NTNU – Trondheim
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Science and Technology

Scaling an Optimized PV-cluster as part of a Microgrid in Wawashang, Nicaragua

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Problem Description

The so-called FADCANIC project is a collaboration between NTNU, Engineers Without Borders Norway, and the Nicaraguan organization FADCANIC. Two students are involved with the project, where identifying possibilities for establishing an independent, reliable and sustainable energy supply to the Wawashang Agroforestal Complex in Nicaragua, is the main scope. The main focus in this project will be to emphasize cultural, social, economical, environmental and technical aspects of the surroundings to make the project sustainable.

As the project is divided between two students, this master-thesis will only investigate the possibilities of exploitation of solar power to provide an optimal electricity supply system regarding economic, technical, cultural, social and environmental aspects for future expansions of the complex.

The intention is that the students do a fieldwork at the complex in Wawashang for a few weeks during the spring 2013, in order to maximize the outcome of the project.

Assignment given: Trondheim, 21.01.2013
Supervisor: Professor Dr. Ing. Marta Maria Cabrera Molinas
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Summary

The rural FADCANIC complex in Wawashang close to the east cost of Nicaragua, is one of the few rural areas in the east that to a certain degree have been electrified. The Wawashang complex is a boarding school with a large plantation and a carpentry shop, educating and giving children and young adults work experience. The complex has limited access to electricity, as the electrical system consisting of decentralized Photovoltaic (PV) panels and diesel generators, is partly defect, inefficient and needs to be re-scaled as the complex will expand and there will be insufficient supply in the future. In this thesis, an investigation around the possibility of installing a large photovoltaic array as a part of a micro-grid for sufficient supply in the future, has been made. It has by the help of the two energy modelling software simulation tools PVsyst and HOMER, been studied whether a photovoltaic system with or without a backup diesel generator combined with the PV-cluster is a feasible, optimal, sustainable and reliable configuration of the system. The term optimality embeds economical, technical, environmental, social and cultural aspects. The main focus will be technical and economical optimality as well as accessibility of equipment has been an important restriction. The closest grid connection is in a village called Kakabila, which is approximately 65 km distant from the Wawashang complex and connection to the grid as an alternative to a microgrid ha been investigated.

It was found that by performing simulations with the two software tools, approximately the same system design was found and by applying PVsyst`s information of technical optimality and HOMER`s results on economical optimality, an optimal design could be identified. By combining the results it was found that even if the reliability of a system with backup would be higher, the optimal system with no backup is stated to be the best fit for the Wawashang complex. This because the design is a result of load profiles for 2023 being applied to the simulations and the hope is to within a couple of years study the biomass potential of the area further for considering integration with the microgrid. The fact that no backup-generator would have to be used, would lead to yearly-avoided emissions of 3777 kg CO_2. The optimal system consists of a 124 kWp PV-cluster consisting of 576 Kyocera PV-modules of 215 Watts and a battery-pack containing 480 Trojan 6V batteries with 420 Ah capacity as well as a 50 kW inverter. The systems has a yearly supply to the user of 136 600 kWh resulting in a yearly shortage of 8000 kWh amounting to 5.5%. The net present cost of the system is according to HOMER 770 101US$. Alternative cost related to connecting to the national grid has been found to be 1 949 928 US$ and underlines the optimality of the suggested system.

This particular thesis has been a collaboration between the Norwegian University of Science and Technology, Engineers Without Borders Norway and the Nicaraguan organization FADCANIC. The work with the thesis has been rather unconventional, pioneering and very dynamical, as a large part of the work with the thesis has been data collection during a 4-week fieldtrip.

Sammendrag

Det avsidesliggende FADCANIC komplekset i Wawashang på østkysten av Nicaragua, er en av de få "landsbyene" i området som til en hvis grad er elektrifisert. Komplekset er en kostskole med en stor plantasje og et omfattende snekkerverksted hvor barn og unge voksne kan få en utdannelse og jobberfaring. Wawashang har begrenset tilgang på elektrisitet i og med at systemet bestående av desentraliserte fotovoltaiske paneler og diesel generatorer delvis er defekte og behøver å bli skalert på nytt. Grunnen til det er planlagt utvidelse av fasilitetene i komplekset, noe som vil føre til utilstrekkelig energiforsyning i fremtiden. Denne masteravhandlingen vil dreie seg om undersøkelser rundt mulighetene for utbyggingen av et stort felt med fotovoltaiske moduler som en del at et microgrid for sikker tilgang på elektrisitet i framtiden. Ved hjelp av de to energi modellerings verktøyene PVsyst og HOMER , har det blitt studert om et fotovoltaik system med eller uten et backup-system med diesel generator, er en gjennomførbar, optimal, bærekraftig og pålitelig konfigurasjon av systemet. Begrepet optimalitet innebærer i dette tilfellet å ta hensyn til økonomiske, tekniske, miljømessige, sosiale og kulturelle aspekter. Hovedfokuset vil være på teknisk og økonomisk optimalitet, samtidig som tilgjengelighet av utstyr har vært en viktig restriksjon. Det nærmeste tilkoblingspunktet til det nasjonale nettet er i en landsby ved navn Kakabila, som er omrent 65 km unna Wawashang og undersøkelser rundt tilkobling til dette, har blitt undersøkt som et alternativ til microgridet.

Det viste seg ved å utføre simuleringer med de to simulerings verktøyene, at begge viste omtrent det samme systemdesignet, og ved å bruke PVsysts informasjon angående teknisk optimalitet og HOMERs resultater når det gjaldt økonomisk optimalitet, kunne et optimalt design identifiseres. Ved å kombinere resultatene, ble det konkludert med at selv om påliteligheten til et system med backup vil være høyere, vil det mest passende systemet for Wawashang være et design uten backup. Dette som et resultat av at last profiler for 2023 har blitt brukt til designet og et håp om at innen et par år vil studiene rundt biomassepotensialet i området lede til at biomasse som energi kilde kan implementeres i microgridet. Det faktum at ingen backup generator vil bli brukt, vil lede til årlig unngåtte utslipp på 3777 kg CO_2. Det optimale systemet består av en 124 kWp PV-klynge bestående av 576 Kyocera PV-moduler med 215 Watt hver og energilagrings fasiliteter bestående av 480 Trojan 6V batterier hver med 420 Ah kapasitet og en 50 kW inverter. Systemet vil årlig levere 136 000 kWh og ha en knapphet på 8000 kWh, tilsvarende 5.5%. Nåverdien av kostnader vil ifølge HOMER, komme på 770 101 US$. Alternative kostnader knyttet til påkobling av nasjonalt nett vil medføre kostnader på 1 764 162 US$, noe som understreker optimaliteten av det foreslåtte systemet.

Denne masterberetningen har vært et samarbeid mellom Norges Tekniske Naturvitenskapelige Universitet, Ingeniører uten grenser Norge og den nicaraguanske organisasjonen FADCANIC. Arbeidet med denne oppgaven har vært temmelig ukonvensjonelt, banebrytende og dynamisk i og med at en stor del av arbeidet har vært knyttet til innsamling av data under den 4 uker lange feltturen.

Preface

This thesis summarizes work done on my Master of Science degree at NTNU the spring of 2013. It is in many ways a continuation of my specialization project *"Scaling a stand-alone PV system as part of a hybrid system in Wawashang, Nicaragua"* and the unique possibility and development through first scaling a system based on assumptions to then go on a field trip for collecting data and then implementing the real data into the simulation tools, has been an amazing journey. Meeting new people, establishing contacts and friendships as well as being able to understand new cultures, has been an amazing possibility of which I am very grateful.

I would first of all like to thank my supervisor Professor Dr. Ing. Marta Molinas, for her time, invaluable advices, involvement and enthusiasm regarding the project. I would also like to express my gratitude to Marco Boninella, my fellow student and friend who was involved with an other part of the project, for his everlasting good mood, laughter and positivity. Gilles Charlier from BlueEnergy is also a person deserving my deepest gratitude for his help during our field trip as a translator, advisor and for the great effort he made by helping us to install the electricity meters. I hope your herb garden did not suffer too severely due to your absence. Henry Myers and Susan Thienhaus also deserve our sincere thanks for their warm welcoming and outstanding willingness to help and assist us during our stay in Wawashang. I would also like to thank Inger Johanne Rasmussen for being a great organizer and IUG for their economical support regarding the fieldtrip.

My friends deserve a heartfelt thanks for their support, laughter and good times through these 5 years towards completing my degree. My mother, father and sister probably deserve the biggest thanks for the love, motivation and support they have given me through the ups and downs during my time as a student. Last but not least I want to thank the love of my life, Marko Kafadaroglu, for being there for me and for accepting my absence during all the hours of work.

Linn Solheim
Trondheim, 30.05.2012

Innholdsfortegnelse

Acronyms, Abbreviations and Nomenclature

AC	Alternating current
Ah	Ampere Hour
DC	Direct Current
FADCANIC	Fundacion para la Autonomia y el Desarrollo de la Costa Atlantica de Nicaragua
HDI	Human Development Index
IUG	Ingeniører Uten Grenser
kWp	Kilo Watt Peak
MPPT	Maximum Power Point Tracker
NASA	National Aeronautics and Space Administration
PV	Photovoltaic
PR	Performance Ratio
Vp	Volt Peak
Wh	Watt hour
β_{opt}	Optimum tilt angle (°)

List of Figures

List of Graphs

List of Tables

Introduction

In times where industrialized nations are struggling dealing with issues like greenhouse effect, CO_2 emissions and trying to turn from a self destructive path to a sustainable development, developing countries have the chance to start off on the right track all from the beginning when it comes to energy supply. By aiding developing countries with electrification in a sustainable manner and sharing knowledge, a healthy trend may appear where these countries can develop in an environmentally sustainable way. However introducing renewable energy technologies to developing countries is not only an advantage regarding the environment, but in many cases also a necessity. In rural parts of the world, where there is little or no access to the national grid, taking advantage of natural resources may be the only reasonable way of electrification.

The Wawashang complex, which mainly is a boarding school built by the organization FADCANIC, is situated on the east coast of Nicaragua. It is one of the few electrified areas in the less developed part of the country in RAAS, the autonomous regions of the Atlantic coast in the southeast. Poor infrastructure, lack of clean water and poor access to electricity, are factors common for this part of the country. However, with the support of the organization FADCANIC, the rural complex Wawashang is to a certain degree electrified by the use of diesel generators and a number of decentralized PV-modules on the roofs of the buildings, yet not all of them functioning. With the involvement of Engineers Without Borders Norway and NTNU, there is an opportunity to expand and optimize the current system for the comfort and convenience of the villagers as well as for extending the capacity of the complex. The goal is to scale a brand new system for the village based on the power demand in 2023, mainly using renewable energies. Initially Photovoltaic and mini-hydro were the energy sources in mind, however the task has proved to be very dynamical and as this solution proved to be unfeasible, a system solely consisting of a large photovoltaic array, was to be the main source of energy distributed by a microgrid. There is also a possibility to use the diesel-generators already present in the complex as a backup system and it has been studied whether to include it or not in a hybrid system is the optimal system configuration. An alternative electrification possibility, which is expansion of the national grid to Wawashang, has also been investigated.

