

	On-grid			**Off-grid**		
Parameter	**All buildings**	**Office and Study Center**	**Office**	**All buildings**	**All buildings - increased battery capacity**	**All buildings -maximising Office**
# modules	190	124	36	190	190	240
# inverters	18	12	4	18	18	25
# rectifiers	-	-	-	5	6	5
# batteries	-	-	-	48	96	48
Prod. [MWh]	60.7	42.1	13.7	53.5	54.9	54.5
Export [MWh]	33.0	17.2	1.2	-	-	-
Import [MWh]	27.2	30.1	42.5	-	-	-
Missing [MWh]	-	-	-	1.4	0.0	0.4
Inv. Cost [kPhP]	3 097	2 026	599	10 402	16 821	11 150
Inv. Cost per W_p [PhP/W_p]	56.2	56.3	57.4	188.8	305.3	160.2
NPV O&M [kPhP]	281	184	54	944	1 527	1 012
NPV NM [kPhP]	1 159	1 839	3 029	-	-	-
NPV fuel [kPhP]	-	-	-	53	-	15
LCOE [PhP/kWh]	**8.79**	**8.42**	**7.71**	**30.32**	**50.45**	**31.90**

The LCOE for the on-grid case with modules located at all buildings is 8.79 PhP/kWh, compared to 8.42 PhP/kWh and 7.71 PhP/kWh for the case with modules at Study Center and Office, and only at the Office, respectively. Based on the LCOE, it is therefore most optimal to only install modules at the Office. The NPV NM costs constitutes to a high share of costs for the on-grid cases, and is as expected highest for the case with modules only at the Office, due to least export to the utility grid.

The LCOE for the off-grid case with modules located at all buildings is 30.32 PhP/kWh, compared to 50.45 PhP/kWh for the same system configuration with increased battery capacity. The aim of obtaining missing energy ≈ 0 was therefore not economically feasible. This is due to the increased battery costs, compared to the relatively low fuel costs to cover the missing energy.

Comparing the LCOE for the off-grid all buildings case to the LCOE with additional modules at the lower office roof, the LCOE increases from 30.32 PhP/kWh to 31.90 PhP/kWh. It is therefore more economical to install less modules, resulting in higher fuels costs, compared to reducing fuel costs with additional modules.

Comparing the LCOE for the on-grid cases to the off-grid cases, it is evident that the LCOE for the on-grid case with modules at all buildings is significantly lower compared to the LCOE for off-grid all buildings case. Comparing the LCOE with utility energy at 7.93 PhP/kWh, it is only profitable to install modules at the Office. All other cases with PV system result in a higher LCOE than today´s situation with utility energy.

8.3.1 Sensitivity Analysis on Discount Rate, Battery Price and Net-Metering

A brief sensitivity analysis on discount rate, battery price and net-metering rates is relevant to illustrate the impact on the LCOE.

The Discount Rate, d

The discount rate is varied from 5% to 12.5 % for the on-grid and off-grid cases and presented in the graph in figure 8.2. Ongrid1, ongrid2 and ongrid3 correspond to the cases with modules located at all buildings, Office and Study Center, and Office respectively. Offgrid1, offgrid2 and offgrid3 correspond to the cases with modules located at all buildings, all buildings with increased battery and all buildings with maximised office area. It is visualised that the discount rate influence the LCOE to a great extent. The LCOE increases with increased discount rate, visualising the unprofitably with the increased project risk.

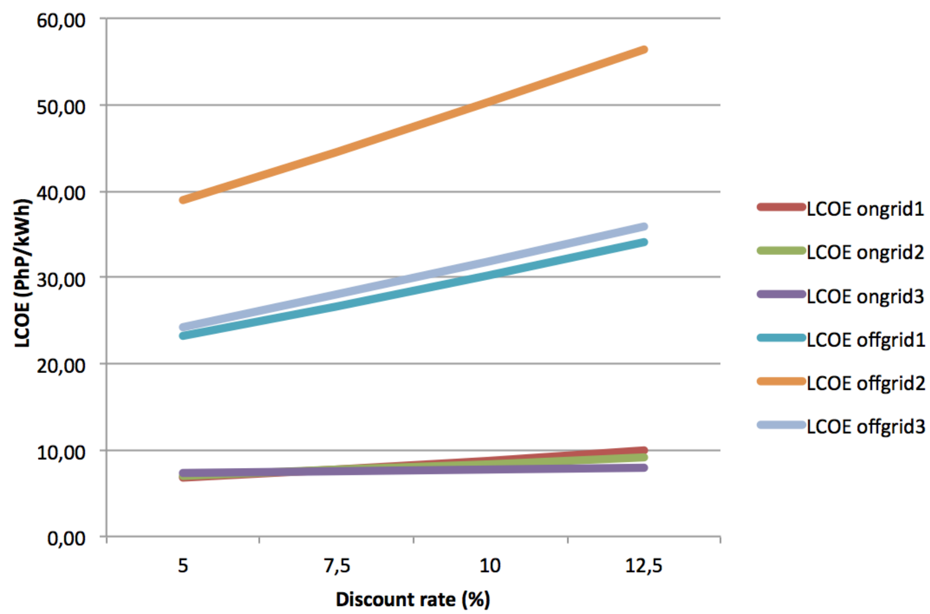

Figure 8.2: Sensitivity for the discount rate, d

In addition, the sensitivity analysis was conducted in order to find the discount rate that resulted in grid parity, i.e the discount rate when LCOE for PV energy equals LCOE utility grid. For this purpose only the LCOE for the on-grid cases were relevant and it is evident that the three off-grid cases will not become profitable compared to LCOE from utility at 7.93 PhP/kWh. The results are presented in the graph in figure 8.3.

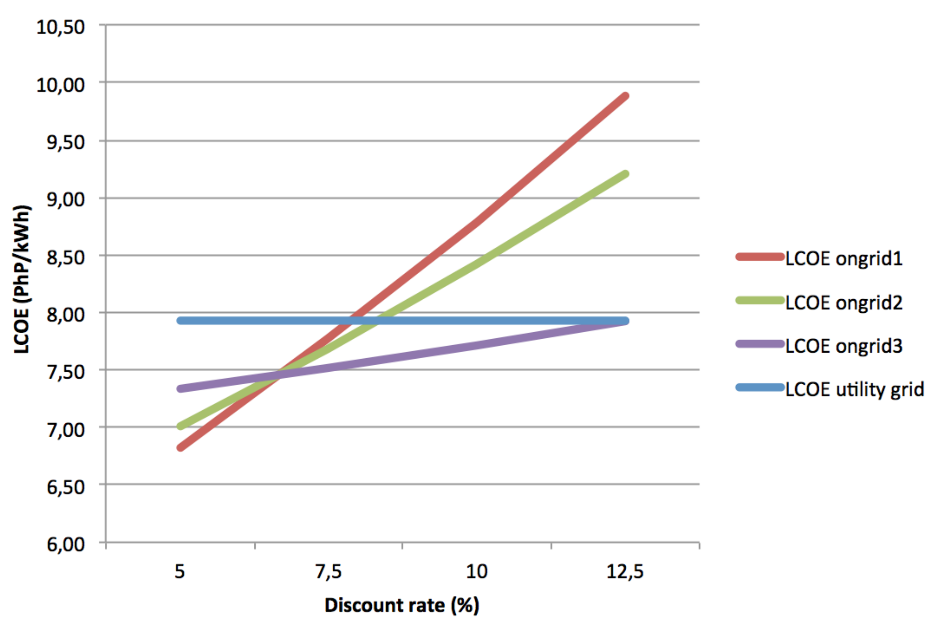

Figure 8.3: Sensitivity for the discount rate, d, with grid parity

The graph illustrates that the intersection with LCOE utility and ongrid1, ongrid2 and ongrid3 is 7.81 %, 8.26 % and 12.88 % respectively. By reducing the discount rate from 10 % to 5 %, the distribution of the most profitable case changes and LCOE ongrid1 becomes most profitable, i.e the case with modules located at all buildings.

Battery Price

As mentioned in section 3.8 there has been a recent cost reduction in EES, and the price of batteries are expected to decrease in near future. Figure 8.4 illustrates how the LCOE for the off-grid cases varies with reduced battery price. The x-axis is the battery price in % of the original battery price for the respective case.

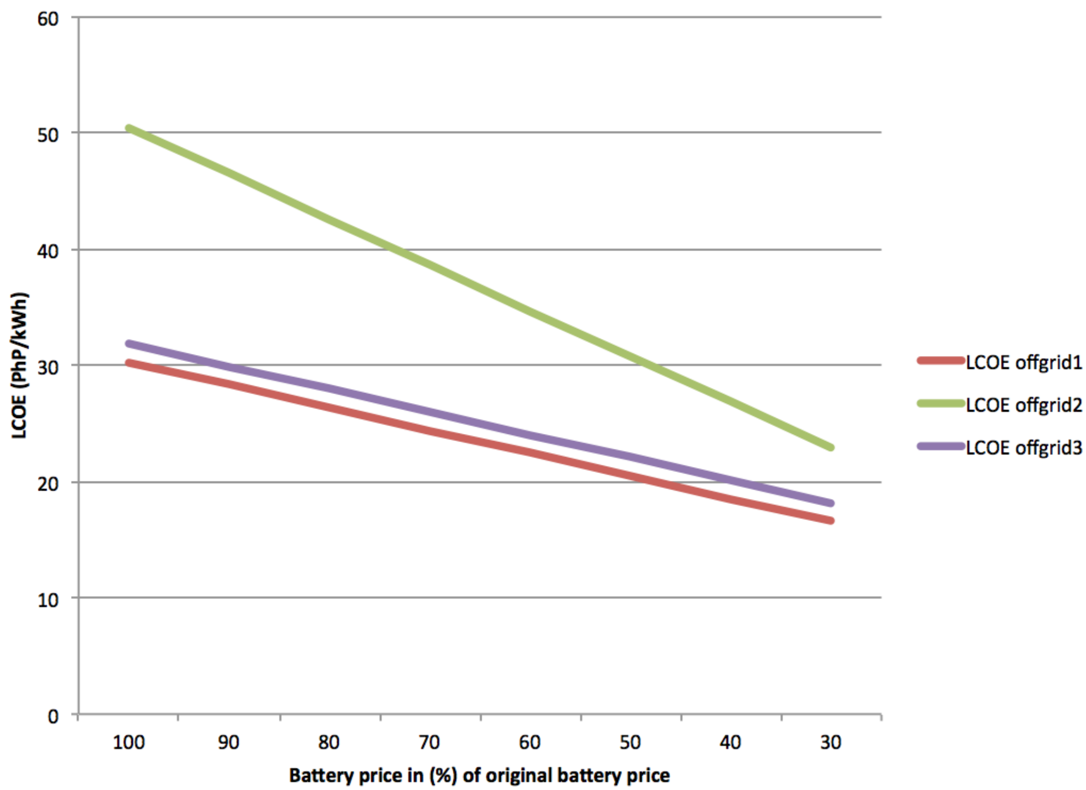

Figure 8.4: Sensitivity rate for the battery price

The LCOE for offgrid1 was reduced from 30.32 PhP/kWh to 16.57 PhP/kWh with a reduction in battery price from original price to 30% of original price. Further LCOE offgrid2 and offgrid3 was reduced from 50.45 PhP/kWh and 31.90 PhP/kWh to 22.95 PhP/kWh and 18.15 PhP/kWh respectively. This implies that the battery price has significantly influence on the off-grid PV system solutions.

The Net-Metering Rate

The REA stated that customers were only required to pay for the net energy consumption [3], which differ from the pricing scheme presented by Leyeco in [23]. To illustrate the difference, LCOE for the on-grid cases was therefore also calculated based on the REA policy as presented in table 8.6.

Table 8.6: LCOE results with NM rates from Leyeco and REA

Parameter	Base Case - All buildings	Study Center and Office	Office
Total NM cost, Leyeco [kPhP]	1 159	1 839	3 029
Total NM cost, REA [kPhP]	-418	929	2 972
LCOE, Leyeco [PhP/kWh]	8.79	8.42	7.71
LCOE, REA [PhP/kWh]	5.83	6.72	7.59

The LCOE is reduced for all cases with REA rates. The reduction is highest for modules at all buildings i.e the case with the most exported energy to the utility grid. When using the Leyeco rates only the Office was profitable compared to the LCOE utility energy. However, with the REA rates all the PV system solutions are profitable compared to the situation of today with energy from utility grid.