To detect the optimal design of the system and whether to include a diesel generator in a hybrid supply system, the two software tools HOMER and PVsyst have been applied to the problem. HOMER is a simulation tool for hybrid systems where various energy sources can be modelled. HOMER not only suggests an optimal configuration of the system regarding net present cost, it also provides an approximate price tag on the suggested design. PVsyst solely determines the technically optimal solution and is a tool solely scaling PV systems. This thesis will not only embrace aspects regarding the sizing of an optimal PV supply system and whether to include a diesel generator regarding economical, technical and feasibility aspects. It will also enlighten aspects like costs, social impact and environmental impact of the implementation of such a system. A comparison between the suggested design of the systems by HOMER and PVsyst will also be performed. However the sizing of an optimal PV-system and the determination of whether a hybrid system is advantageous or not, will be the main scope of this thesis. The likelihood of implementation of the system in reality will not be discussed in this thesis as other students in the future will work on other approaches and solutions to the problem, before the final suggestion is to be evaluated by FADCANIC and Engineers Without Borders Norway and financing has to be provided.

It should be noted that retrieving information was a significant part of the scope of this thesis. Because even if scaling an optimal PV system was the goal, this was not possible without proper data for implementing into the software. As the necessary data was not obtainable, a 4-week fieldtrip to Wawashang was organized and partly financed by Engineers Without Borders Norway. A fellow student, Marco Boninella, who was focusing on detecting the mini-hydro potential in the area, also participated in the fieldtrip. The main goal of the trip was to identify a 24h load profile for the whole complex, inspect the current system and to get a better impression of how the new system should appear. Due to the fact that a lot of information was gathered during the fieldtrip and through conversations and correspondence with the contact persons, the sources are somewhat controversial and unusual. However, the thesis in general is rather special since it is a pioneering project, as the frame, conditions and scope of this thesis has changed dramatically compared to what was anticipated before the fieldtrip to Wawashang for collecting data.

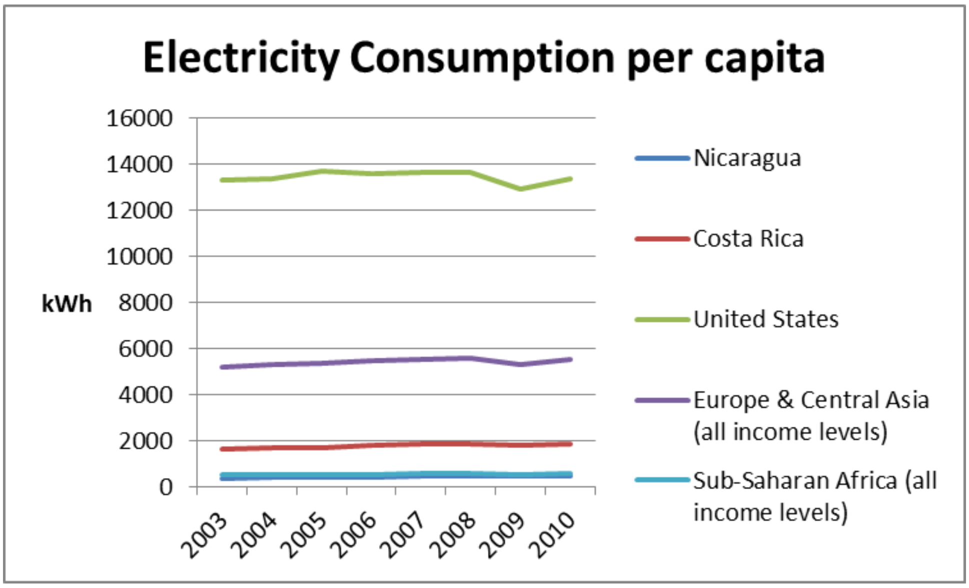
This thesis has the same problem base as the specialization project *"Scaling a stand-alone PV system as part of a hybrid system in Wawashang, Nicaragua"* written by the author, however the approach and conditions are different as well as proper data has been accessed and implemented in the simulation tools and the software HOMER has been applied to the problem.

1 Background

Nicaragua is the largest country in Central America and has a tropical climate with diverse regional differences, like the warm and moist low situated areas in the east where the summers here are especially wet. The HDI, human development factor of the country is 0,565 [1], which is below the average of 0,682 [1], placing Nicaragua number 115 on the ranking list in the world. The east side of the country where the area in question is located has a lower development and lower population density than the rest of the country. The poor infrastructure and electrification in the area are important reasons for this. Other characterizing factors of Nicaragua as a whole, is the high infant mortality, low access to pure water, poverty and underemployment. However the education level is better than in most developing countries, there is a relatively high life expectancy and the export activity in the country is increasing. However, ignorance and low understanding of pollution and garbage burning and dumping, are severe problems regarding pollution of drinking water and air. This will be further discussed in chapter 11.

1.1 Electricity Situation Nicaragua

According to the world data bank 72% of the population of Nicaragua had in 2009 access to electricity. However the study does not say anything about the amount, price, quality or reliability of this electricity, so the numbers are likely to be much lower if the definition of access to electricity would require a certain standard. Below one can see an overview over the electricity consumption per capita for Nicaragua compared with the consumption of the United States, Costa Rica, Europe, Africa and Central Asia.



Graph 1 Electricity consumption per capita [2]

As one can see, the electricity consumption per capita in Nicaragua is surprisingly far below their Central American neighbour, Costa Rica. This may possibly confirm the suspicion of low energy reliability and quality, as the 72 % with access to electricity must have an extremely low usage if the total consumption is as low as implied in graph 1. The poor consumption is probably not made by choice, but is a result of overpricing, low reliability and quality. It is a common problem that people unable to pay for electricity secretly attach to the public grid, consuming energy that is not being paid for. This creates fall-outs and an unreliable grid where the most active hours of the day might be "black" in large areas of cities.

The 28% of the population without access to the grid is mostly rural areas where large areas have no access at all to any grid and their society is characterized by physical hard work and a low level of education as all villagers must participate in keeping the wheels turning in their society and family. The Wawashang complex is an exception as it is already to a certain degree electrified, however experimenting with sizing photovoltaic projects there, might at a later point of time open doors for applying knowledge from Wawashang to other areas in need of electrification. Below one can see an overview over the level of electrification and the access the inhabitants in the different part of Nicaragua have to electricity.

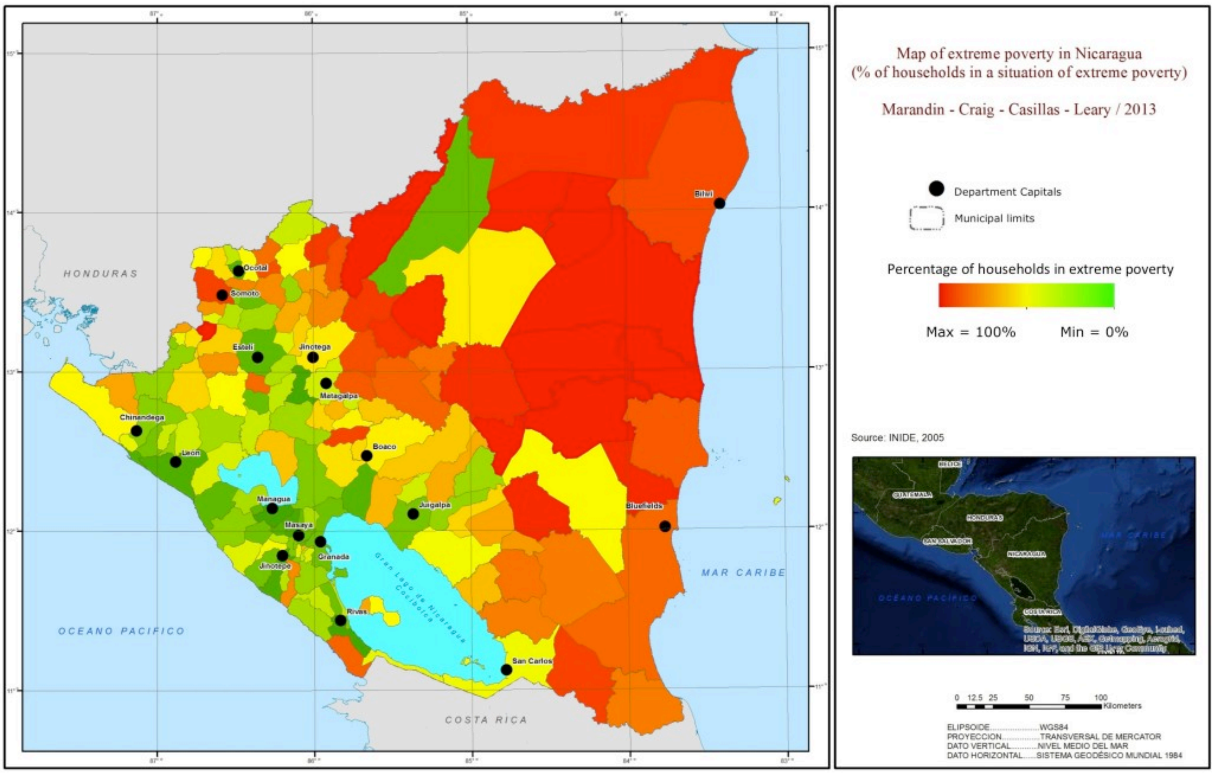


Figure 1 Overview over access to electricity in Nicaragua [3]

The natural alternative to the investigated system in Wawashang, would be to attach to the national grid. However, looking at the map over national grid connections in Nicaragua in figure 2, one can see that the distances are relatively large. The approximate distance from Kakabila where the closest grid attachment is located, to Wawashang is according to Google Maps close to 57 km. However this distance is a straight-line measurement as there is no infrastructure, and the extension of the grid will practically be longer as the terrain is not flat and the grid will not follow a straight line. It is impossible to give an exact distance, however an estimation of 65km has been determined for this thesis. An expansion of the grid of well over 65 km could be very costly, and the low and spread population and lack of infrastructure in the east autonomous regions are strong arguments that a grid expansion will not be the best solution. The cost regarding a grid extension will be further investigated in chapter 10.

Figure 2 Current grid connections in the area [4]

1.2 Resources Nicaragua

Nicaragua has a nature rich on resources like arable land, fresh water, fisheries, gold, timber and last but not least renewable energy potential like wind, hydro, and geothermal. However the lack of finances to exploit such resources for electrification, are the reason for the inactivity within those fields in the country. Solar power is a resource that could provide Nicaragua and especially rural areas of Nicaragua with electricity and would be an excellent opportunity for exploiting their natural resources.

1.2.1 Solar Resource

In the overview on the below, one can get an approximate idea of the irradiation magnitude in Nicaragua. The intensity of the irradiation is strongly varying regarding the location of the country. It is clear that the highest irradiation intensity is reached in the western part of the country with between 5 and 6.5 kWh/ m^2/day. In the eastern part of the country the irradiation is lower, and between 4.5 and 5 kWh/ m^2/day can be expected. Even if the irradiation in the east is lower than in the west, the potential is more than sufficient for being exploited. According to the European Solar Radiation Atlas, the average daily irradiation in Europe is about 2.16kWh/m^2/day, implying a quite decent irradiation for the area in question. In chapter 2.3 more detailed irradiation data for Wawashang will be presented.

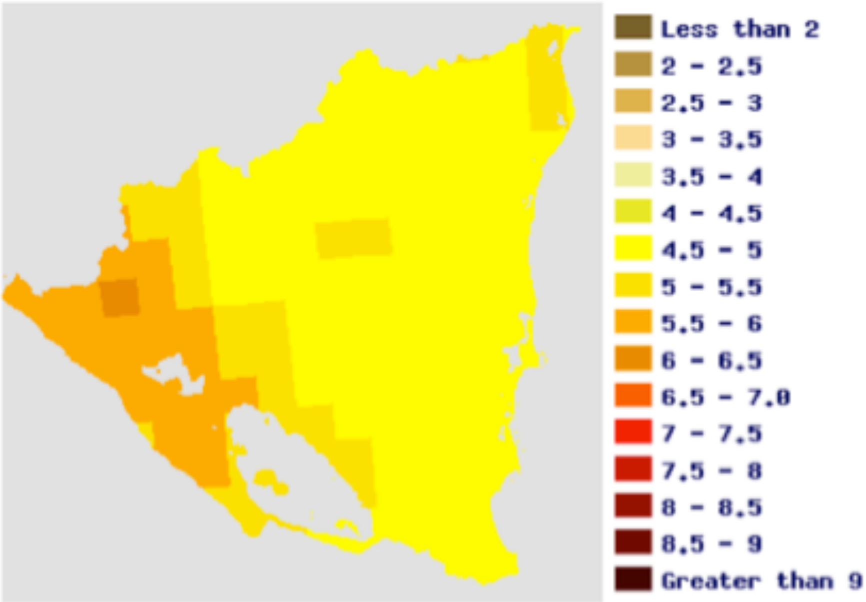


Figure 3 Solar resource in Nicaragua in kWh/m^2/day [5]

1.3 Relations and Cooperation

For being able to fully understand all aspects of this thesis it is essential to understand the connections, relationships and cooperation between the different instances and NTNU. In this subchapter a brief description of all the instances is provided.

1.3.1 FADCANIC

FADCANIC is a Nicaraguan organization established in 1987 with a mission to nurture, strengthen and develop the process of Autonomy of the Atlantic Coast of Nicaragua from civil society through the qualitative transformation of social, economic, cultural and political relations that benefit the indigenous and ethnic communities of the region. [6]

One of FADCANICs greatest achievements and commitment is the Centre for Agroforestry Development Wawashang. The centre is as the author sees it, divided into three parts; The School of Environment and Agroforestry, the agroforestry centre and the natural preserve in Kahka Creek. The School and the agroforestry centre is situated at the same location and are closely linked together as some of the students by practical work are getting parts of their education at the plantations of the agroforestry centre. Kahka Creek is not a part of the Wawashang complex and is situated close to the nearest village, Pueblo Nuevo on the other side of Wawashang river, and is the home of a hyper diverse rainforest with several thousand species of plants and animals. It is a natural reserve owned by the FADCANIC organization and is kept for preservation of the rainforest and for research. The accommodation facilities there are in the future meant to be used for ecotourism and conferences.

The Wawashang complex is in many ways extremely important for the autonomous regions of Nicaragua. Not only do they provide education and working skills for young people, keeping them away from criminality, they also perform very important research on high quality seeds and maximization and adaption of crops due to climate changes in the Agroforestry centre.

Before arrival in Wawashang Henry Myers was the main contact in FADCANIC, however during the fieldtrip in Wawashang Susan Myers became a very important contact person as her invaluable experience, insight and willingness to help was outstanding.

1.3.2 BlueEnergy

Blue Energy is a non profit organization established in 2003, working with providing clean water and energy for the less wealthy part of the population with ongoing projects in France, Nicaragua and USA. On the Caribbean Coast of Nicaragua, BlueEnergy are mainly working on connecting communities to water and energy as well as public education and promotion of sanitation, hygiene and energy efficiency. [7]

Establishing a connection with the BlueEnergy crew, was originally not a part of the mission for the fieldtrip, however as there was some time left in Bluefields before departing to Wawashang, a suggestion was made that a meeting should be organized. The meeting turned out to be a success and all parts were surprised about the close to common goals and interests between the two parts, when it came it the Wawashang complex. Blue Energy had actually made a preliminary suggestion of a microgrid in Wawashang a couple of years back in time, however with a different combination of energy sources. There were an agreement of sharing all information in the future and great number of reports were presented as well as the load profiles and the data collected during the field trip was to be shared as a favour in return.

This contact is not only going to be important for the work being done currently, but will however also be extremely important for the continuing work when new students are getting involved with the project.

1.3.3 Engineers Without Borders Norway

Engineers Without Borders (EWB) is an organization with focus on engineering as a contributor to development work and to channel technological competence and find solutions for aiding developing countries. EWB Norway was established in 2011 and operates independently of the worldwide the organisation that first saw the light of day in 1982. [8]

This report is the first product of the collaboration between Engineers Without Borders on-going project with NTNU and the starting point of a concept called meaningful masters. Engineers Without Borders has helped with the financing of the fieldtrip as well as with establishing the contact with FADCANIC and is in many ways the core of this project.

2 The Wawashang Complex

The Wawashang complex consists of the Plantation, the boarding school and a carpentry. In total in the private boarding school there are 120 students of various age from 1st to 3rd year. In addition to the students there are on a general basis 10 professors, 5 persons from the technical staff, 5 full time employed carpenters and capacity for 20 visitors staying overnight. So the maximal numbers of accommodated persons in the complex is 136. [9] For over 8 years there has been a continuous improvement and expansion of the complex, something which is an important reason for the desired expansion of the electrical system. In 2023 it is expected that the maximum accommodation in the complex will be for 328 people. [9] In the coming sub-chapters, the function of these areas in the Wawashang complex as well as Kahka Creek, will be presented more detailed. Below a simple map over the area is displayed, however a more detailed map and legend will be provided in coming chapters, the map below is only for getting an idea of the area in question.

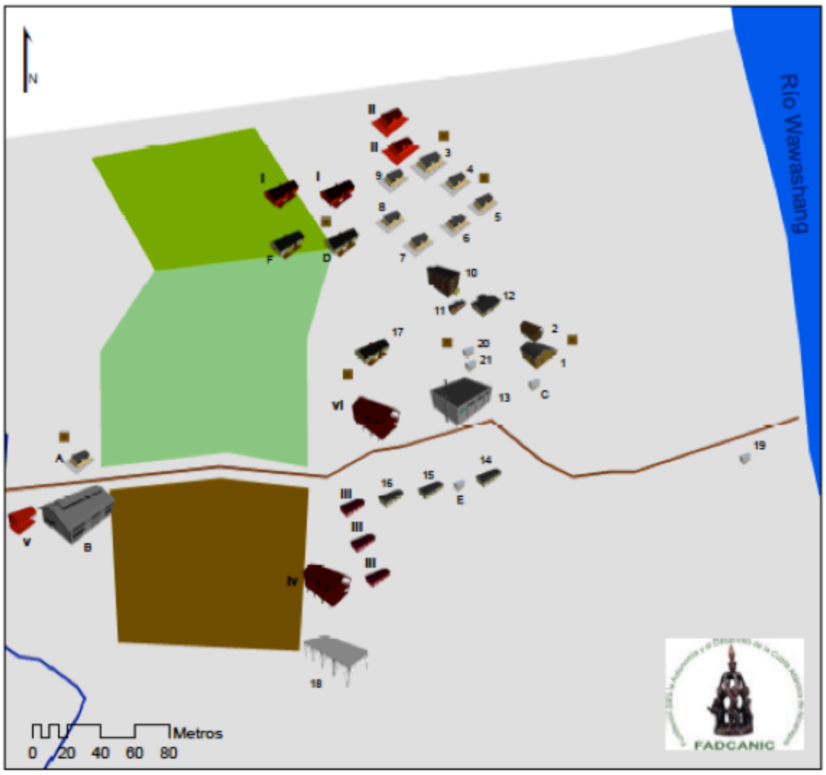


Figure 4 Simple map over the Wawashang area [10]

2.1 The Boarding School

The school is closely connected to the agricultural research centre and the carpentry, as the students can get specialization within either agricultural and environmental skills or carpentry proficiency. Education that provides practical experience is valued highly and the best basis for getting a regular income in an area where most people are living-hand-to-mouth. That is why 80% of the education is practical projects and participation and 20% is classroom education. Every morning from 6am to 7.30am the students have specific chores to perform before the school starts at 8am and lasts until 4pm. In addition to the education for the boarding school students, the school offers adult education every Wednesday, as very few of the adults in the area has completed any education. As it is a private school the curriculum can be decided freely. The focus being put on environment and sustainable resource management is very important regarding that the lack of knowledge in those areas are creating severe damages to both water, forest and air.

The reason for the increased power demand in the school facilities, is the increasing number of students, professors and visitors they will be able to receive in the future. By 2032, 328 people, which is almost be a 2.5 doubling of the capacity of the complex is expected. This number includes 234 students, 21 professors, 5 carpenters, 8 technical staff and capacity for 60 visitors. [9]

2.2 The Carpentry

The Carpentry shop is relatively new in the complex and it has been in operation for about 2.5 years. Production of furniture to this and other FADCANIC pjojects is the main activity, however the last years furniture are also being commercially sold and the current demand is too high to be served by the current facilities. Due to this prohibitively high demand, the working days in the carpentry are long. Currently there are 8-10 hours of activity in the carpentry, however it was told that 12-hour working days are not uncommon in the most busy periods of the year. A lot of the wood being used in the carpentry is wood from fallen trees in hurricanes and they are being conscious about the issue of deforestation.

The carpentry is currently equipped with two gasoline generators of 10 and 24kW for electricity supply, however these are causing an unwanted dependency of fossil fuels, as well as when only using machines with low loads, the energy efficiency is very low. That combined with rising diesel prices, is the reason why they wish to convert to renewable energy sources also for the carpentry's electricity supply. Currently the equipment has to be used in groups as all of the equipment cannot be used at once. This because some of the machinery is extremely power demanding. The equipment in the carpentry will be further explained in coming chapters.

2.3 The Agricultural Center

The agricultural centre in the Wawashang complex is composed with 260 hectares of an assortment of fruit trees and agricultural crops. Research regarding conservation and multiplication of the genetic diversity of appropriate plants and crops for various producers in the area, is the main focus and intention of the agricultural facilities. However the facilities are also a source of income as seeds and plants have are being sold at high prices. Six full time employees as well as 50 part time workers, are connected to the work being done at the plantation and agricultural centre. There is also a small farm connected to the agricultural centre, which currently houses 27 pigs and 180 African goats. This farm is currently not electrified, but will be taken into account regarding the new supply system and will be connected to the microgrid. The irrigation of the crops are currently being provided by gasoline driven pumps, however a part of electricity from the hybrid system will be assigned to pump power. The irrigation system and electrical pumps needed for irrigation will not be discussed nor mentioned further in this thesis, however the power demand will be taken into account in the future demand.

2.4 The Kakha Creek Forest Reserve

Kahka Creek is a forest reserve of over 600 Ha which is managed by the FADCANIC organization. There is a main building with accommodation for 10-15 persons as well as a classroom and a small carpentry. Currently it does not seem like there is much activity in the classrooms and carpentry, however the main building is frequently visited both by the FADCANIC staff as well as visitors from all over the world who come to see the and discover the rainforest. The facilities are also intended to be an educational opportunity for local children and for them to learn about the value of the natural resources and their preservation. An other function of the forest reserve facilities is to explore and protect the wide variety of animals and plants. There are 4 full time employed workers who take care of the facilities and welcome the visitors. BlueEnergy installed the microgrid consisting of solar panels, a battery pack and a diesel generator, which is supplying Kahka Creek with electricity, approximately two years ago. As the system is quite sophisticated and neat and the total energy potential is not fully exploited, finding a way to optimize this system seemed hard. That is why a decision was made together with the contact person in FADCANIC that the electricity supply system in Kahka Creek should remain as it is and not be improved as initially intended.