Chapter 9

Discussion

9.1 Objective 1

Obtain an understanding of the climatic condition, energy situation and solar energy potential in the Philippines

The future demand and supply situation for Visayas in figure 2.3 illustrated sufficient power capacity in the Visayas grid until 2021. At the time of the fieldwork, Streetlight experienced frequent power outages and this is most likely related to the grid operation and maintenance. One of the larger projects for the grid operator Leyeco is the implementation of a new sub-station in Northern Tacloban, which hopefully will improve the current grid situation. Nevertheless, the future demand-supply outlook projects an energy shortage from 2022-2025 in the Visayas region. Both the on-grid and off-grid PV system can limit the consequences from energy shortage in the utility grid for Streetlight´s center in Tagpuro.

The energy mix for the Philippines, presented in figure 2.5, relies mostly on non-renewable sources such as coal, natural gas and oil-based power plants. Fuel prices on oil and coal are influenced by varying market prices which are difficult to foresee. Higher fuel prices can result in higher energy prices, making it more profitable with renewable investments, or in worst-case it can lead to energy deficit. The PV system will provide energy from a renewable energy source, unaffected by varying fuel prices.

The solar potential in the Philippines is high with a DNI of 1 300 kWh/m^2 and GHI of 1 800 kWh/m^2, however residential PV systems are not widespread. The limited market could result in higher costs of system components as well as operation and maintenance compared to for instance an European market. However, Streetlight can create ripple effects by implementing a residential PV system and contribute to growth of PV systems in the Tacloban area. The project can therefore have a higher value than the PV system itself, because it can create a sustainable energy development in the local community. If so, the system prices might decrease according to increased supply and demand in the local PV market.

There are instruments to reduce the dependence on fossil fuels in the Philippines, such as the REA. The REA stated that there is FIT for each kWh of energy supplied to the grid for renewable energy. After meeting the local grid operator Leyeco it was found that this regulation was not implemented into the local regulations in Tacloban. However, net-metering is implemented. In the net-metering scheme it was assumed that the average cost of imported energy was 7.93 PhP/kWh, while the exported energy was 2.67 PhP/kWh, making it unattractive to exchange energy with the grid. However, the net-metering rate could increase in the future and FIT scheme can be implemented. In this regard, the LCOE for the grid connected PV systems can be reduced. The average electricity tariff for the Philippines, illustrated in figure 2.4, is the largest among the ASEAN-5 countries at 9.00 PhP/kWh, although the average Leyeco electricity price was calculated to be 7.93 PhP/kWh.

The process for implementing a PV system will differ for the on-grid and the off-grid PV system solutions. When an on-grid system is implemented the PV system must be compliant with the local DU standard. The DU can conduct inspections and remove the generation at any time due to maintenance, test, repair or emergency conditions. The QE is also liable for damages of the DU if the customer execute changes in the PV system without informing the DU. However, for an off-grid system the DU does not impose any regulations. If the regulatory system is without corruption and misuse of the regulations these regulations can be reasonable. However, the cooperating stakeholders should be evaluated to avoid being hold liable for damage or getting the generation unit removed without reason.

9.2 Objective 2

Examine the energy/power demand and determine the load profile of Streetlight´s center in Tagpuro

The solar potential in Tagpuro matches well with the daily load profile for the center in Tagpuro with a peak when the solar potential is highest during the day. A PV system in Tagpuro is therefore feasible based on the correlation between the meteorological data and the load profile.

The load profile was determined by theoretical estimation based on observations and assumptions. A 1-2 years perspective was dimensioned for, due to the assumption that the energy use would be stable after 1-2 years. However, the operation of the center is uncertain, and external factors such as politics, economy and social factors can change the operation of the center rapidly. An on-grid system can be more suitable for an unknown future load profile, since the surplus energy can be supplied to the grid. An off-grid system has to be more carefully designed according to the load-profile.

Despite the uncertainties, the load profile was determined as exact as possible with the information available. The electrical equipment was assumed to operate at rated power and time of consumption was rounded up, which may lead to an overestimate of the load profile. Water boilers and irons were overestimated by assuming one hour of consumption, to visualise the maximum power consumption in the load profile with hourly resolution. The operation time of the water pump was also rounded up to fit the hourly resolution and assumed to operate at the times when PV production is maximum. However this is not the case today and most water pumps operate continuously during the day depending on a floater level. To implement a solution with pump operation at specified time intervals, an additional timer together with a float level switch could be used. The pump could also be switched on and off according to the PV production at the corresponding day, increasing the match between the energy production and energy consumption.

The method for calculating power consumption consisted of finding total water consumption based on a percentage share of daily water use for each person at each building. This was based on number of people in each building and how many hours in a day they use the building. The total daily Filipino water use of 186 l/capita/day is not necessarily accurate or applicable for Streetlight Tagpuro. There are also uncertainties related to the number of people in each building and the percentage share of their daily water use being consumed at Tagpuro.

Lighting and computers were evaluated as critical loads, because they provide safety and regular operation of the center and were determined based on interviews with Streetlight. However, critical load can also be determined in a more conservative way, only taking into account the fundamental needs. The equipment that is part of the critical load should be energy saving apparatus. This should be emphasised for lights that are on during the night.

The load can be controlled according to the PV production and equipment can be turned on/off according to the weather forecast. Load management can be incorporated and the customer can be conscious and aware of when to consume energy and consume energy according to the times of PV production. If the PV system is being installed, it is advised that Streetlight as an organisation creates internal knowledge about load management and PV energy production in order to achieve an efficient system. It is also advised that Streetlight focuses on energy-saving apparatus, independent on whether they will have a PV system or not, to reduce electricity costs.

9.3 Objective 3

Study, design and evaluate PV system solutions applicable for Streetlight´s center in Tagpuro, including an evaluation of on-grid and off-grid PV system solutions

System topologies and system components

The on-grid PV system solutions assumes the system topology presented in the diagram in figure 3.12. The off-grid simulations assumes an AC-coupled topology as presented in figure 3.14. PVsyst does not allow selection of inverters or rectifiers, neither dividing into sub-arrays or string design in the stand-alone design. However, the string design and corresponding number of inverters were assumed equal for the on-grid and off-grid system. The AC-coupled system was chosen since the loads at the center already are AC, and it is beneficial to have a flexible and easily expandable system. The AC-coupled system is also applicable as a hybrid system if implementing other generation units. The DC-coupled system presented in figure 3.13 was further excluded due to difficulties finding a suitable DC-DC converter (controller) and DC-AC converter for the total PV system. However, a DC-coupled system would enable DC-loads.

It is assumed that PVsyst considers a DC-coupled off-grid system, with DC-DC converters and with DC loads, i.e without inverters. Since an AC-coupled system has been constructed, the inverter and rectifier loss may differ from the converter loss presented in the loss diagrams. The loss of the inverters connected to each string corresponds to 2.9 % for the on-grid simulations. In addition, there will be a loss related to the rectifiers due to an efficiency of 95.8 %. However, when adding the inverter and rectifier efficiency, without taking into account the % energy stored in the battery, the converter loss is 7.1 %, exactly corresponding to the converter loss presented in the off-grid loss diagrams. However, this would be lowered when taking into account the % energy stored in the battery.

In the process of realising the PV system, the particular supplier should perform his own analysis on the selection of system components. Therefore, the choice of PV module, inverter, rectifier and battery must not be considered absolute. They rather serve as a possible solution and their results are valid for illustrating the solar potential in Tagpuro. System concepts of modules and inverters were presented in section 3.7. The system concept used for modules and inverters was the string inverter concept using one inverter per string implying a large number of inverters. However, to decrease the number of inverters, an inverter could have the input of several strings. This is a trade-off between investment costs and is evaluated in section 9.4. The multiple MPP regulator concept can also be utilised, however additional DC-DC converters are then needed.

A back-up generator is assumed included for both the on-grid and off-grid system. However, it was not possible to account for the unreliable grid situation by including rate of power outages in PVsyst. The generator has therefore not been included for fuel consumption for blackouts. The fuel consumption of the generator have been taken into account when the missing energy > 0. However, the missing energy may be an overestimate since only critical loads will have to be supplied by a back-up generator when the PV system can not supply the load.

It is not possible to include a battery in the on-grid designs and a battery was therefore only included in the off-grid simulations. However, it could be advantageous with a battery in the on-grid PV system topology. This battery could have been dimensioned for a 24-hour blackout, corresponding to one autonomous day for the total load. The battery could have been further reduced by only dimensioning the battery for one autonomous day for the critical load. By including a battery the use of the back-up generator would be reduced. Further the exchange of energy with the utility grid would reduce and the self-supplied energy consumption would increase.

When installing a battery in the system, there need to be additional space for the battery. Installing the selected Exide Classic batteries of 6900 Ah correspond to a volume of 4.86 m^3. However, if another lead-acid battery or a lithium-ion battery with higher energy density is used, the size can be reduced significantly. If the lead-acid battery Concorde PVX-6480T was used 312 batteries would be needed corresponding to 3.99 m^3. If the lithium-ion battery GWL WB-LYP1000AHC was used 105 batteries are needed corresponding to 2.72 m^3 [47]. In addition to additional space, the battery will need energy to cool the battery to operate at a stable temperature of 20 °C. This has to be done to maximise the battery lifetime, however this energy has not been taken into account in the simulations.

3D model in PVsyst

The center in Tagpuro was constructed as a 3D model in PVsyst to evaluate the possible PV production, as well as performance parameters such as shading conditions and system losses. To construct the center, several assumptions had to be taken, and the measures were based on visual estimates, measurements and architectural drawings. However, there can be deviations in the 3D model and the actual center, affecting the results.

Meteorological Database

The selection of meteorological database proved to have significant impact on the energy production. The PV system with NASA-SSE produced 11.5 MWh more compared to Meteonorm Tagpuro. Due to this conservative result, Meteonorm Tagpuro was selected for the off-grid and on-grid simulations. However, the actual PV production may be higher than what was achieved in the simulations. This would further lead to decreased costs for all the cases.

Temperature

The temperature default settings in PVsyst were left unchanged, except the lower temperature for absolute voltage limit that was changed from -10 to +20 °C. However, this value could be an underestimate improving the performance of the system since the minimum temperature for

Tacloban is +22 °C according to [39]. Further there is an uncertainty related to the temperature values left at default value.

The temperature loss from the loss diagram can be reduced with having an additional cooling system for the PV modules. This system would imply additional energy use and it is unknown whether improved performance from reduced temperature loss would even out the extra energy demand. One possibility would be to have a cooling system which could be used for heating up water.

Shading Irradiance Loss

The shading irradiance loss contributes to a high share of the total system losses in all the PV system solutions. Removal of trees are therefore an important consideration to increase the system performance and the production. If the trees in front of the Orphanage are removed the energy production for the on-grid case with modules at all buildings increase from 60.7 MWh to 66.9 MWh. In this case more energy can be exported to the grid, and the costs from net-metering will be reduced. However, if the trees are removed, it can lead to increased energy demand due to increased temperature inside of the buildings. If so, it is not recommended to remove the trees.

Optimum Tilt Angle

The optimum tilt angle for a PV system is equal to the latitude angle as a rule of thumb. The latitude angle in Tagpuro is 11.34 °, however the tilt angle used in all simulations are the roof tilt angle of 18 °. The optimal tilt angle of 11.34 ° could improve the total energy production. In order to obtain this, it would require an additional mounting system on the roof to lower the tilt angle until optimum angle. It can further be cost-effective to track the movement of the sun, and tilt the modules respectively. Single axis trackers, that track either the azimuth or the altitude angle, or two axis trackers, that track both angles, can be used for this purpose.

9.4 Objective 4

Conduct an economical evaluation of the PV system solutions

Due to limited information, several assumptions had to be taken when conducting the economical evaluation. The input parameters in the LCOE were assumed equal for the on-grid and off-grid PV systems. However, the annual system degradation LF, might be higher for the off-grid system since lead-acid batteries can have a high degradation rate.

The discount rate proved to be sensitive for the LCOE results and PV systems are only profitable with a low discount level. The selected discount rate at 10 % may be a source of error and is based on the reference project by ADB, non-OECD countries by IRENA and Sepalco. The rate is influenced by the local market and market risks, which is difficult to predict.

An economic lifetime of 25 years has been assumed, based on the lifetime of the modules. The modules have the longest life-time of the system components and it is estimated that inverters, rectifiers and batteries will need to be reinvested during the economic lifetime. Inverters and rectifiers in year 12.5 and battery in year 10 and 20. The inverters and rectifiers may possibly last as long as the modules, and the reinvestment of the inverters may be excluded. However, the battery may have a shorter lifetime than expected, for instance if the temperature is above 20 °C. This will increase the investment cost of the off-grid PV system significantly.

The mechanical and electrical mounting equipment as well as the control system and monitoring equipment were calculated based on the share of total material costs from Multiconsult´s report. However, this report is based on an on-grid system, and rectifiers and batteries are not included in the total material costs. Rectifiers and batteries are added separately after the share of total material costs for the off-grid system. The cost of the mechanical and electrical mounting equipment as well as the control system and monitoring equipment can therefore be an underestimate for the off-grid cases.

The module and inverter price from Solaric (December 2016) and rectifier price from Optimus Energy (January 2015) may vary and other suppliers may be chosen. Several suppliers were contacted in order to obtain battery prices; Solaric, Solarzone and Solar System Philippines. The battery price were not provided by any of the suppliers contacted, and the price used from Shop Solar Wind has a high uncertainty. Further, it was found that they do not ship the Excide Classic to the Philippines. Nevertheless, the price used is reasonable to compare the on-grid and off-grid cases as well as illustrating relative battery costs.

The Thinkpower inverters may be replaced by the SMA inverter 5000TL with the rating 5 kW and two MPPT inputs. In this case, 2 inverters are required at the Office, with 9 modules in series located at 4 string. 4 inverters are required at the Study Center with 11 modules in series located at 8 strings, and 3 inverters are required at the Orphanage with 11 modules in series located at 6 strings. This corresponds to 9 inverters. In May 2017 Solaric confirmed to provide the SMA 5000TL inverter for 168 100 PhP per unit. This correspond to a total inverter cost of 1 512 000 PhP, which is 3.1 times more than the cost with Thinkpower inverters. According to the Solaric price list, the investment cost do not decrease when the number of inverters is reduced, due to increased price for increased inverter capacity.

The required number of rectifiers in the off-grid systems were found based on the limits in the datasheet for the rectifier used. However, the design implies a number of rectifiers that obtain a current close to the maximum current. An increased number of rectifiers can therefore be considered, increasing the investment costs of the off-grid cases.

The Fuel Cost has only been added for the off-grid cases when the missing energy > 0. This implies that the fuel consumption during blackouts for the on-grid system are not taken into account. There will be fuel costs also for the on-grid system, however due to the uncertainties of blackouts the fuel consumption during blackout are not incorporated in the economic analysis. The fuel price for diesel at 31.2 PhP/l is assumed to be constant, although it is expected to vary.

The Net-Metering Costs are calculated based on the meeting with the local grid company Leyeco as well as the net-metering policy document provided by Leyeco. However, these policies may change. According to the REA presented in chapter 2, customers are only required to pay for the net energy consumption. In this case the price of imported energy would equal price of exported energy. This implies that the Net-Metering Costs will be significantly reduced. Further, if FIT is implemented into the regulations the income from exported energy may be higher than the costs from imported energy resulting in a net income.

The LCOE utility is 7.93 PhP/kWh and equals the average electricity price. It is based on the assumption that the electricity price will remain constant the next 25 years and without considering general inflation. However, the price will vary, but there is high uncertainty related to the extent of the variation. According to figure 2.3, there will be a future energy deficit in Visayas. Considering the energy deficit and frequent typhoons damaging the grid, the price might increase. However, evaluating the future grid development plans where Leyeco will upgrade their utility grid, the price might decrease, and hence the LCOE utility grid might decrease.

9.5 Objective 5

Evaluate the PV system solutions in a holistic approach examining various aspects that can influence the outcome of the project

As described in section 2.1, Tagpuro is located in a vulnerable area regarding natural catastrophes and measures have to be taken when implementing a PV system. It should be emphasised that the structures of the PV system will have to be dimensioned to tolerate regular typhoons in the area. If the PV system is not designed for the climatic conditions, it is not economical to invest in. Further, Sepalco had challenges related to rats and damaged DC-cables. However, the PV farm is located on a previous rice-field and it is assumed that this problem will not be as extensive in Tagpuro. Nevertheless, the cables at ground level should be sealed to prevent the damage from rats.

The PV system must tolerate the climatic conditions and the roof mechanical structures must tolerate the PV system. When locating modules at all buildings the total weight of the modules are 3 610 kg at a total area of 320.79 m^2. The roof needs a mechanical structure that enables the weight. Further the mounting equipment and penetration of the roofs should be installed with respect to the water drainage of the roof. Further the PV system should be located in such a way that it is not possible to get injured. This should also be considered regarding criminality, where one can get injured if trying to steal equipment in the PV system. Considering criminality, the on-grid solution is more feasible than the off-grid solution, due to the cost and storage of the battery. The battery can also imply a source of risk considering fire.

Streetlight´s operation is uncertain and therefore the PV system can be dimensioned scalable. A proposition can thereby be to install the modules for one building at a time. A first installation step could consist of modules at the Office. A second installation step could be to expand with modules at the Study Center, covering annual critical load demand. If this becomes insufficient in the future, as predicted in the load determination presented in chapter 6, modules can also be implemented at the Orphanage. The trees south of the Orphanage can then be removed, however this should be evaluated by Streetlight.

The on-grid solution can question the concept of self-sufficiency. The off-grid solutions provides Streetlight with self-sufficient energy, and there is no interaction with the utility grid. However, the battery needed to be unrealistically large to obtain a self-sufficient system without a backup generator. It is further proven in the LCOE results that it is very expensive to be self-sufficient. Since Streetlight highlights that their energy source should be a renewable energy source, self-sufficiency could be undermined in correlation to the non-renewable energy that have to be consumed to be self-sufficient. Further, the on-grid solutions are also dependant on non-renewable energy when consuming energy from the grid.

Objective 5 will be further emphasised in the following chapter 10.

Chapter 10

Conclusion and Further Work

A summary of the technical and economical results for the three on-grid and three off-grid cases are presented in table 10.1. Based on Levelized Cost of Energy (LCOE) and investment costs, the on-grid solutions are preferable compared to the off-grid solutions, due to high battery costs. For the PV system with modules located at all buildings, the on-grid solution had a LCOE of 8.79 PhP/kWh compared to 30.32 PhP/kWh for the off-grid solution. Based on total investment costs, it is preferable to invest in a smaller PV system and 36 modules at the Office building is the cheapest option at 599 kPhP. This is also the only system solution that is competitive with utility LCOE of 7.93 PhP/kWh. However, the economical analysis is sensitive to a change in variables, and a different discount rate, battery price and net-metering rate will change the economical results.

Table 10.1: Technical and economical results on-grid and off-grid cases

	On-grid			**Off-grid**		
Parameter	**Base Case - All buildings**	**Office and Study Center**	**Office**	**All buildings**	**All buildings - increased battery capacity**	**All buildings -maximising Office**
Installed capacity kW_p	55.1	36.0	10.4	55.1	55.1	69.6
# modules	190	124	36	190	190	240
# inverters	18	12	4	18	18	25
# rectifiers	-	-	-	5	6	5
# batteries	-	-	-	48	96	48
Prod. [MWh]	60.7	42.1	13.7	53.5	54.9	54.5
Inv. Cost [kPhP]	3 097	2 026	599	10 402	16 821	11 150
Inv. Cost per W_p [PhP/W_p]	56.2	56.3	57.4	188.8	305.3	160.2
LCOE [PhP/kWh]	**8.79**	**8.42**	**7.71**	**30.32**	**50.45**	**31.90**

The focus of this thesis has been to map the potential production, different PV system possibilities and to give an indication of the PV systems economical feasibility. The design of a PV system for Tagpuro can be solved in different ways, and Streetlight has many possibilities. Both on-grid and off-grid PV solutions can fulfil the requirements regarding implementation of predictable renewable energy. However, the on-grid and off-grid solutions varies from each other and a short summary of the possibilities and limitations they provide are given in figure 10.1. The most feasible solution will depend on which factor Streetlight highlights the most.

	On-Grid	Off-Grid
Possibilities	Flexible towards uncertain load profile	Satisfies self-sufficiency
	Back-up from grid if PV system is not operating	Avoid local regulations for grid-connection
	Consequences from brownouts reduced	Avoid consequences from utility brownouts/blackouts
	Avoid additional battery costs	
Limitations	Must act in accordance with regulations for grid-connection	Less flexible towards uncertain load profile
	Consequences from blackout will still be present	Vulnerable to climatic damage and crime
		Fuel consumption from the back-up generator when missing energy > 0
		Expensive solution

Figure 10.1: Possibilities and limitations for the on-grid and off-grid case

The on-grid and off-grid cases provide different opportunities and limitations. If an on-grid PV system is chosen the cost can be reduced compared to an off-grid system, however the issues with blackouts are not solved, although brownouts can be reduced. Blackouts from utility are eliminated in the off-grid case, however it comes at a significant higher cost. The preferable system solution is therefore a consideration between these aspects and has to be evaluated by Streetlight.

The consequence of an off-grid system out of operation is high and the system is more vulnerable to climatic damage and crime. Having an on-grid configuration, Streetlight is less vulnerable if the system is damaged or out of operation, having the grid as a backup. In addition, the on-grid case contribute to the community and feeds surplus energy to the utility for the use for other consumers. Ideologically this topology can therefore be more in coherence with Streetlights vision.

The on-grid case can be more flexible and scalable. It can be installed at several steps without having to increase battery capacity and can include more buildings gradually. The off-grid case is less flexible when it comes to designing the system according to an uncertain load and additional batteries need to be included when the PV system is up-scaled. On the other hand, the on-grid solution requires the system to operate in accordance to the local grid regulations which may imply additional costs, which has not been evaluated.

Based on aforementioned results, a gradual implementation of an on-grid PV system for the center in Tagpuro is recommended. A gradual implementation can verify the assumptions on production results obtained in this master thesis. It is recommended to install modules first at the Office building as phase 1, followed by the Study Center as phase 2 and last, Orphanage as phase 3 - if the goal is to have modules at all buildings and supply total annual load demand. Between phase 1-2 and phase 2-3, it is recommended with an evaluation of the PV system performance and production, based on 6-12 months of operation. A gradual implementation will reduce risk and uncertainty. In addition, a gradual implementation will ensure knowledge and experience about the PV system production and costs, before concluding if it is profitable to expand the implementation. The recommended implementation is visualised in figure 10.2.

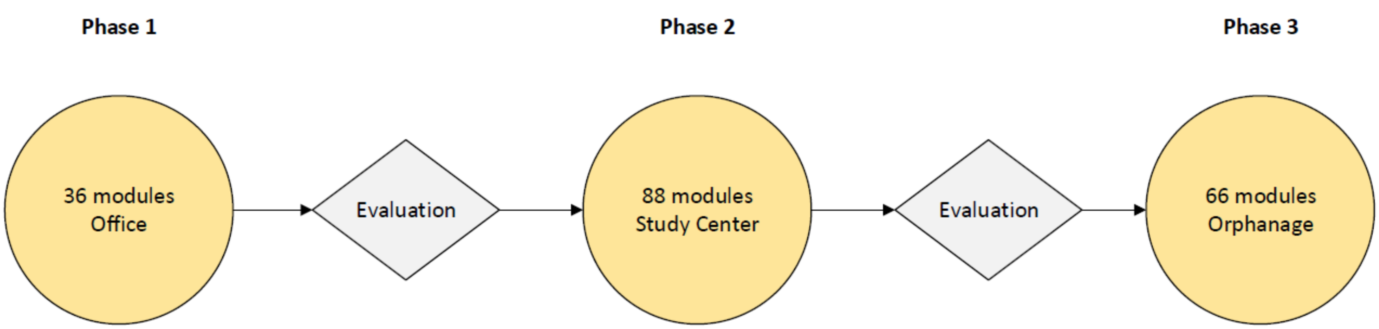

Figure 10.2: Recommended gradual implementation of the on-grid PV system

Further Work

For further work, it is recommended to evaluate whether a roof PV system is feasible considering roof mechanical structures and wind loads. Another alternative is to evaluate PV modules installed at the south-oriented building facade instead of the roof.