2.5 Resources in the Wawashang Complex

In the Wawashang complex not only solar power and hydropower are obvious sources of energy, there are also possibilities of using other renewable energy sources. Using biomass for generation of power is probably the most appropriate and relevant energy source that have not been exploited and properly explored until now. Below the potential and opportunities of the various energy sources in the Wawashang area will be presented, however the potential of hydropower and biomass will not be further discussed in this thesis.

2.5.1 Biomass

The complex contains various potential sources of biomass. The carpentry produces a large amount of by-products and waste, like sawdust and waste wood. From the plantation there are large amounts of coconut husks and bagasse that are left to rot which could be a great source of energy. Below an overview with the potential of all organic solid waste is displayed. Waste wood and sawdust are presented on a monthly basis and coconut husks and bagasse are presented on a daily basis. The daily data are provided by BlueEnergy in a project proposal for National Geographic. [11] Monthly data are provided by Marco Boninella from his thesis" Hybrid off grid energy system for the Wawashang area, east Nicaragua" . [12]

Debris	**Kg/month**	**MJ/month**	**kWh termal/month**
Waste wood	334	85682	23949.5
Sawdust	4284	16779	4698.1
TOTAL			**28647.6**
	Kg/day	**MJ/day**	**kWh termal/day**
Coconut husks	13.2	220.4	61.7
Bagasse	55	462	129.36
TOTAL			**191.1**

Table 1 Biomass potential in Wawashang [11] [12]

As one can see, there is a significant potential for using biomass as an energy source if used in a boiler or steam engine. To include biomass as a power source in the microgrid planned for the PV cluster was an idea that came up during the fieldtrip, however regarding the timeframe in question, there was simply not enough knowledge nor capacity to look into this opportunity at this point. However when it comes to the continuation of the work with the Wawashang complex, it is highly recommended to look into this opportunity, especially as the hydro potential is expected to be very much lower than expected and as it is expected that other renewable energy sources are needed for a completely reliable sustainable energy production in the complex in the future.

2.5.2 Hydropower

According to Marco Boninella`s specialization project *"Feasibility of micro hydro power in the Wawashang area, east Nicaragua"*, it was expected that the Wawashang area had a significant potential of hydropower. However during the fieldtrip to Wawashang, it was stated that the potential was much lower than expected as the head of the river was changing over a much longer area than expected, giving a very low head. The measurements performed during the fieldtrip were only informative regarding the dry season, however calculations are insinuating that there is a very small potential in general. The measurements will be continued and recorded during a whole year and the data can be used by other students continuing the project, as well as the locals. However regarding this thesis, the amount of data is simply too small and the expected power of hydro potential is too low to consider implementing in the microgrid. Depending on configuration and season of energy production, the power production is not expected to exceed 1-3 kW. [12]

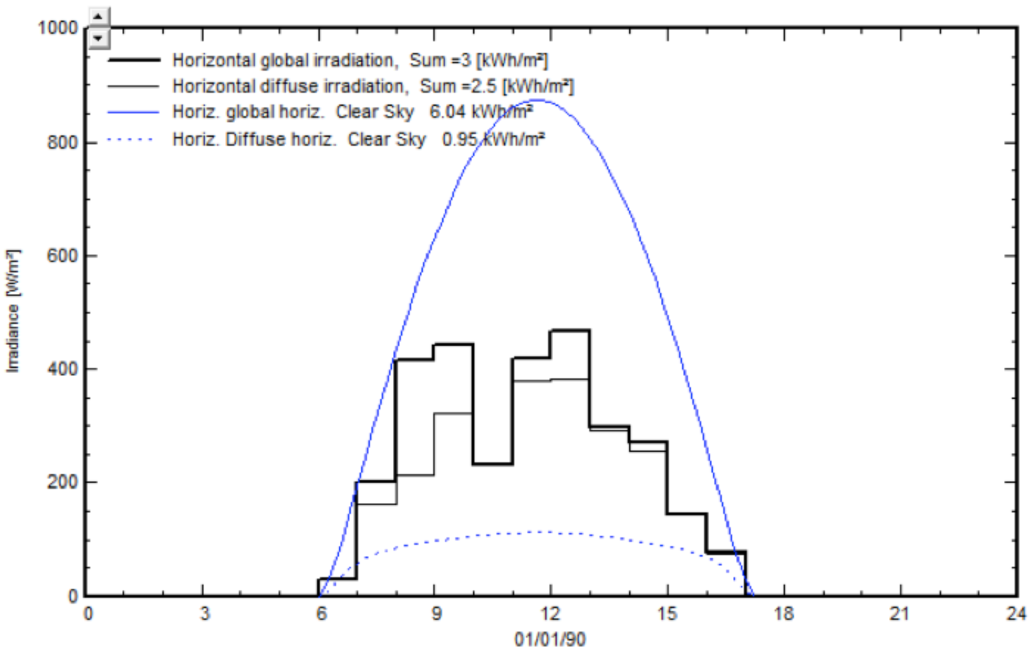
2.5.3 Solar Power

The solar power potential, which is the base of this thesis, is significant. The current supply system is mainly based on solar power and this seems like a good solution except from the very low power of the installed panels, poor distribution possibilities and imperfect installation conditions. Weather and irradiation data was provided through one of the simulation tools, PVsyst. PVsyst offered a few opportunities for the import of data regarding expected irradiation. By implementing accurate coordinates of Wawashang, data from the Meteonorm database could be obtained and estimations by interpolation to the closest weather station made monthly averages for Wawashang available. According to Google earth, the longitude and latitude for Wawashang were 12.65 and -83.75. An other option to retrieve meteorological data, was to use data from NASA and in a similar manner to Meteonorm obtain the irradiation and temperature data in Wawashang. Synthetic hourly data could be produced by using the NASA database and as the hourly data from the Meteonorm software weren't available for Wawashang for reasons unknown, using the NASA data was the best option for an accurate simulation base.

On the next page in Table 2, the averaged global temperature and irradiation in kWh/m^2 per month is displayed. Graph 2 shows the irradiation and temperature fluctuations during a 24h period. One can detect a sunrise at 6am and a sunset at 5pm. It is of high importance to understand that the data in the overviews below only are an estimation of the irradiation and temperature. Meteorological data are impossible to foresee and cannot be predicted other then getting an approximation by looking at historical data. The numbers in Table 2 and Graph 2 are not guaranteed and could be higher or lower than stated. Therefore a sensitivity analysis has been performed in HOMER to detect the values of which the system becomes suboptimal. The result of the sensitivity analysis will be presented in chapter 15.

	Global Irrad. kWh/m².mth	Diffuse kWh/m².mth	Temper. °C	Wind Vel. m/s
January	133.0		24.8	
February	143.8		25.1	
March	169.6		25.8	
April	174.3		26.7	
May	156.9		26.6	
June	121.2		26.4	
July	115.0		26.2	
August	124.6		26.3	
September	131.4		26.2	
October	128.7		26.0	
November	118.5		25.7	
December	121.8		25.2	
Year	**1638.8**		**25.9**	

Table 2 Irradiation and temperature data, Wawashang [13]



Graph 2 Hourly Irradiation data, Wawashang [13]

3 Dynamisms of the Thesis

It is important that the reader understands the fact that the scope in this thesis has dramatically changed during the work with it. The reason for this is that a fieldtrip collecting data has greatly changed the foundation of which the thesis was based. A graph showing the complementation between the irradiation and precipitation was the starting point of the idea of a hybrid electrical supply system consisting of hydropower and solar power in a microgrid. However, due to discoveries during the fieldtrip, the concept had to be abandoned. In the coming subchapters the change of the information and thereby the scope of thesis is stated before and after the discoveries during the fieldtrip.

3.1 Prior to the Fieldtrip to Wawashang

Before the fieldtrip to Wawashang, the idea was more or less the concept that is presented in the authors' specialization project *"Feasibility of micro hydro power in the Wawashang area, east Nicaragua"* and Marco Boninellas´s specialization project *"Feasibility of micro hydro power in the Wawashang area, east Nicaragua"*. Regarding the authors specialization project, briefly summarized, the goal was to scale three or more standardized decentralized systems for each separate building in the complex or to look at the opportunity of many small clusters spread over the village with individual distribution systems. A supply of hydropower was also planned through a microgrid and it was expected that on a yearly average the two supply systems would contribute to covering 50% of the demand each as a rough estimate, however more exact numbers were expected to be found during the fieldtrip.

3.2 Post Fieldtrip

During the fieldtrip it was discovered that the size of the hydro potential was ignorable because the expected head of the river was changing over a long distance and there was no sudden drop as expected. Therefore the load that was intended to be covered by hydropower, would have to be covered otherwise, or there would have to be a supply system solely consisting of solar power. The only obvious source of power which could be combined with the solar power in an easy configuration would be to use one or more of the diesel generators that were currently there as a backup system. However whether this was an economically feasible and optimal system was left to find out from the simulations in PVsyst and HOMER.

During the fieldtrip it was also discovered that placing the modules on each building with a electricity demand would give a suboptimal system as achieving an azimuth of 0 degrees, keeping the tilt low and keeping the roofs shade free would be a great challenge because of the shapes of the roof and direction of buildings as well as large amount of trees surrounding every building. It was also registered that a decentralized system is hard to perform maintenance on and not being able to distribute unused energy from one building to an other where the demand is not being met, is also not a very energy efficient solution. It was a conversation with our BlueEnergy contact, Gilles Charlier, that the idea of a centralized PV cluster and battery bank possibly attached to a diesel backup system through a microgrid, surfaced.

An other discovery during the fieldtrip was the large amount of biomass not being used productively. The numbers presented in the chapter regarding resources in the Wawashang complex are a start, however as mentioned earlier, this field of power supply has not been explored enough and it will not be considered to be integrated in the microgrid at this point. Including this energy source into the microgrid in the future could be very likely and the fact that other energy sources could be added to the system in the future, is a good reason for investing in a microgrid distribution system.

As the goal was to scale a clustered PV-system it was considered whether the already present modules in Wawashang in any way could be used. It seemed like a good idea to make different clusters with modules of different sizes, as modules of different size can not be coupled together without the less powerful module drawing power from the more powerful ones. However when trying to implement this idea to the simulation programs PVsyst and HOMER, it turned out to be impossible because of limitations in PVsyst. The total load profile stating the demand which was retrieved during the fieldtrip, cannot be split up and be implemented into different PV systems with a known number of PV modules as demand and installed effect are not the same parameter. So even if HOMER allows for different types of modules and the currently present equipment could be set as zero for ensuring that it would be integrated, the idea of integrating the already present modules and batteries had to be left since the base of simulations had to be the same for being able to compare and combine results.

So the scope of the thesis had shifted to become an economical and technical optimization of scaling a centralized clustered PV system attached to a large battery bank with or without a diesel generator backup system distributed by a microgrid.

4 Methodology

The methodology part of this thesis will be divided into three parts. One part will emphasize the empirical research from the fieldtrip to Wawashang. The second part will explain the system scaling process regarding the use of the software HOMER and PVsyst along with the secondary data that has been implemented into the software. The third part of this chapter is dedicated to validity and reliability.

4.1 Primary data; Empirical Research

The whole reason and motivation behind the fieldtrip to Wawashang was to be able to collect empirical data for implementing into the software. The various data being collected during the fieldtrip were:

→ Identifying suitable location for new clustered PV systems
→ Determination of Azimuth
→ Mapping of Current system
→ Study shading of chosen area, both horizon and object shading
→ Determination of load profiles for all buildings with electrical installations

The detection of the load profile was by far the most important, complex and time-consuming data retrieval during the work with this master thesis and it was done together with the other student involved with the project, Marco Boninella. Since the methodology behind it was so complex, the methodology regarding the determination of the load profile will be presented in its own subchapter. However the rest of the bullet points will be explained in the following paragraphs.

Detecting one large area for a space demanding clustered PV-system was time pressured. This because the idea of the centralized PV-cluster instead of decentralized systems on the roofs, came up as a solution all in the end of the stay in Wawashang. As space is not an issue since FADCANIC has a large area of land at disposal, time nor focus was not put on finding the perfect spot for the PV-cluster other than a brief suggestion that the sports court would be moved and the current area for sports court would be used.

A compass was used for retrieving the azimuth data and even though it turned out that it is not a 100% accurate to determine the true south by the use of a compass as the magnetic south pole is slightly different from the geographical one. However an approximation is in this case sufficient, because the PV cluster was decided to be put on a large field and not on a specific roof. Then the azimuth can be freely chosen and set to be zero, which is the optimal angle. If the PV system would have been planned to be spread over all the roofs of the houses with an electrical demand like it was anticipated before the fieldtrip, detecting the correct azimuth for all those buildings, would have been much more important. That is because the houses are immobile and the roofs have a decisive factor for the azimuth that can be applied to the modules. The detected azimuths have not been relevant for this thesis, however as the data had been collected and as it might be useful for the future students working on this project, it is stated in this report. For the same reason all buildings were measured and approximate ground area is stated in the same overview.

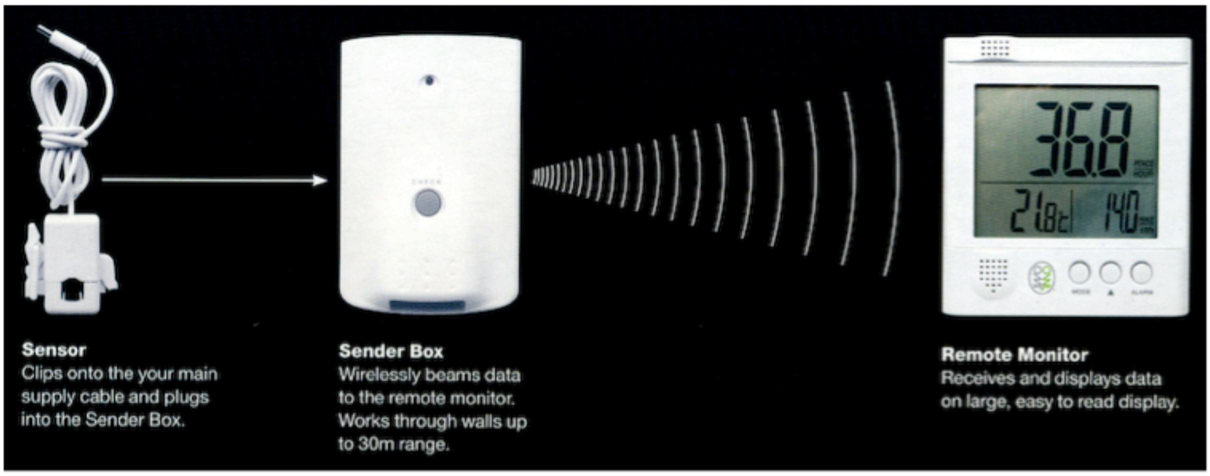
The mapping of the current system was an other data collection point with a quite simple methodology. Wires were followed and all the inventory identified and counted for determining which parts of the current systems could be used for the planned clustered PV system. This was done despite that the limitations of the software made the implementation of the current equipment impossible and the information has not really been used for the scaling of the system. However the information is expected to be useful for other students taking over the work with the FADCANIC project.

The shading of the complex, both near-and horizontal shading, was also studied during the fieldtrip. This was done by walking multiple rounds in the complex during the hours when the sun was around its highest point, to try to detect shading on the roofs where the current system are placed, and also on the sports field where the new system is planned.

4.1.1 Load Profile Detection

For being able to scale a optimal electrical system regarding in the Wawashang complex, it was a necessity to be able to detect a 24h usage profile. It was desired to be able to monitor and store data on electricity usage over a period of as many representative days as possible and to use that data as a base for determining the future electricity demand in the complex. The way that this should be done was that each building with a electrical system should be monitored, and as a clustered PV-system was planned, all those load profiles would have to be merged to a total load profile valid for the current usage of the entire complex. This total load profile would have to be modified to yield for the future demand by the use of a predetermined multiplier.

Finding the right devices for the detection of the current load profiles regarding electricity usage in the Wawashang complex turned out to be a much more complicated process than expected. Multiple companies with different types of devices for electricity were contacted, however for different reasons no match was found with the device that was needed. Voltage limitations, complex mounting, monitoring that required WiFi or extensive cabling were common issues that put a stop to further cooperation. After numerous phone calls and extensive research being done, a device that seemed to be perfect for the purpose of measuring load profiles was detected, the OWL+USB system. The concept of the Owl device is sensors being clipped over the main electricity feed cable to measure the current. The sensor is being connected to something called the sender that is mounted on the wall right next to the main feeder. The sender is transmitting signals to a display-unit, which has been programmed for the specific system and a fixed voltage had been set. The current being measured combined with the fixed voltage determines the power usage minute by minute and thereby also energy consumption. Data from up to 30 days can be stored on the display unit and transferred to a windows computer by USB cable. Below a illustration of the system is displayed.



Figur 5 OWL smart meter [14]

As there was a high uncertainty around the current system and which of those systems would make feasible measure points, there were uncertainties regarding the amount of kits that should be ordered. However a rough estimate was made, and it was approximated that the maximum would be 15 OWL units being installed. The three-phase system requires 3 sensors to measure the current over all three phases and the single-phase systems need 1 sensor each. So in total 15 OWL+USB kits were ordered from Britain as well as a few extra sensors for the three phase system. Below a picture illustrating how the OWL devices were implemented and how data was extracted is displayed.

Figure 6 Implementation and extraction of data of OWL devices

The interpretation of the data, determination of the multiplier regarding future load profiles, reliability and other details around the determination of the load profiles will be presented in chapter 8.

4.2 Secondary data; Data Retrieval for Simulations

Two simulation tools, PVsyst and HOMER, were used during the work with this master-thesis. PVsyst is a simulation software purely for scaling photovoltaic systems, and even if it is possible to set generators as backup systems, this is done in a very simple way and is not equal to scaling it as a hybrid system. HOMER on the other hand, is a hybrid system simulation tool for all kinds of energy sources, which unlike PVsyst is suited for economical optimization rather than technical optimization. Using the two software will give a unique possibility and insight to compare the two approaches and combine the results for the design of the system. However because both simulation tools are used, the same parameters will have to be implemented in both software, for a fair base of comparison. As HOMER mainly is set for economical optimization, an important point was to only use modules, batteries, inverters and so on where the price was known. Together with price information, making sure the equipment was also deliverable, were decisive factors when choosing the type of equipment.

4.2.1 PVsyst

The simulations in PVsyst require a lot of parameters being implemented and a great deal of work has been done to retrieve proper data for implementation in PVsyst. Some data could not be retrieved during the fieldtrip, as Wawashang is a very small place and no types of data records are being kept. This is data like, operational temperatures for the PV-panels, albedo, tilt angles and so on. All of these data are presented and accounted for in coming chapters and have been collected from different alternative sources as there obviously is no direct literature on the matter. However the most important data like the load profiles and irradiation data has been carefully selected or physically retrieved. When it comes to the determining the future load profile for the entire village, an own chapter is dedicated to the work regarding the processing of the data, collaboration with our contact persons in FADCANIC and defending the final outcome. The irradiation data was as mentioned earlier imported into PVsyst from NASAs database by implementation of the exact coordinates and an automatic interpolation between the closest weather stations.

It was attempted to use some of the already present solar panels and batteries as well as one of the diesel generators for the scaling of the new system, however scaling a system in PVsyst does not allow choosing many different types of panels for one cluster and splitting up the demand based on a known capacity of a module cluster is not feasible. So this limitation in PVsyst discarded the idea of using parts of the current equipment in the complex.

As it is desired to compare a system with and without a backup generator, two sets of simulations have to be performed in PVsyst. One where a 10kW diesel generator is included and one where there is no backup supply system. The through reports produced by PVsyst will be the base for the conclusion whether a system with a diesel generator as backup is optimal or not. It is important that one realize that in PVsyst, the back-up generator is only modelled as an alternator+rectifier element, ensuring the recharging of batteries when the solar energy is insufficient to satisfy the user's needs. HOMER treats the backup generator in a different way and has a much more sophisticated and realistic way of including the diesel generators into the simulations.

4.2.2 HOMER

The simulation tool HOMER does not only require technical data, however also economical data. So as mentioned earlier, when information on both matters is needed, this limits the choice of equipment used. In HOMER only one main simulation was needed to find the approximate optimal and all the suboptimal configurations of the system. However HOMER demands the implementation of different sizes of all parameters regarding the equipment that can be implemented into the system so that different sizes can be evaluated and the optimal configuration found. This means that in addition to choosing the type, size and price of modules, different alternatives regarding the size of the PV array in total has to be chosen. The same yields for the battery pack, the generators and the converter. HOMER then takes all these alternatives and possibilities into account and by combining them in different ways, an approximate optimal system is identified. However as a wide range of sizes of PV array, converter and battery pack have to be implemented, it is compulsory perform multiple simulations to narrow down and find the exact numbers and thereby the exact system configuration which leads to an optimal configuration.

The economical data implemented into HOMER, has been provided by BlueEnergy and the parameters regarding the PV-part of the possible hybrid system, are naturally the same data that has been used in PVsyst. The same irradiation data from NASA has manually been implemented into HOMER for providing the same base for comparison. However as one can imagine, the databases for modules, batteries and the other parts of the hybrid system are slightly different from PVsyst. However when identical objects have not been found, the equipment with the characteristics closest to the ones in PVsyst are chosen. The reason for this is that PVsyst has the largest database where the appliances with price information related to them can be found. In chapter 12 the modules and batteries that have been chosen and the limitations of the databases will be further discussed. The data regarding the gasoline consumption and other data regarding the diesel generator has been taken from reports provided by BlueEnergy and FADCANIC as well as unavailable data had to be approximated through articles solving similar problems.

HOMER also allows a sensitivity analysis for many of the implemented parameters, and fuel price, real interest rate and irradiation were the parameters that were performed a sensitivity analysis on. This means that one can change the magnitude of these parameters that are uncertain in the future separately and monitor when the optimal system configuration is changing with respect to the altered parameter. In chapter 14 the HOMER simulations are further described.

4.3 Validity and Reliability

To be able to say something about the results, conclusions and the likeliness that the outcome of the thesis is correct, the terms validity and reliability have to be discussed. Validity refers to whether a test measures what we wish to measure while reliability refers to the consistency of the results.

4.3.1 Validity and Reliability of Primary Data

The validity of the primary empirical data, which is the data that was collected regarding the load profiles of the Wawashang complex, is expected to be very high. Tests were made for every installation of the smart-meters to check if the meter was installed in the right way. As an example all appliances in the building were turned off and a light was switched on to detect the reaction of the OWL smart meter and whether the measurements had the right magnitude. In this way it could be proven that the OWL smart meter, sender and sensor was working with high validity and reliability. The reliability of the empirical data is also expected to be high, as minute-by-minute data could be checked and disturbances therefore could be detected. However as the data processing and sorting was made manually, it has to be taken into account that mistakes theoretically could occur during that process. The fact that the primary data has not been used directly in the thesis and that a multiplication factor had to be applied for imitating future electricity demand, lowers the validity and reliability. However there is no other reasonable way to modify the data for future demand than to use the empirical data as a base and implement a multiplication factor.