If a roof PV system is considered feasible, the decision of an on-grid or off-grid system has to made. When the desired system has been specified, various evaluations have to be conducted in order to obtain a detailed technical design and economical analysis. This will consist of evaluating the installation and mounting solutions, safety requirements, local regulations and project risk. Installation, commissioning and operation procedures have to be followed. Compliance with the manufacturer´s instructions must be ensured and possible warranty obligations should be taken into consideration. Safety requirements will have to be examined and involves overvoltage protection such as lightning protection, surge arresters, switches and grounding. This should be evaluated by examining the location and frequency of lightning strikes. A detailed evaluation would influence the technical design and economical analysis compared to the evaluation conducted in this thesis.

Hopefully, Streetlight will obtain sufficient funding if it is evaluated to implement a PV system. If the PV system is rated as successful, the solution could be replicated in other areas in Tacloban and stimulate to sustainable development in the region.

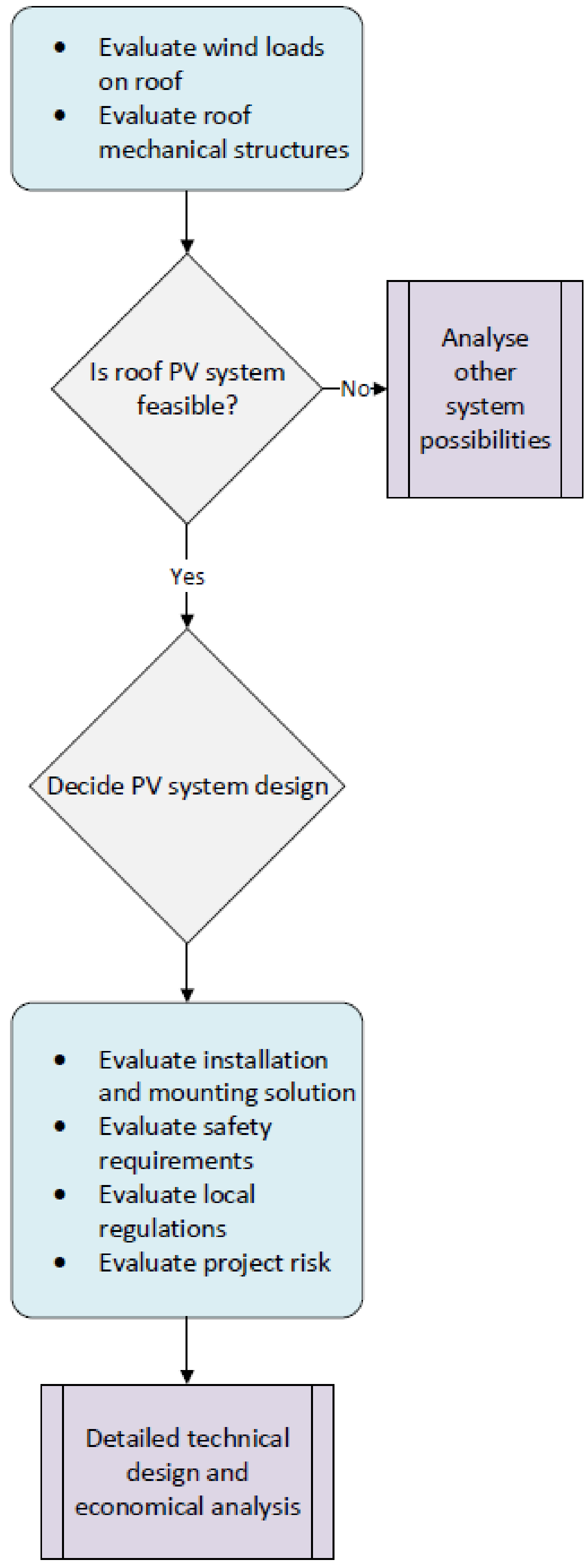

Figure 10.3: Recommended further work

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Appendix A

Acronyms

ADB Asian Development Bank

AM Air-Mass

ASEAN-5 Association of Southeast Asian 5 Nations

ASEI Asia Solar Energy Initiative

DHI Direct Horizontal Irradiation

DNI Direct Normal Irradiation

DOE Department of Energy

DSOAR Distribution Services and Open Access Rules

DU Distibution Utility

EES Electrical Energy Storage

EPIRA Electric Power Industry Reform Act

ERC Energy Regulatory Comission

FIT Feed-in Tariff

IRENA International Renewable Energy Agency

IUG Engineers Without Borders Norway

LCOE Levelized Cost of Energy

m a.s.l Meter above sea level

NM Net-Metering

MPP Maximum Power Point

MPPT Maximum Power Point Tracking

NASA-SSE National Aeronautics and Space Administration - Surface Meteorological and Solar Energy Programme

NGCP National Grid Corporation

NGO Non Governmental Organisation

NPC National Power Corporation

NREB National Renewable Energy Board

O&M Operation and Maintenance

PAGASA Philippine Atmospheric Geophysical and Astronomical Services Administration

PCC Point of Common Coupling

PCU Power Conditioning Unit

PDC Philippine Distribution Code

PEC Philippine Electrical Code

PhP Philippine peso
1 PhP = 0.166862 NOK [17]
1 PhP = 0.017973 Euro [44]

PR Performance Ratio

PV Photovoltaic

QE Qualified end user

REA Renewable Energy Act

SOC State of Charge

STC Standard Test Conditions

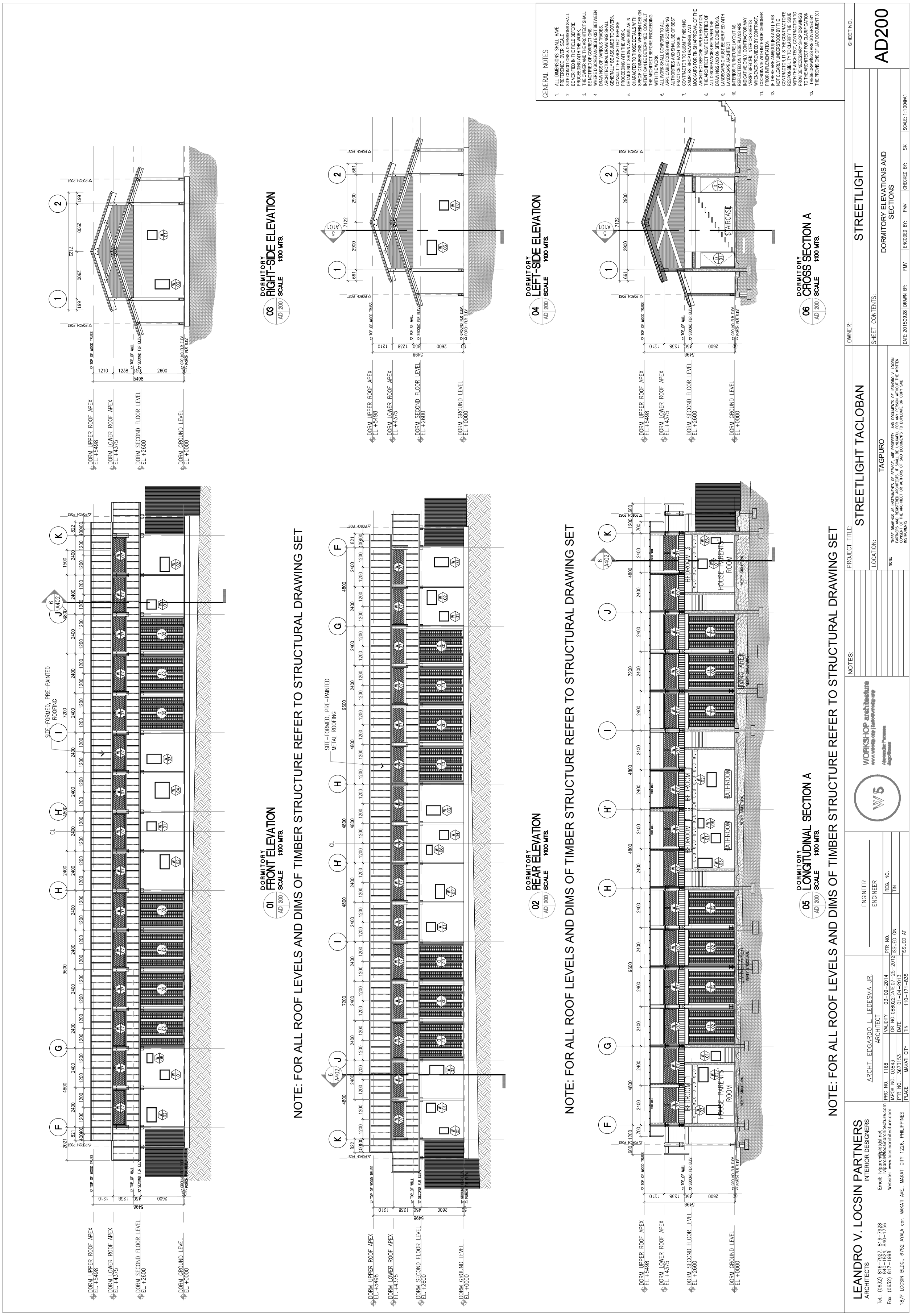
TMY Typical Meteorological Year

TSO Transmission System Operator

VAT Value Added Tax

Appendix B

Architectural drawings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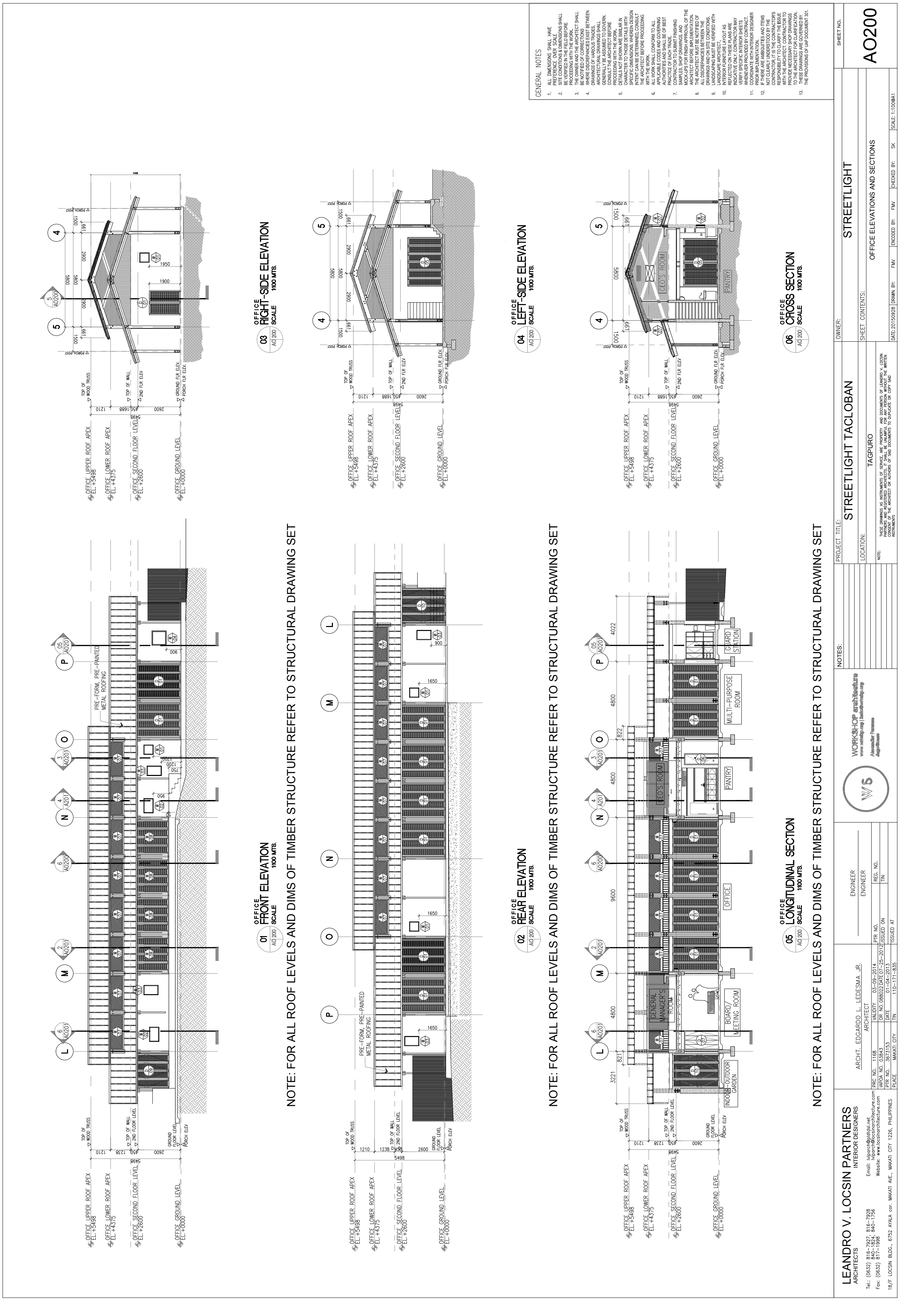
GENERAL NOTES
LEANDRO V. LOCSIN PARTNERS
ARCHITECTS
INTERIOR DESIGNERS
WORKSHOP architecture
STREETLIGHT TACLOBAN
TAGPURO
STREETLIGHT
DORMITORY ELEVATIONS AND SECTIONS
AD200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OFFICE LONGITUDINAL SECTION
OFFICE RIGHT-SIDE ELEVATION
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OFFICE CROSS SECTION
NOTE: FOR ALL ROOF LEVELS AND DIMS OF TIMBER STRUCTURE REFER TO STRUCTURAL DRAWING SET
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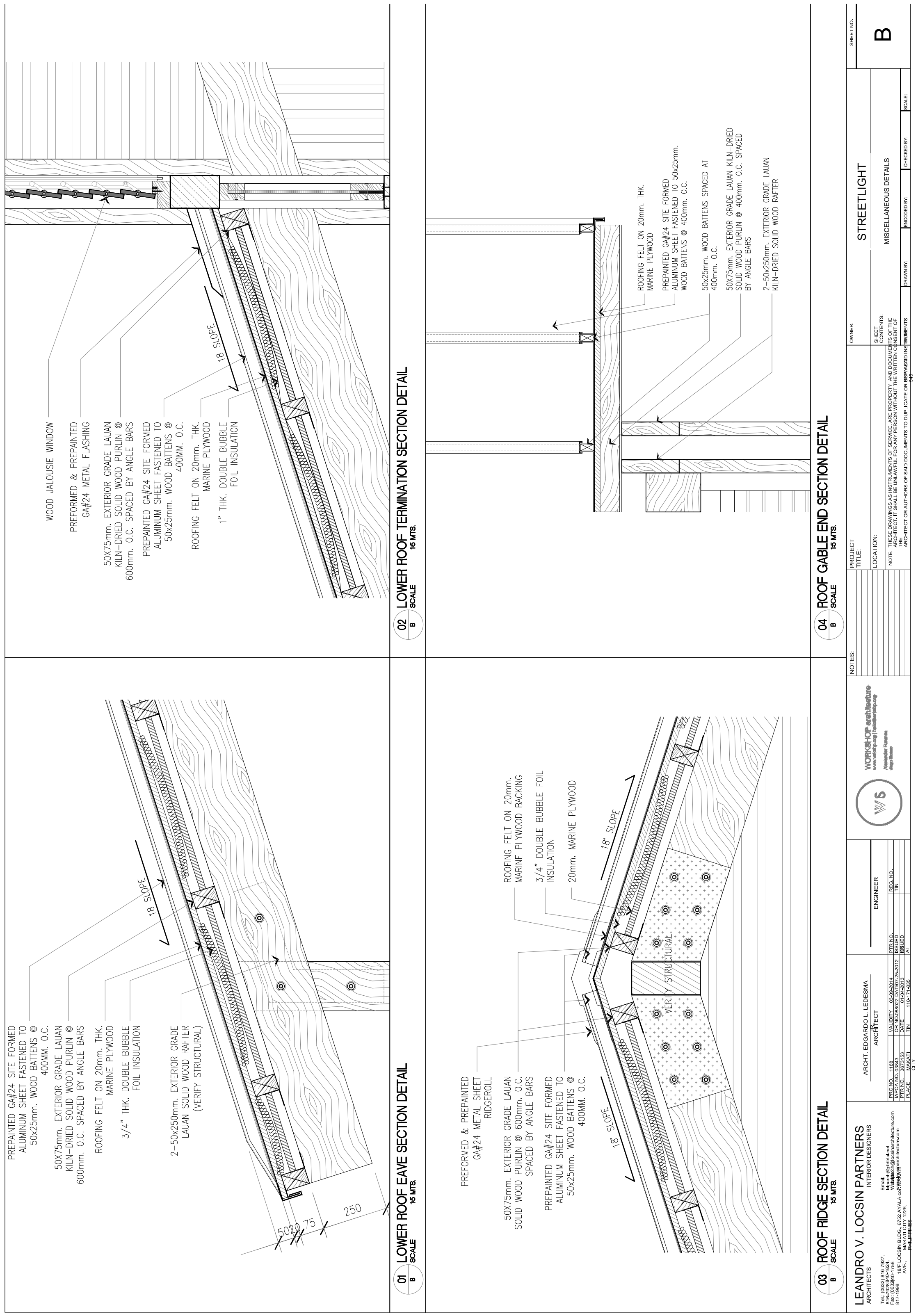
AO200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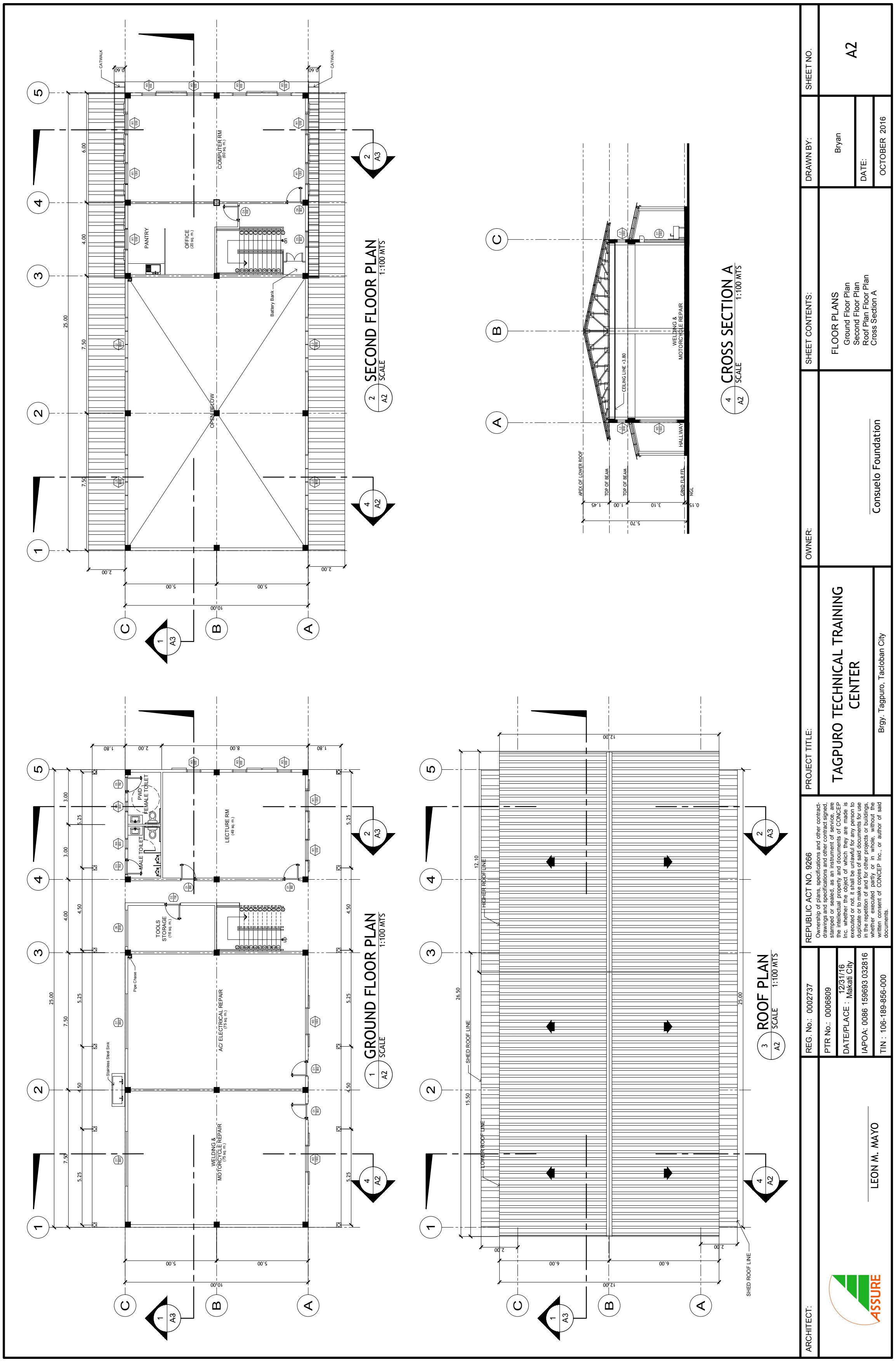
LOWER ROOF TERMINATION SECTION DETAIL
ROOF RIDGE SECTION DETAIL
ROOF GABLE END SECTION DETAIL
PREPAINTED GA#24 SITE FORMED ALUMINUM SHEET FASTENED TO 50x25mm. WOOD BATTENS @ 400MM. O.C.
50X75mm. EXTERIOR GRADE LAUAN KILN-DRIED SOLID WOOD PURLIN @ 600mm. O.C. SPACED BY ANGLE BARS
ROOFING FELT ON 20mm. THK. MARINE PLYWOOD
3/4" THK. DOUBLE BUBBLE FOIL INSULATION
2-50x250mm. EXTERIOR GRADE LAUAN SOLID WOOD RAFTER (VERIFY STRUCTURAL)
WOOD JALOUSIE WINDOW
PREFORMED & PREPAINTED GA#24 METAL FLASHING
1" THK. DOUBLE BUBBLE FOIL INSULATION
PREFORMED & PREPAINTED GA#24 METAL SHEET RIDGEROLL
20mm. MARINE PLYWOOD
VERIFY STRUCTURAL
18 SLOPE
LEANDRO V. LOCSIN PARTNERS
ARCHITECTS
INTERIOR DESIGNERS
ARCHT. EDGARDO L. LEDESMA
ARCHITECT
ENGINEER
WORKSHOP architecture
NOTES:
PROJECT TITLE:
LOCATION:
OWNER:
STREETLIGHT
SHEET CONTENTS:
MISCELLANEOUS DETAILS
DRAWN BY:
ENCODED BY:
CHECKED BY:
SCALE:
SHEET NO.
B