4.3.2 Validity and Reliability of Secondary Data

When it comes to the validity and reliability of the secondary data it is also expected to be high. Sources were carefully chosen and even if all parameters that were implemented into the software were not necessarily a perfect fit, these are considered reasonable estimations. Regarding the reliability and validity of the software itself, PVsyst and HOMER, these are well tested and well-reputed tools for scaling energy supply systems. A 100% accuracy can not be expected as unpredictable data like irradiation and demand only to a certain degree can be estimated, however if realistic parameters are implemented, the system design produced by the software is expected to be a good fit. PVsyst nor HOMER can guarantee for the reliability and validity of the simulation results as parameters mainly are implemented by the user. However the fact that these software tools are popular for large companies is an indicator that they have an acceptable liability.

5 Impact of Electrification

When considering electrification or expansions of electrical systems, not only practical, technical and economical aspect must be considered, but also the social impact must be analysed. What kind of changes does the increased access to electricity lead to for a rural village? Electrification and electrical expansion has a much bigger impact than one would think, and is an extremely important step in the developmental process of a country or an area. Very simplified one can state that better access to electricity leads to more productive hours in the evening, more productive hours leads to people reading or doing useful work. More useful work being done, leads to a better educated individuals, and finally all the educated individuals lead to a stronger society with a better workforce, a better economy and more opportunities to create values.

According to the world banks report ”*The Welfare impact of rural Electrification: A Reassessment of the Costs and Benefits*”[1], the most important social improvement factors of electrification are increased production, improved health situation and better education of the people. However the impact of electrification will always depend on the intentions and visions of the individuals in question. The specific use of the energy is also crucial for whether the electrification leads to increased education or just entertainment and comfort. An important factor is to show villagers and people potentially getting access to electricity, the endless opportunities and development electrification can lead to. Introduce them to the global world of the Internet where globalization, information exchange and self-education can lead to the significant development. Electrification is a crucial step towards development for the developing countries of the world, however for these countries to be able to take advantage of electrification, issues like illiteracy and lack of technological understanding needs to be dealt with. There is also no doubt that primary needs have to be covered before even considering investing in goods like electrification. All in all, if the willingness to learn, literacy and technological competence is present, there is no limit for the possible development of countries getting electrified.

There is no doubt that there in general will be environmental consequences and impacts as a result of electrification. However these impacts will be very dependant on the energy sources being used when electrifying new areas. It is well known that as the developing countries are getting industrialized and social factors like electricity and energy access are stabile, the living standards will rise and the demand of goods will grow proportionally. When that happens, an increase of various emissions will be close to unavoidable. However, these extra emissions can be controlled and kept to a minimum by using renewable energy sources instead of fossil. As a matter in fact, applying renewable energies for rural areas are almost compulsory, as the fossil fuels are scarce and a price-race has already started between the western countries. A price-race less developed countries and rural areas cannot take part in. The problem is just that the developing countries are depending on powerful nations to keep up the research to push prices of renewable energies down, however ignorance, postponements and the ability to pay today’s fossil fuels, are making it too easy for them to avoid making changes and invest in research.

5.1 Impact of Expansion of Electrical System in Wawashang

As mentioned before Wawashang is one of the few rural areas with access to electricity, so for that reason the effect of installing a new and improved PV system there will not be a major turning point. The complex already have diesel generators and a number of PV modules, so one could say that they are far ahead of their neighbour villages on the east coast of Nicaragua. However an optimization of their system would be a big advantage for the villagers and improve their every day activities, as an expansion of the current system would contribute to electricity consumption not being rationed to the same level as before, at the same time as a larger amount of students can be accommodated in the boarding school. That does not mean that extensive usage can take place, but the villagers will be much more free to use energy in the hours without daylight and will have a much better opportunity to be productive in the evening hours.

One will see many of the improvements already mentioned, however better opportunities and facilities for education could be the most important impact for Wawashang. Since the students are familiar with computers and can read and write, they have a great base to take good advantage of the extra hours by the computer and light for reading in the evening. The fact that the comfort level for the inhabitants will rise due to the other improvements the expansion will lead to, will contribute to their well being and health, and will probably contribute to an even better learning and educational environment for a larger number of students.

5.2 Environmental Impact of Electrification

Creating awareness around environmental damage due to anthropological emissions not only in industrialized countries, but also in developing countries is of high importance. For developing countries to follow a development in tact with nature in a sustainable way and avoiding the industrialized countries mistakes is crucial. The abundance of fossil fuels is already a major problem in industrialized countries all over the world, but developing countries also take over the trends and easy solutions. The abundance of scarce fossil energy sources in developing countries is not only damaging for the environment, but also creates a race of getting hands on desired resources and that again leads to sky-high prices where developing countries will be the first ones not being able to follow the price race. This is one of the reasons why development and use of natural resources is so important for countries expanding their electrified areas.

For the village Wawashang, not only the independence of fossil fuels is a positive effect of using renewable resources, avoided emissions will also be a positive environmental effect of the new system. This because the diesel generators are not to be used at all or just as a backup if that turns pot to be the optimal configuration and this will result in a much lower amount of emissions or even a zero emission system.

Heavy deforestation is a major problem in Nicaragua, 70 000 hectares [15] of forest is being cut down every year and most of it is used as an energy resource for cooking in rural areas where environmental awareness is not a main focus. Garbage disposal is an other environmental challenge in Nicaragua. Approximately only 40% [15] of the garbage is being picked up, and that only in the central areas of Nicaragua, to be burned or collected in garbage areas. There is no special handling for toxic and poisonous waste.

The rest of the waste not being picked up from the government, is being burned to dispose of it, or even dumped in the rivers or lakes. It is not necessary to say that this behaviour is damaging for the environment and also affects the population of Nicaragua in form of polluted water, which is a major problem in the area.

Below a diagram over the share of total primary energy supply in Nicaragua in 2009 is displayed. It is stated that bio-fuel/waste and oil are the main resources, which sadly implies a trend of ignorance when it comes to the environment. It is the trend of increased part of total energy supply being connected to severe emissions, that needs to be turned around by renewable energy sources like photovoltaic, hydro-power and wind power parks. This not only to protect the planet, but also because oil and fossil fuels in the long run will be too expensive for them to afford. The fact that the electricity mix in Nicaragua has severe emissions connected to the energy sources applied, gives an other incentive for staying off the national grid and building an own mini grid supply system.

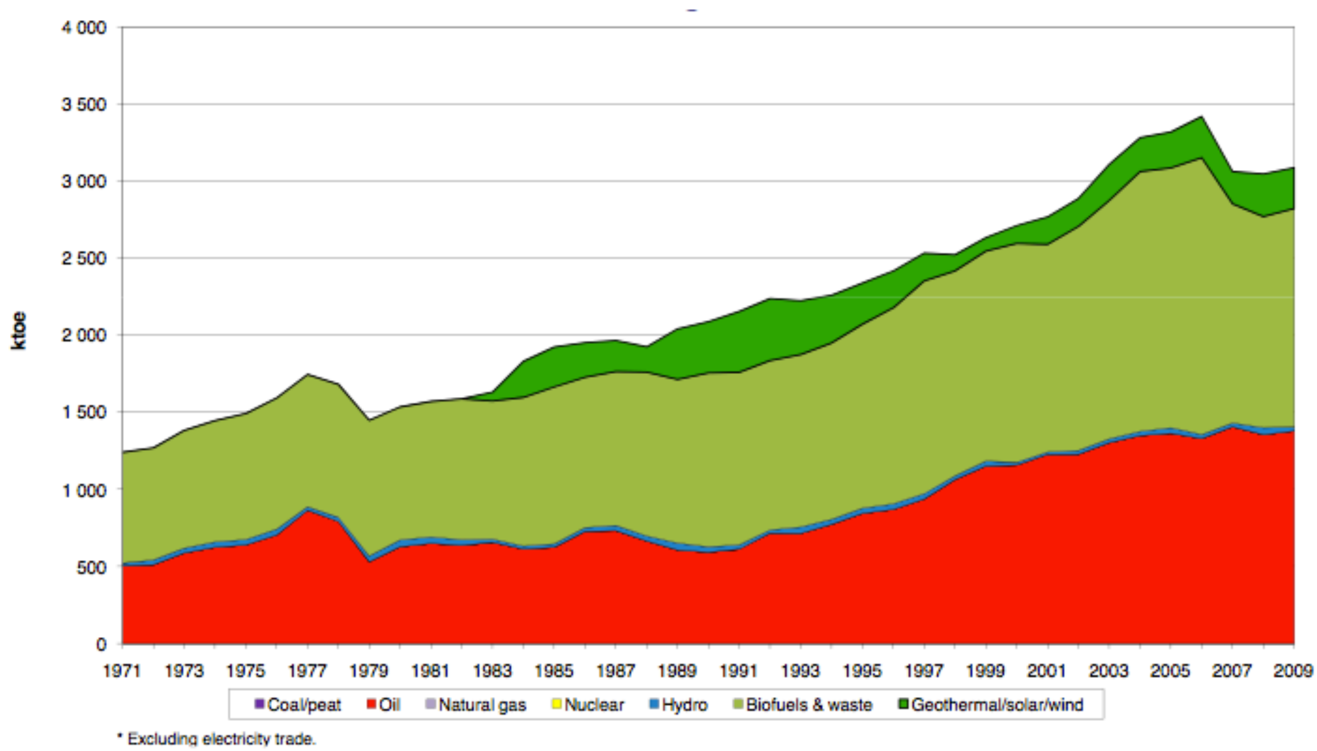


Figure 7 Share of primary energy supply in Nicaragua 2009 [2]

6 Current Situation in the Wawaschang Complex

An important part of the work being done during the field trip, was to get an overview over the complex and to map the current system and identify connected buildings. In the following subchapters, a through map over the area with a detailed legend will be displayed as well as an inventory list of the electrical installations that are currently in the area. The problems and difficulties with the current system will also be discussed and an overview over the different electricity demanding appliances will also be displayed.

6.1 Detailed Map over the Complex and Current System Connections

The current system is consisting of diesel and gasoline generators as well as various decentralized PV-systems on the rooftops. There are no common distribution line for the complex, however the gasoline diesel generators in the building for food processing are being used as a backup for either the offices, auditorium or the kitchen. The house of professors is also distributing electricity to all the student dorms. All connections can be visualized in the map below with the belonging legend. There is also a farm in connection with the complex, however the farm is too distant to be included in the map represented in figure 8. The same yields for the plant nursery where plants are pollinated. The Azimuth in the legend is referred to with number of degrees and S or L, which states whether the azimuth is measured on the long or short side of the roof.

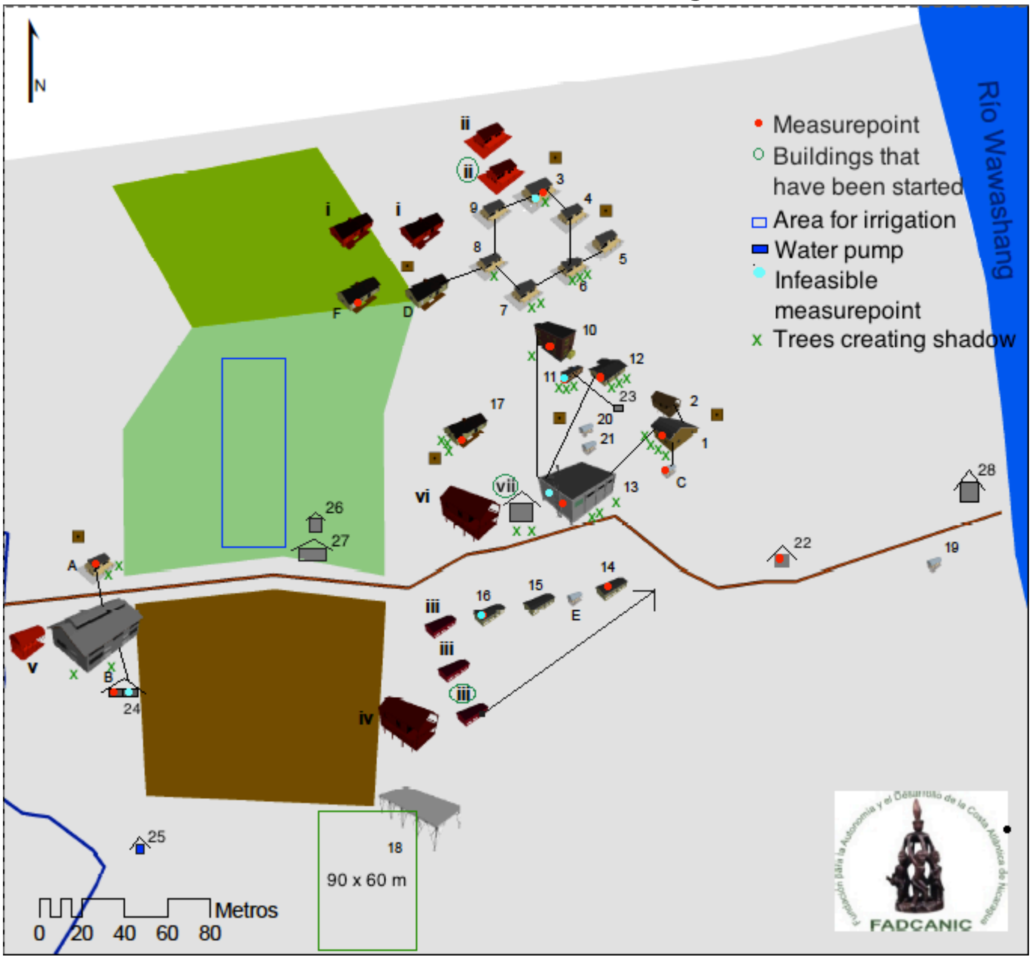


Figure 8 Detailed Map over the Wawashang Complex [10]

LEGEND				
Existing buildings				
Nr	Name	Measurepoint	Azimuth	Roof Area (m)
1	Dining area	x	-20 L	9.8 x 25.8
2	Kitchen		-20 L	9.2 x 11
3	House of Professors	x	-10 S	13.5 x 24
4	Student dorm Orinoco		20 L	13.4 x 9.5
5	Student dorm Bélen		-10 L	13.4 x 9.5
6	Student dorm Karawala		-50 L	13.4 x 9.5
7	Student dorm Angloamerica		100 L	13.4 x 9.5
8	Student dorm Panchón		10 L	13.4 x 9.5
9	Student dorm Rama Ray		-30 L	13.4 x 9.5
10	Auditorium, Centre	x	10 L	13.8 x 10.7
11	Laboratory	x	5	5.4 x 9.6
12	Offices	x	-5 L	8.4 x 7.3
13	Food processing building	x	20 L	21.1 x 21.1
14	Computer room, teachers offices and library	x	10 L	14.4 x 14
15	Classroom		10 L	11.4 x 14.4
16	Classroom	x	50 L	11 x 14.1
17	House of technical team, guests and professors	x	10 S	14.4 x 23.4
18	Sports court		-20 L	30 x 13.5
19	House of CPF		-	-
20	Shed 1		-	-
21	Shed 2		-	-
22	Pump house	x	-	-
23	Fruit drying installation		-	-
24	Generator sheds carpentry	x	-	-
25	Shed for water pumps for irrigation		-	-
26	Shed for gardening		-	-
27	Shed (no walls) for soil preparation		-	-
28	Wharf		10	7 x 6
A	House of carpenters	x	0 L	9.8 x 13.6
B	Carpentry		-90 L	31 x 16.6
C	Building of water treatment	x	-10 L	3.6 x 6.5
D	House of IBIS, student dorms		15 L	12 x 23.3
E	Classroom		10 S	6.8 x 7.5
F	USAID, student dorms	x	15 L	24.3 x 13.6
Planned buildings				
i	Student Dorms (2 modules)		-	-
ii	Student Dorms (2 modules)		-	-
iii	Classroom		40 L	11 x 15.5
iv	Building for leisure activities, option 1		-	-
v	Classroom for carpentry		-	-
vi	Building for leisure activities, option 2		-	-
vii	Food processing building nr. 2		20 L	10 x 10
Buildings out outside scope of map				
	Kahka Creek	x		See other map
	Farm area			See other map
	Plant nursery		10 S	11 x 7

Table 3 Legenf for Figure 8

6.2 Configuration of Current System

On the following page one can see an overview over the present installations in the complex and the type of supply. The information about the currently installed effects was collected during the fieldtrip as well as some of it was provided by the contacts in FADCANIC.

No	Description	Size of current Installation	Supplier	Comment	Marked in map as
1	**Carpentry**	10 000 W 24 000 W	Diesel generators		B
2	**Sports court**	none	none		18
3	**Computer room**	1755 W	PV panels	New panels installed during stay in Wawashang	14
4	**Library and teachers offices**				
5	**Kitchen and dining room**	1015 W	PV panels	Has backup from food processing building	1 and 2
6	**Classrooms**	(1200 W)	PV panels	System not functioning, no electricity Previously attached to electrical system of the computer room	15,16, iii
7	**Student dorms and house of Professors** **USAID Building**	599 W 800W	PV panels PV panels	PV panels only in professors dorms, connected to the different student dorms USAID Building has own PV system	3,4,5,6,7,8,9, i and ii F
8	**Building for water processing** **Pump house**	100W 4850 W	PV panels Gasoline pump		22 C
9	**Offices**	672	PV panels	Has backup from generators in food processing building	12
10	**Auditorium**	1350	PV panels	Has backup from generators in food processing building	10
11	**House of technical team, guests and professors**	1560	PV panels		17
12	**Irrigation system**	3300 kW	Gasoline pump		25
13	**Food processing building (backup generators)**	10 000 W 7500 W	Gasoline Generators		13
14	**Quality seed production facility**	(400 W)	PV-panel	PV panels stolen, no functioning system	Not in map, too distant
15	**Forestal and Livestock farm**	None	None		Not in map, too distant
16	**Street lights and wharf**	None	None		28
17	**Kahka Creek**	2093 W 12 000 W	PV panels Gasoline generator		Not in map, too distant
18	**Building for leisure activities**	Not yet built	Not yet built		Iv and vi
19	**House of Carpenters**	340 W	PV panels	System installed during stay in Wawashang	A
20	**Laboratory**	(816 W)	PV panels	System not functioning as Inverter is missing	11
	Approximate Total present installed effect	59 691 W	PV panels + generator power	Kahka Creek and pump power not taken into account	

Table 4 Currentby installed effect iin the Complex

As one can see the total installed effect in the complex is 59 691 W and close to 57 % of the installed power is in the carpentry, implying that the carpentry by far has the highest impact on the complex's energy demand. The systems are mainly single-phase systems operating with 110-120V except from the carpentry, system nr 1 in table 4, where the high electrical loads imply a three-phase system operating with both 220 and 440 V.

6.3 Inventory List

During the fieldtrip an effort was made to identify the equipment present in the current system for evaluating if some of it could be used for the new energy supply system. However as it has been stated earlier, it turned out that during the scaling process by the use of PVsyst and HOMER, that there was no way to include the current modules in PVsyst as only one type of modules could be simulated. Therefore in HOMER the economical evaluation was based on a brand new system. However in reality, modules and batteries that are currently in the village could be used for the design of the new system by dividing the cluster into smaller connected clusters where different types of modules can be implemented into the different clusters as combining them in the same cluster is unfeasible. However further than displaying the current equipment, it will not be further discussed and no suggestions will be made how to use the current equipment in the new and optimized system. The table below gives one an overview over the functional equipment present in the village at this moment. A more through overview stating the where the equipment is placed is provided in appendix 1.

Inventory	Type and power	Amount
Inverters	Magnum Energy 1500 W	2
	Xpower Plus 1200 W	2
	WAGAN TECH AC 1500 W	1
	IGTECH 1500 W	1
	Xantrex, 1500 W	3
Inverters in Kahka Creek	Magnum, 4000 W	1
Batteries	Deka Pro Master 6V	2
	Willard 12 V	2
	Trojan 6V	118
	Crown 6V	47
Batteries in Kahka Creek	Trojan 6V	28
PV modules in Complex	EGE 100W	8
	GeEnergy 20W	16
	Solar Shell 85 W	18
	Solar Shell 28 W	38
	SunSwifer 35 W	1
	China 18 W	4
	Isofoton, 55 W	29
	Trina Solar 225W	4
	Kyocera, 136 W	6
	Kyocera 85W	8
	Isofoton,100W	3
	SunWize, 85W	3
	Unknown 85W	4
	Unkjnown 50W	2
PV modules in Kahka Creek	Kyocera, 130W	5
	Kyocera, 135W	1
	Photo Watt, 75W	2
	Kyocera, 65W	2
	Kyocera, 54W	2
	BPSolar, 230W	4
Controllers	Xantrex C 40	7
	Xantrex C 60	1
	Xantrex C 34	9
	Steca Solar 6ª	1
Controllers in Kahka Creek	Xantrex C 35	1
	Xantrex C40	1

Table 5 Total inventory of the Wawashang complex

6.4 Appliance list

The appliance list presented below, describing the appliances present in the complex in Wawashang, is provided by Gilles Charlier, the contact person from BlueEnergy. The list is presented with the proviso of mistakes , shortcomings and changes, the important factor is that the reader understands which sort of appliances are being used in the complex even if the list might not be exact and complete. One can see that light bulbs and mobile phone chargers are the appliances which exist in a very large quantum in the complex. It is differentiated between the appliances in the carpentry and the rest of the complex, as the demand in the carpentry is of a much higher scale.

Place	Component	Power demand (W)	Number
House of carpenters	Light bulbs	15	8
Teachers offices, Library and computer Room	Light bulbs	15	26
	Computer	250	6
	Screen	60	2
	Printer	120	2
Dining Room and Kitchen	Light bulbs	22	11
	Freezer	(20)	1 Defect!
Office	Fan	40	5
	Printer	120	2
	Light bulbs	22	6
	Phone	4	1
	Walky Talky Charger	80	1
	Scanner	15	1
	Router	10	1
	Modem	5	1
	Cell phone Charger	2.5	4
Auditorium	Light bulbs	15	17
	Fan	40	8
	Light bulbs	22	8
	Refrigerator	20	1
	Computer	200	2
Laboratory	Light bulbs	15	4
	Light bulbs	22	1
	Electrical oven	1300	1
Student Dorms and House of Professors	Light bulbs	22	36
	Light bulbs	15	40
	Cell phone Chargers	4	90
House of technical team, guests and Professors	Light bulbs	15	23
	Cell phone Charger	4	8
	Fan	40	8
	Computer	200	4
Food processing Building	Light bulbs	15	7
	Fan	60	2
	Mill	750	1
	Coco grinder	250	1
	Grinder	300	1
	Fridge	30	1 Defect!
Total			**10 635 W**

Table 6 Appliance list excluding carpentry [16]

Group	Appliance	kW	Total
1	Planer	3.5 kW	
	Edger	1 kW	
	Circular saw	2 kW	
			6.5 kW
2	Hand sander	0.6 kW	
	Circular Saw	2 kW	
	Compressor	1.8 kW	
			4.4 kW
3	Drill	1.6 kW	
	Router	1.5 kW	
	Hand circular saw	2 kW	
			5.1 kW

Table 7 Appliance list carpentry [16]

6.5 Problems with Current System

The current system is mostly functional, however some defects and missing inventory, as well as too easy access to poorly insulated high voltage whirring are characterizing the system conditions. Lack of, or no maintenance being performed and un-sealed battery packs, are dramatically lowering the lifetime of the equipment as well as the dusty PV-panels are having a reduced efficiency. Shade and suboptimal angles of the modules are also factors that affect the efficiency of the system. The accessibility to the wooden boxes with the batteries is attracting rats, as well as they could be hazardous to curious students. In the carpentry where the energy is supplied by diesel generators, the main problem is the lack of power. This results in limitations and certain equipment can only be used in predetermined groups. The system in the carpentry is also problematic as there is a chaos of whirring and only one person with understanding of how things are connected and functioning.