SECOND FLOOR PLAN
SCALE 1:100 MTS
GROUND FLOOR PLAN
SCALE 1:100 MTS
ROOF PLAN
SCALE 1:100 MTS
CROSS SECTION A
SCALE 1:100 MTS
COMPUTER RM
OFFICE
PANTRY
OPEN BELOW
Battery Bank
CATWALK
LECTURE RM
MALE TOILET
FEMALE TOILET
PWD
TOOLS STORAGE
AC/ ELECTRICAL REPAIR
WELDING & MOTORCYCLE REPAIR
Pipe Chase
HIGHER ROOF LINE
LOWER ROOF LINE
SHED ROOF LINE
HALLWAY
CEILING LINE
TOP OF BEAM
APEX OF LOWER ROOF
ARCHITECT:
LEON M. MAYO
ASSURE
REG. No.: 0002737
PTR No.: 0006809
DATE/PLACE: 12/31/16 Makati City
IAPOA: 0086 159693 032816
TIN: 106-189-856-000
REPUBLIC ACT NO. 9266
PROJECT TITLE:
TAGPURO TECHNICAL TRAINING CENTER
Brgy. Tagpuro, Tacloban City
OWNER:
Consuelo Foundation
SHEET CONTENTS:
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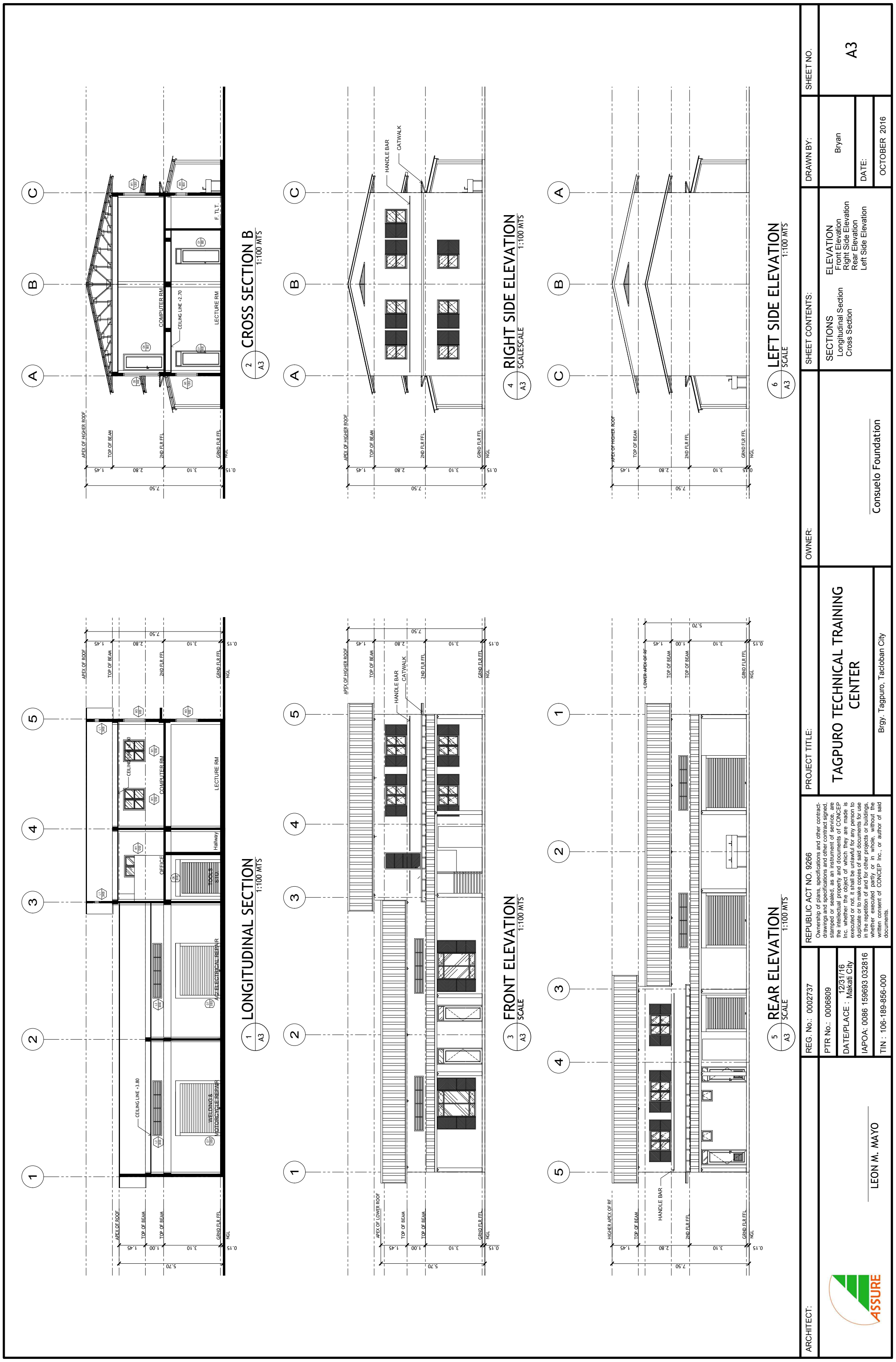
Ground Floor Plan
Second Floor Plan
Roof Plan Floor Plan
Cross Section A
DRAWN BY:
Bryan
DATE:
OCTOBER 2016
SHEET NO.
A2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CROSS SECTION B
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REAR ELEVATION
1:100 MTS
LEFT SIDE ELEVATION
1:100 MTS
ARCHITECT:
ASSURE
LEON M. MAYO
REG. No.: 0002737
PTR No.: 0006809
DATE/PLACE : 12/31/16 Makati City
IAPOA: 0086 159693 032816
TIN : 106-189-856-000
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Brgy. Tagpuro, Tacloban City
OWNER:
Consuelo Foundation
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SECTIONS
Longitudinal Section
Cross Section
ELEVATION
Front Elevation
Right Side Elevation
Rear Elevation
Left Side Elevation
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Bryan
DATE:
OCTOBER 2016
SHEET NO.
A3

Appendix C

Needs Assessment

The needs assessment consisted of several questions and topics that were discussed during the fieldwork. A summary of the questions are given below:

Topic	**Questions**
General	Number of buildings that will be supplied by solar power? Number of people living there full-time (during day-time)? Number of people during day-time? Future expansion plans? Main activities during day-time?
Energy and critical load	What are main users of energy? What are they used for? What would you define as critical users of electricity? Is there one load that has a high demand? How often are equipment in use (day-schedule) How often are equipment in use at the same time (day-schedule) How is the water supplied? How are the washroom facilities? WC? Would this be a future need?
Energy problems	How often does blackout happen? How long do they last? What are the consequences of blackout? How do you adapt to these consequences? Brownouts; how has it affected you? How much equipment has been damaged? What do you think these problems lead to in the future? How can brownouts and blackouts be a limitation in the future?
Existing back-up generator	Is it diesel or petrol? How often in use? Manually or automatically switched on during a blackout? Used at other times than blackout? How expensive are fuel costs? Estimates? Are they varying? Supplying total load or specific/critical loads?
Related to PV system	Is brake-ins a common problem? Is it normal with PV systems in the area? What are the perceptions towards a PV panel? Do you see the PV system as a potential target for criminals? How would the children react to a PV system on the site? When is sunrise and sunset? Where is sunlight least influenced by shading? What are the future plans of the site? Any new buildings? Is there need for any new building structures?

Appendix D

Price List

December 2016

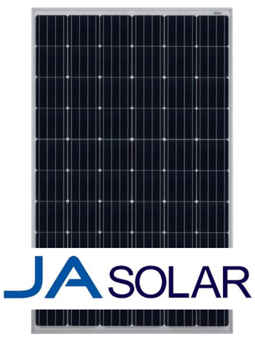
Dealer/Installer Price List

The Dealer Rates listed herein are vat exclusive, and subject to change

SOLARIC
TURN ON THE SUN

SOLAR PANELS / MODULES

JA SOLAR



DESCRIPTION	DEALER RATE
Monocrystalline Panel	
290W | 40mm	**P 9,500.00**
280W | 40mm	**P 9,200.00**

JA Solar Promo: When you buy 10+ pcs

FREE PV Duplex cable 1M per panel and MC4 pair for every 10 Panels purchased

SERAPHIM | DURAFLEX

DESCRIPTION	DEALER RATE
Monocrystalline Panel, BLACK	
Duraflex 265W	**P 9,500.00**
Eclipse 310W	**P 15,000.00**

Seraphim Promo: When you buy 10+ pcs

FREE PV Duplex cable 1M per panel and MC4 pair for every 10 Panels purchased

PANASONIC

DESCRIPTION	DEALER RATE
Monocrystalline Panel	
H.I.T. 240W | 35mm	**P 15,000.00**

LG SOLAR NEON

DESCRIPTION	DEALER RATE
Monocrystalline Panel	
Neon 12 yrs warranty 310W | 40mm	**P 15,000.00**

NEW STOCK ARRIVES WEEKLY

Call / Email us for updates on the latest solar panel availability

Polycrystalline Panel	**JA Solar: 270W while supplies last only.**	
	270W | 40mm	**P 7,500.00**

CABLES & CONNECTORS

Duplex PV Cable UV Resistant

DESCRIPTION	DEALER RATE
4mm2 per meter	**P 100.00**
6mm2 per meter	**P 140.00**

MC4 Connector

DESCRIPTION	DEALER RATE
TUV Certified MC4 Compatible	**P 80.00**

Medusa Head

DESCRIPTION	DEALER RATE
up to 4 Panels in Parallel	**P 800.00**

Y Connector

DESCRIPTION	DEALER RATE
2 panels in parallel	**P 350.00**

Clamps, Screw & Rails | Built tough - not your ordinary rails

End Clamp, Mid Clamp, L Foot

DESCRIPTION	DEALER RATE
End Clamp	**P 50.00**
Middle Clamp	**P 50.00**
L Foot with Rubber	**P 100.00**

Bigfoot w/ 3 woodscrew | Hanger Bolt

Bigfoot w/ 3 woodscrew	Hanger Bolt
DEALER RATE	DEALER RATE
P 300.00	**P 300.00**

Grounding & Cable management

DESCRIPTION	DEALER RATE
Grounding Lug	**P 150.00**
Grounding Weeb	**P 10.00**
Cable Clip	**P 15.00**

Rails & Splices

DESCRIPTION	DEALER RATE
2.1 Meters	**P 560.00**
3.2 Meters	**P 860.00**
Rail Splice	**P 80.00**

dealer@solaric.com.ph | 1120 J.P. Rizal Avenue, Makati City | (02) 504 – 0092 / +63 917 860-3141 | www.solaric.com.ph

December 2016

Dealer/Installer Price List

The Dealer Rates listed herein are vat exclusive, and subject to change

SOLARIC
TURN ON THE SUN

GRID TIE INVERTERS

All of our grid tied inverters have internet monitoring, a DC disconnect switch, and a 5 year warranty!

THINKPOWER

DESCRIPTION	DEALER RATE
Grid Tie inverter w/ Wifi, limiter compatible	
ThinkPower 1500	P 22,000.00
ThinkPower 2200	P 24,000.00
ThinkPower 3000	P 27,500.00
TP 3600 Dual MPPT	out of stock
TP 5000 Dual MPPT	P 39,000.00

SolarEdge - 12 year warranty

OPTIMIZERS	DEALER RATE
P300 (1:1, 60 cell)	P 3,000.00
P600 (1:2, 60 cell)	P 3,500.00
P350 (1:2, 72 cell)	P 4,500.00
P700 (1:2, 72 cell)	P 5,000.00

INVERTERS	DEALER RATE
5kW, single phase	P 66,000.00
6kW, single phase	P 76,000.00
27.6kW, *3phase 400V*	P 180,000.00
(operates as 17kW if 3phase/230V delta)	
Wifi Kit	P 5,000.00

GOODWE & SolaX

DESCRIPTION	DEALER RATE
SOLAX Mini 1kW	P 18,000.00
GoodWe NS Series (limited stock, closeout sale)	
GW NS 1000	P 17,000.00
GW NS 1500	P 20,000.00
GW NS 3000	P 25,000.00

Hybrid Inverters

SOLAX Hybrid SKSU 5kW	
SolaX includes ATS and CT clamp for zero export function	P 135,000.00

GoodWe ES 5kW Hybrid

Lithium Compatible

GW5048-ES Hybrid	P 120,000.00

OFF GRID & HYBRID INVERTERS

HOG Stackable 5kVA

DESCRIPTION	DEALER RATE
Max 3000W Solar, built in parallel kit, can stack up to 6 units to total 30kVA	P 37,500.00

HOG Lite 3kVA & 5kVA

DESCRIPTION	DEALER RATE
5kVA/48V (Max solar: 145VDC / 80A)	P 27,000.00
3kVA / 24V (Max solar: 100VDC / 40A)	P 16,500.00

No parallel function / No genset start function

HAGRID 3kW & 5kW

DESCRIPTION	DEALER RATE
3kW (max 4500W Panels)	P 41,650.00
5kW (max 10kW panels + has built in parallel kit, stack up to 6 to get to 30kW)	P 85,000.00

MESLA Battery Bank

DESCRIPTION	DEALER RATE
Narada EOS VRLA 48V/600Ah	P 200,000.00

OTHERS

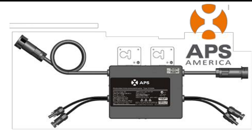
SMA- SB3000 grid tie inverter

DESCRIPTION	DEALER RATE
SMA 3000 Made in Germany	P 50,000.00

Think Power Zero Export SmartBox

DESCRIPTION	DEALER RATE
Limiter	P 7,000.00

Micro Inverter



DESCRIPTION	DEALER RATE
APS 500W w/ full accessories	P 12,500.00

MC4 Crimper with startup tools in bag

DESCRIPTION	DEALER RATE
Spanner wrench, MC4 crimper & wire stripper	P 5,000.00

Optimus ENERGY

INVERTERS

DIRECT FROM SMA WITH DC SWITCH FACTORY SET TO PH SETTINGS

SMA

DESCRIPTION	SINGLE BUY	5+ BUY	10+ BUY
SEA FREIGHT			
SMA 1600TL	48,859	46,123	44,169
SMA 2100TL	56,125	52,982	50,737
SMA 2000HF	65,208	61,556	58,948
SMA 3000TL-21	77,742	73,389	70,279
SMA 4000TL-21	82,708	78,076	74,768
SMA 5000TL-21	94,166	88,893	85,126
SMA Sunny Island 3.0M Off Grid Inverter	153905	145,287	139,130
SMA Sunny Island 4.4M Off Grid Inverter	175,433	165,609	158,591
SMA Sunny Island 6.0H Off Grid Inverter	191,579	180,850	173,187
SMA Sunny Island 8.0H Off Grid Inverter	226,561	213,874	204,811
SMA Solar Charge Controller 2.4kW	49,116	46,366	44,401
AIR FREIGHT			
SMA 1600TL	55,623	52,508	50,283
SMA 2100TL	62,888	59,367	56,851
SMA 2000HF	71,971	67,941	65,062
SMA 3000TL-21	84,506	79,774	76,393
SMA 4000TL-21	89,471	84,461	80,882
SMA 5000TL-21	100930	95,278	91,240
SMA Sunny Island 3.0M Off Grid Inverter	161,919	152,852	146,375
SMA Sunny Island 4.4M Off Grid Inverter	183,447	173,174	165,836
SMA Sunny Island 6.0H Off Grid Inverter	199,593	188,415	180,432
SMA Sunny Island 8.0H Off Grid Inverter	234,575	221,439	212,056
SMA Solar Charge Controller 2.4kW	55,880	52,751	50,516

Note: All prices listed here exclude VAT. Prices are subject to change at any time without notice. All prices are EX works Manila.

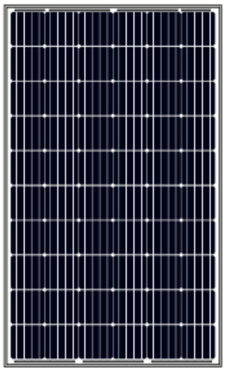
Appendix E

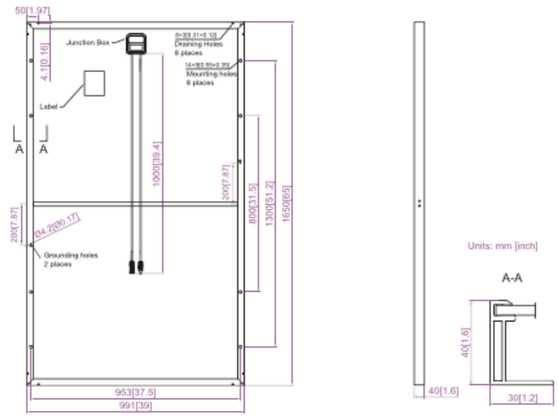
Data Sheet

JA SOLAR

JAM6(K)-60/280-300/PR

Engineering Drawings





MECHANICAL PARAMETERS

Cell (mm)	Almost Full Square Mono 156.75x156.75
Weight (kg)	19.0 (approx)
Dimensions (L×W×H) (mm)	1650×991×40
Cable Cross Section Size (mm^2)	4
No. of Cells and Connections	60 (6×10)
Junction Box	IP67, 3 diodes
Connector	MC4 Compatible
Packaging Configuration	27 Per Pallet

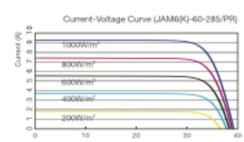
WORKING CONDITIONS

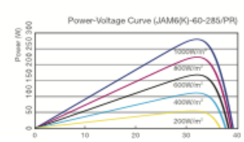
Maximum System Voltage	DC 1000V (IEC)
Operating Temperature	-40℃~+85℃
Maximum Series Fuse	15A
Maximum Static Load, Front Maximum Static Load, Back	5400Pa (112 lb/ft^2) 2400Pa (50 lb/ft^2)
NOCT	45±2℃
Application Class	Class A

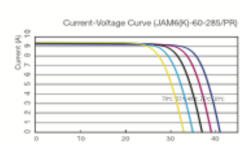
ELECTRICAL PARAMETERS

TYPE	JAM6(K)-60-280/PR	JAM6(K)-60-285/PR	JAM6(K)-60-290/PR	JAM6(K)-60-295/PR	JAM6(K)-60-300/PR
Rated Maximum Power at STC (W)	280	285	290	295	300
Open Circuit Voltage (Voc/V)	39.05	39.25	39.46	39.64	39.85
Maximum Power Voltage (Vmp/V)	31.60	31.70	31.80	32.03	32.26
Short Circuit Current (Isc/A)	9.38	9.46	9.57	9.66	9.75
Maximum Power Current (Imp/A)	8.86	8.99	9.12	9.21	9.30
Module Efficiency [%]	17.12	17.43	17.74	18.04	18.35
Power Tolerance (W)	-0~+5W				
Temperature Coefficient of Isc (αIsc)	+0.060%/℃				
Temperature Coefficient of Voc (βVoc)	-0.300%/℃				
Temperature Coefficient of Pmax (γPmp)	-0.390%/℃				
STC	Irradiance 1000W/m^2, Cell Temperature 25℃, Air Mass 1.5				

I-V CURVE







NOCT

TYPE	JAM6(K)-60-280/PR	JAM6(K)-60-285/PR	JAM6(K)-60-290/PR	JAM6(K)-60-295/PR	JAM6(K)-60-300/PR
Max Power (Pmax) [W]	204.71	208.36	212.02	215.67	219.33
Open Circuit Voltage (Voc) [V]	35.81	36.01	36.24	36.46	36.65
Max Power Voltage (Vmp) [V]	28.55	28.62	28.81	28.87	28.94
Short Circuit Current (Isc) [A]	7.64	7.73	7.81	7.89	7.98
Max Power Current (Imp) [A]	7.17	7.28	7.36	7.47	7.58
Condition	Under Normal Operating Cell Temperature, Irradiance of 800 W/m^2, spectrum AM 1.5, ambient temperature 20℃, wind speed 1 m/s				

Electrical data in this catalog do not refer to a single module and they are not part of the offer. They only serve for comparison among different module types.

JA Solar 03.2016

T SERIES

- IP65 Weather Protection
- Excellent Low Light Sensitivity
- Rugged cast Aluminium Chassis
- WiFi module as standard for free
- 5 Year Warranty Standard
- Leading edge capacitor control technology
- Dynamic MPPT efficiency >99.9% (Euro efficiency >97.2%)

Wuxi Thinkpower New Energy Technology Co.,Ltd.
Add: Room 103,Building No.1,A District, 530 evelopment Zone,No.100, Jinxi Road,Binhu District,Wuxi
Tel:+86(0)510-85192198 E-mail: info@thinkpower.com.cn http://www.thinkpower.com.cn

Thinkpower

TECHNOLOGY PARAMETERS

Model No	T1500TL	T2200TL	T3000TL
DC side/Input parameters			
Max. DC power [W]	1800	2500	3400
Max. DC voltage [Vdc]	450	500	550
Min.System start/Operating voltage[Vdc]	75/100	75/100	75/100
MPPT voltage range[Vdc]	100~450	100~500	100~550
Max. input current [A]	10	13	15
Number of MPP trackers	1	1	1
Strings per MPP tracker	1	2	2
AC side/output parameters			
Nominal output power [W]	1500	2200	3000
Maximum output power [W]	1650	2420	3300
Nominal output voltage/range [V]	208,220,230,240/180~265	208,220,230,240/180~265	208,220,230,240/180~265
AC grid frequency/range [Hz]	50,60/±4.5 auto-selection	50,60/±4.5 auto-selection	50,60/±4.5 auto-selection
Maximum output current [A]	8	12	17
AC connection(with PE)	Single phase	Single phase	Single phase
Current distortion(THDi) [%]	<1.5	<1.5	<1.5
Power factor [%]	> 99.9	> 99.9	> 99.9
Efficiency			
Maximum conversion efficiency[%]	97.3	97.4	97.5
European efficiency[%]	97.0	97.1	97.2
MPPT efficiency[%]	99.9	99.9	99.9
Protection			
DC reverse-polarity protection	yes	yes	yes
Short circuit protection	yes	yes	yes
Ground fault/residential current monitoring	yes	yes	yes
Grid monitoring	yes	yes	yes
DC/AC side varistors(thermally protected)	yes	yes	yes
General Parameters			
Dimension(L/W/H)[mm]	375*480*136		
Weight（kg）	14.5	15	15.6
Embedded DC Switch	Optional		
Night Mode support	Optional		
Night power consumption[W]	< 0.2		
Isolation type	Transformerless		
Protection degree	IP65		
Operation temperature[ºC]	-25 ~ 60		
Heat Dissipation	Convection		
Acoustic noise level[dB]	<25		
Altitude[m]	<2000 without power derating		
Storage temperature[ºC]	-30 ~ 80		
Real Time Clock module	yes		
LCD Display	Graphic and digital segment		
Communication Interface	Standard Wifi		

Warranty: 5 year standard. 10/15/20 year extension options *More technical characteristics are available on demand and customized.

Technical Data	Sunny Island 4.4M[1]	Sunny Island 6.0H	Sunny Island 8.0H
Operation on the utility grid or generator			
Rated grid voltage / AC voltage range	230 V / 172.5 V to 264.5 V		
Rated grid frequency / permitted frequency range	50 Hz / 40 Hz to 70 Hz		
Maximum AC current for increased self-consumption (grid operation)	14.5 A	20 A	26 A
Maximum AC power for increased self-consumption (grid operation)	3.3 kVA	4.6 kVA	6 kVA
Maximum AC input current	50 A	50 A	50 A
Maximum AC input power	11500 W	11500 W	11500 W
Stand-alone or emergency power operation			
Rated grid voltage / AC voltage range	230 V / 202 V to 253 V		
Rated frequency / frequency range (adjustable)	50 Hz / 45 Hz to 65 Hz		
Rated power (at Unom, fnom / 25°C / cos φ = 1)	3300 W	4600 W	6000 W
AC power at 25°C for 30 min / 5 min / 3 sec	4400 W / 4600 W / 5500 W	6000 W / 6800 W / 11000 W	8000 W / 9100 W / 11000 W
AC power at 45°C continuously	3000 W	3700 W	5430 W
Rated current / maximum output current (peak)	14.5 A / 60 A	20 A / 120 A	26 A / 120 A
Total harmonic distortion output voltage / power factor at rated power	< 4% / −1 to +1	< 4% / −1 to +1	< 4% / −1 to +1
Battery DC input			
Rated input voltage / DC voltage range	48 V / 41 V to 63 V	48 V / 41 V to 63 V	48 V / 41 V to 63 V
Maximum battery charging current / rated DC charging current / DC discharging current	75 A / 63 A /75 A	110 A / 90 A / 103 A	140 A / 115 A /130 A
Battery type / battery capacity (range)	Li-Ion[2], FLA, VRLA / 100 Ah to 10000 Ah (lead-acid) 50 Ah to 10000 Ah (li-Ion)		
Charge control	IUoU charge procedure with automatic full charge and equalization charge		
Efficiency / self-consumption of the device			
Maximum efficiency	95.5%	95.8%	95.8%
No-load consumption / standby	18 W / 6.8 W	25.8 W / 6.5 W	25.8 W / 6.5 W
Protective devices (equipment)			
AC short-circuit / AC overload	● / ●		
DC reverse polarity protection / DC fuse	– / –		
Overtemperature / battery deep discharge	● / ●		
Overvoltage category as per IEC 60664-1	III		
General Data			
Dimensions (W / H / D)	467 mm / 612 mm / 242 mm (18.4 inches / 21.1 inches / 9.5 inches)		
Weight	44 kg (97 lbs)	63 kg (138.9 lbs)	63 kg (138.9 lbs)
Operating temperature range	−25°C to +60°C (−13°F to +14°F)		
Protection class in accordance with IEC 62103	I		
Climatic category as per IEC 60721	3K6		
Degree of protection according to IEC 60529	IP54		
Features/function			
WLAN, Speedwire / Webconnect / SI-SYSCAN (Multicluster)	● / ● / –	● / ● / ○	● / ● / ○
Micro SD memory card for extended data logging	○		
Display via smartphone, tablet, laptop / multifunction relay	● / 2		
Three-phase systems (including rotating magnetic field) / battery-backup function	● / ●		
State of charge calculation / full charge / equalization charge	● / ● / ●		
Battery temperature sensor / data cables	○ / ●		
Certificates and approvals	www.SMA-Solar.com		
Cover color yellow / aluminum white	○ / ○		
Warranty 5/10 years	● / ●[4]		
For off-grid applications			
Automatic rotating magnetic field detection / generator support	● / ●		
Parallel connection / Multicluster	● / ●		
Integrated soft start	●		
Accessory			
For off-grid applications			
Battery fuse[3]	○		
Sunny Island Charger SIC50-MPT[3] / SMA Cluster Controller	○ / ○		
For on-grid applications			
Sunny Home Manager / SMA Energy Meter / automatic transfer switch for battery backup[3]	○ / ○ / ○		
● Standard feature ○ Optional feature – Not available 1) Cannot be used in Multicluster systems 2) see "List of Approved Batteries" at www.SMA-Solar.com 3) Procurement via external supplier 4) When registering All specifications, last updated: April 2017			
Type designation	SI4.4M-12	SI6.0H-12	SI8.0H-12

Network Power > Classic Solar > Classic OPzS Solar > **Benefits**

GNB INDUSTRIAL POWER

Classic OPzS Solar

Energy storage for outstanding power applications

The Classic OPzS Solar range has been well proven for decades in medium and large power applications. Due to their robustness, long design life and high operational safety they are ideally suitable for use in solar and wind power stations, telecommunications, power distribution companies, railways and many other safety equipment power supplies. The wide range of available capacities and sizes provides a solution for every power need, even in harsh environments.

Your benefits:

> **Optimised design for renewable energy applications** – highest cycling ability and long life

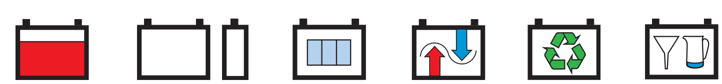
> **Special alloy and large electrolyte reserve** – very long topping up intervals

> **Low maintenance** – saving costs

> **Completely recyclable** – low CO_2 footprint

Specifications:

> Nominal capacity (C_{120} at 25 °C): 70.0 - 4600 Ah
> Very thick tubular positive plates for the most demanding applications
> Up to 2800 cycles at 60 % depth of discharge (C_{10}) with IU charging profile at 20 °C. For enhanced performance and for systems ≥ 48 V we recommend IUI charging to reach 3000 cycles and more.
> Designed in accordance with IEC 61427 and IEC 60896-11
> Screw connectors for a better contact and reliability
> Also available in dry-charged version with separate electrolyte
> High quality transparent or translucent containers for easy maintenance



Nominal capacity 70.0 – 4600 Ah | Block battery/ Single cell | Tubular plate | up to 3000*+ cycles at 60 % depth of discharge | Recyclable | Low maintenance

*Using IUI charging at 20 °C

Network Power > Classic Solar > Classic OPzS Solar > **Technical data**

GNB INDUSTRIAL POWER

Classic OPzS Solar

Technical data

Technical characteristics and data

Type	Part number	Nom. voltage V	Nominal capacity C_{120} 1.85 Vpc 25 °C Ah	Length (l) max. mm	Width (b/w) max. mm	Height* (h) max. mm	Installed length (L) max. mm	Weight incl. acid approx. kg	Weight acid** approx. kg	Internal resistance mOhm	Short circuit current A	Terminal	Pole pairs
OPzS Solar 190	NVSL020190WC0FA	2	190	105	208	395	115	13.7	5.20	1.45	1400	F-M8	1
OPzS Solar 245	NVSL020245WC0FA	2	245	105	208	395	115	15.2	5.00	1.05	1950	F-M8	1
OPzS Solar 305	NVSL020305WC0FA	2	305	105	208	395	115	16.6	4.60	0.83	2450	F-M8	1
OPzS Solar 380	NVSL020380WC0FA	2	380	126	208	395	136	20.0	5.80	0.72	2850	F-M8	1
OPzS Solar 450	NVSL020450WC0FA	2	450	147	208	395	157	23.3	6.90	0.63	3250	F-M8	1
OPzS Solar 550	NVSL020550WC0FA	2	550	126	208	511	136	26.7	8.10	0.63	3250	F-M8	1
OPzS Solar 660	NVSL020660WC0FA	2	660	147	208	511	157	31.0	9.30	0.56	3650	F-M8	1
OPzS Solar 765	NVSL020765WC0FA	2	765	168	208	511	178	35.4	10.8	0.50	4100	F-M8	1
OPzS Solar 985	NVSL020985WC0FA	2	985	147	208	686	157	43.9	13.0	0.47	4350	F-M8	1
OPzS Solar 1080	NVSL021080WC0FA	2	1080	147	208	686	157	47.2	12.8	0.43	4800	F-M8	1
OPzS Solar 1320	NVSL021320WC0FA	2	1320	212	193	686	222	59.9	17.1	0.30	6800	F-M8	2
OPzS Solar 1410	NVSL021410WC0FA	2	1410	212	193	686	222	63.4	16.8	0.27	7500	F-M8	2
OPzS Solar 1650	NVSL021650WC0FA	2	1650	212	235	686	222	73.2	21.7	0.26	7900	F-M8	2
OPzS Solar 1990	NVSL021990WC0FA	2	1990	212	277	686	222	86.4	26.1	0.23	8900	F-M8	2
OPzS Solar 2350	NVSL022350WC0FA	2	2350	212	277	836	222	108	33.7	0.24	8500	F-M8	2
OPzS Solar 2500	NVSL022500WC0FA	2	2500	212	277	836	222	114	32.7	0.22	9300	F-M8	2
OPzS Solar 3100	NVSL023100WC0FA	2	3100	215	400	812	225	151	50.0	0.16	12800	F-M8	3
OPzS Solar 3350	NVSL023350WC0FA	2	3350	215	400	812	225	158	48.0	0.14	14600	F-M8	3
OPzS Solar 3850	NVSL023850WC0FA	2	3850	215	490	812	225	184	60.0	0.12	17000	F-M8	4
OPzS Solar 4100	NVSL024100WC0FA	2	4100	215	490	812	225	191	58.0	0.11	17800	F-M8	4
OPzS Solar 4600	NVSL024600WC0FA	2	4600	215	580	812	225	217	71.0	0.11	18600	F-M8	4
OPzS Solar 280	NVSL060280WC0FB	6	294	272	206	347	282	41.0	13.0	2.68	2283	F-M8	1
OPzS Solar 350	NVSL060350WC0FB	6	364	380	206	347	392	56.0	20.0	2.39	2800	F-M8	1
OPzS Solar 420	NVSL060420WC0FB	6	417	380	206	347	392	63.0	20.0	1.96	3106	F-M8	1
OPzS Solar 70	NVSL120070WC0FB	12	82.7	272	206	347	282	35.0	15.0	18.1	688	F-M8	1
OPzS Solar 140	NVSL120140WC0FB	12	139	272	206	347	282	45.0	14.0	9.26	1314	F-M8	1
OPzS Solar 210	NVSL120210WC0FB	12	210	380	206	347	392	64.0	19.0	6.46	1884	F-M8	1

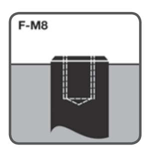
Type	C_6 1.75 Vpc	C_{10} 1.80 Vpc	C_{12} 1.80 Vpc	C_{24} 1.80 Vpc	C_{48} 1.80 Vpc	C_{72} 1.80 Vpc	C_{100} 1.85 Vpc	C_{120} 1.85 Vpc	C_{240} 1.85 Vpc
OPzS Solar 190	122	132	134	145	165	175	185	190	200
OPzS Solar 245	159	173	176	190	215	230	240	245	260
OPzS Solar 305	203	220	224	240	270	285	300	305	320
OPzS Solar 380	250	273	277	300	330	350	370	380	400
OPzS Solar 450	296	325	330	355	395	420	440	450	470
OPzS Solar 550	353	391	398	430	480	515	540	550	580
OPzS Solar 660	422	469	477	515	575	615	645	660	695
OPzS Solar 765	492	546	555	600	670	710	750	765	805
OPzS Solar 985	606	700	710	770	860	920	970	985	1035
OPzS Solar 1080	669	773	784	845	940	1000	1055	1080	1100
OPzS Solar 1320	820	937	950	1030	1150	1230	1295	1320	1385
OPzS Solar 1410	888	1009	1024	1105	1225	1305	1380	1410	1440
OPzS Solar 1650	1024	1174	1190	1290	1440	1540	1620	1650	1730
OPzS Solar 1990	1218	1411	1430	1550	1730	1850	1950	1990	2090
OPzS Solar 2350	1573	1751	1770	1910	2090	2200	2300	2350	2470
OPzS Solar 2500	1667	1854	1875	2015	2215	2335	2445	2500	2600
OPzS Solar 3100	2080	2318	2343	2520	2755	2910	3040	3100	3250
OPzS Solar 3350	2268	2524	2550	2740	2985	3135	3280	3350	3520
OPzS Solar 3850	2592	2884	2915	3135	3430	3615	3765	3850	4040
OPzS Solar 4100	2775	3090	3125	3355	3650	3840	4000	4100	4300
OPzS Solar 4600	3099	3451	3490	3765	4100	4300	4500	4600	4850
OPzS Solar 280	203	206	229	250	296	304	287	294	338
OPzS Solar 350	245	257	284	311	374	383	355	364	424
OPzS Solar 420	284	309	322	354	420	432	408	417	482
OPzS Solar 70	55.0	51.5	63.7	69.4	78.4	79.8	81.0	82.7	92.9
OPzS Solar 140	95.4	103	108	118	141	145	136	139	162
OPzS Solar 210	131	154	162	177	206	217	203	210	234

Capacities in Ah (C_6 – C_{240} at 25 °C)

* Includes installed connector, the above mentioned height can differ depending on the used vent(s).

** Acid density d_N = 1.24 kg/l

Terminal and torque



12 Nm for blocks;
20 Nm for cells

Data is also valid for dry charged version.
Change **»W«** (Wet) to **»D«** (Dry) in the part number.
E.g.:

> filled and charged: NVSL120070 **W** C0FB

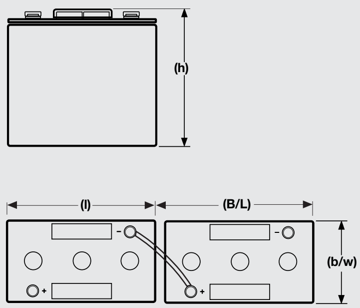
> dry charged: NVSL120070 **D** C0FB

Classic OPzS Solar

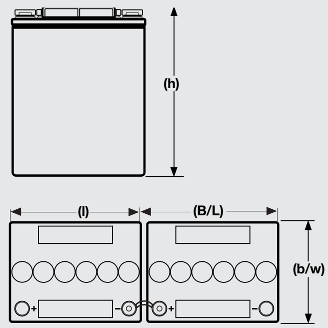
Drawings

Drawings with terminal position

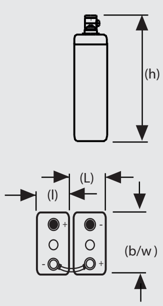
6 V Blocks



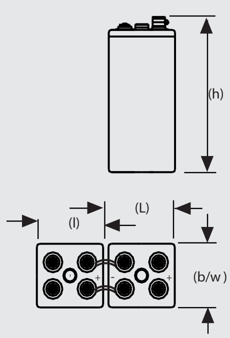
12 V Blocks



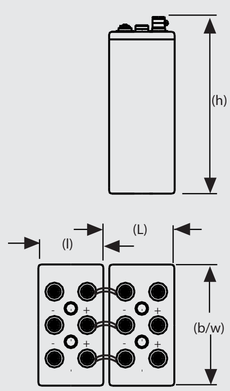
OPzS Solar 190 – OPzS Solar 1080



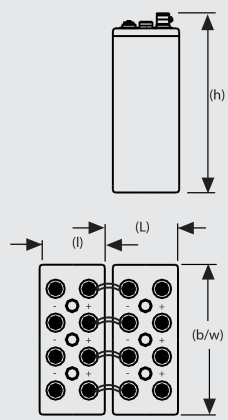
OPzS Solar 1320 – OPzS Solar 2500



OPzS Solar 3100 – OPzS Solar 3350



OPzS Solar 3850 – OPzS Solar 4600



Not to scale!