The main problem with the current system is the too low power production regarding the increasing capacity in the future, at the same time as modernisation of the complex requires an increased amount of electrical appliances. This leaves the current system far from sufficient. The energetic inefficiency is also an issue and the usage of the generators is not optimal as there is no distribution line which could use the excess energy to charge the batteries as well as the power cannot be distributed between the buildings the way the system is currently configured. It was also discovered during the fieldtrip that the PV-modules are mounted in a suboptimal way regarding inclination angle, azimuth and shade.

7 Expansion of Electrical System

In this chapter the motivation behind the system expansion will be presented as well as the expanded system loads will be discussed and the enhanced system explained.

7.1 Motivation behind System Expansion

The system is partly defect and it is not serving the energy demand that the activities in the various buildings require, especially not regarding future demand. An other reason for the expansion of the system, is that the people living in the complex will be able to add more appliances or extend the hours of usage of existing appliances to increase the comfort and improve education facilities. The increased capacity of the complex is however likely to be the most important reason for the desired expansion of the electrical system. The main goals they want to execute are:

→ Allowing more hours using light bulbs in the evening/ adding light bulbs in class rooms, dorms, sport and recreation facilities, corridors and so on
→ Electrification of classrooms where system is currently out of order
→ Adding machines to the carpentry
→ Allowing more hours at the computers/ adding computers in the computer room
→ Provide electricity for a new library
→ Adding cold storage facilities to kitchen and provide energy for food processing
→ Computers and printers added in the teacher offices
→ New irrigation system
→ Exchanging the gasoline pumps for the irrigation to photovoltaic power
→ Electrification in the forestall park and livestock farm
→ Expanding loads in sports court, carpentry shop, quality seed productions facility, auditorium, teachers and technical staff house and agroforestal offices.
→ Increased capacity of students, professors and visitors in the complex in general
→ Electrifying planned classrooms, recreation centres, student and professor dorms

7.2 The Expanded System Loads

An overview that early on was presented by FADCANIC, was an overview showing the estimated power demand for all buildings in the future, see table 8. This list was intended to be used for the scaling of the new system by applying the magnitudes of the demand for up scaling the current load profiles to get approximate load profiles that yields for the future demand. However, the validity and origin of the numbers in the table, as well as the timeframe for when the demand would reach the stated level, were studied during the fieldtrip and proven to have little connection to reality. Therefore other measures had to be applied for the determination of the size of the new system. In cooperation with FADCANIC it was decided that within 2023 the load profiles will be 5 times the current demand for the whole complex excluding the carpentry, which is expected to experience a doubling of demand regarding the current load profiles. The reasoning behind this conclusion will be explained thoroughly in chapter 8 along with the load profiles that were detected for entire the complex and the total future load profile. Below the disregarded overview over future demand-peaks that were given by the FADCANIC contact is displayed.

No.	Description	Watts
1	Carpentry and wood working shop	50 000
2	Sports and physical recreation facilities	5 000
3	Computer Room	5 000
4	Library & Teachers offices	3 000
5	Kitchen and cold storage facilities	6 000
6	Classrooms	4 000
7	Students Dorms	9 000
8	Water System	4 000
9	Agroforestal offices	3 000
10	Auditorioum	5 000
11	Teachers and Technical staff house	5 000
12	Irrigation System	3 000
13	Food processing structures	4 000
14	Quality seed production facility	2 500
15	Forestal and livestock farm	6 000
16	Street lights & Wharf	4 000
17	Kahka Creek	5 000
18	Recreation Center Facilities. Estimated need.	8 000
	Total Estimated Power Demand	**131 500**

Table 8 Overview over extended system peak power demand [17]

7.3 The Enhanced System Configuration

The currently planned system is a microgrid distributing power from a centralized PV-cluster with the possibility of having a large diesel plant as backup. A microgrid is a cluster of small (< 500 kW) energy sources, storage systems, and a load that presents itself to the grid as a legitimate single entity. [18] As possibility for energy storage, a large battery pack is intended. The potential excess energy from the diesel generator will always be stored in the batteries as long as the controller allows it, however this only if the system with a diesel generator as a backup system proves to be the optimal design. Regarding that the current system relies on power from PV panels and gasoline and diesel generators, one might ask how the new system will be different from the current one. However the system being centralized and allowing energy to be shared when it before was limited to supply for one building, in addition to the spare energy form the diesel generator being allowed to charge the batteries, are key factors stating a significant improvement. All advantages of the enhanced system are stated below:

- ➔ Possibility to charge batteries with excess energy from diesel generator
- ➔ Easier maintenance, as all PV-panels and batteries are located at the same place
- ➔ Possibilities to serve a much larger demand in the future
- ➔ Further energy sources could easily be added to the microgrid
- ➔ Possibility to share and in an optimal way distribute energy which before had to remain within one specific building, risking spillage and unused energy
- ➔ Danger avoided as high voltage cables, batteries and other power related appliances will be placed out of reach and in a fenced area

- ➔ In the carpentry where manual coupling was required when changing from using one tool-group to another, will be unnecessary.
- ➔ The system will rely much less on fossil fuels as the optional generator would only operate as a backup
- ➔ The limited rely on fossil fuel results in operating costs close to zero and more foreseeable expenses
- ➔ The system will have optimized azimuths and inclination angles as well no shadow will decrease the efficiency of the system

The dynamism of the thesis demanding a system solely relying on solar power changes the economical aspect and also greatly influences the feasibility of the project. The economical situation has changed because the hydropower was anticipated to be the less costly part of the hybrid system with simple technology and generally low costs. For compensating for weak reliability of system at times when the solar irradiation is low due to cloudy weather, the 10 kW diesel generator currently being used in the carpentry, will be tested for integration in the mini grid and used as a backup solution and excess energy will be used for charging the batteries. However as the system will be scaled with and without a backup system in both software tools, before performing the simulation it is unknown which system configuration will be the optimal one.

An important issue is where the PV-cluster should be placed. Currently there is no large, plain, area, which does not have a function. However the 5400 m^2 sports field (see map in figure 8), which is not affected by any shade, would be perfect for being used for placing the PV-cluster. Both because of the minimal shade, completely plane ground and also because it is not in the way for any activity. However, it is obvious that an other sports field has to be prepared as the PV cluster should not affect the kids activity pattern. But the Wawashang complex has large areas of land and flatting out a part of the land where there is no plantation and just low bushes, would not cause any large difficulties. A high fence would have to surround the PV cluster so that unwanted interference with the system is be avoided. A heavy focus will not be put on defending where the PV-cluster should be placed, as that is something that must be collaborated together with the FADCANIC team, however the approach which is already stated will be presented as a suggestion.

As mentioned in chapter 2.1 where the resources of the area are being discussed, there are significant amounts of bio-waste from the carpentry and building for food processing, which when being burned could be a great source of power . Using the bio-waste from the carpentry and the food processing in a steam turbine, could be a significant source of energy and could be a major contribution to the microgrid and lower the number of PV-modules and batteries significantly. However the research around that opportunity is in a starting phase and lack of specialization and sufficient data excludes the option of taking these factors into account at this point of time. However it is highly recommended to implement this source of energy into the microgrid once the potential of power production has been further explored.

7.4 The Diesel Generator Backup System

Only having one renewable energy source for supplying the entire village is affecting the reliability of the system. However whether the cost regarding such a hybrid system would be worth the increased reliability is left to discuss after the results from the simulations in PVsyst and HOMER have been presented. In the Wawashang complex there are currently four generators, two diesel generators of 24kW and 10kW and two gasoline generators of 7.5 kW and 10 kW. For the software PVsyst only one generator can be suggested as a backup and the diesel generator with a peak power of 10 kW is the generator that will be suggested. This because it is expected that the fuel-costs related to this generator is the lowest (see table 9 below), as well as the large diesel generator would create too much waste power not taken up by the batteries and running it would become energetically inefficient. At the same time it is desired to keep the power production from the diesel generators as low as possible to avoid emissions and to keep the system as energetically sustainable as possible. In HOMER only the two diesel generators were suggested as a backup as they are more environmental friendly.

Plant	Daily Usage	Consumption
Big Diesel Generator Carpentry, 26 kW		2.84 l/h
Small Diesel Generator Carpentry, 10 kW	10h	26.5 l/day
Gasoline generator Food Processing Building, 10 kW		18.92 l/day

Table 9 Diesel/Gasoline generator consumption [17]

Forming a hybrid energy system by combining renewable and conventional energy sources with a battery bank can provide an economic and reliable supply of electricity if the irradiation in the area is insufficient. The reason for this is that the inclusion of a diesel generator could reduce the size of the battery bank and increases the reliability of the system dramatically. The diesel generator equalizes and charges the batteries and acts as a backup generator for extended periods of low solar input or high load demand. By using a diesel generator as backup for a PV system, the two energy supply possibilities which alone have weaknesses, could have those weaknesses eliminated and create benefits from their differences. PV systems with large investment costs, low operating costs and a unreliable and unforeseeable supply combined with a generator with low investment costs, high operating costs, high emissions, a high reliability and low energy efficiency when operated at low loads, could lead to a reliable, efficient, low emissions and low operational cost based system. It is not being said that this is the generally optimal solution as there are other aspects than the technical aspects that need to be satisfied, like economical and environmental aspects. However a study of systems installed in the USA concludes that hybrid energy systems are cost-competitive with conventional systems where the ratio between peak and minimum loads exceeds 3:1 [19] , something which one in the coming chapter will see is the case for the demand in Wawashang.

7.4.1 The Diesel Backup System Configuration

A photovoltaic-diesel hybrid energy system generates AC electricity by combining the photovoltaic array with an inverter and depending on the operation of the inverter, different system configurations are possible. The three different types are [19]:

→ Series hybrid energy systems
→ Switched hybrid energy systems
→ Parallel hybrid energy systems

A series configuration rectifies the power generated by the diesel generator followed by converting it back to AC before supplying the load, something which creates additional losses as well as a larger inverter is required. The series configuration also contributes to demand a larger battery bank that is being cycled more frequently and shortens its lifetime. The advantages of such a coupling is that the power supply will never be interrupted as long as the generator is running as well as the inverter can control the power output of the generator. An other advantages are that no switching of energy source is needed.

Switched configuration is the most common configuration. It only allows operation with either the engine driven generator or the inverter as an AV source even if both energy sources are charging the battery bank. The main advantage with this configuration, is that the loads can be directly supplied by the generator instead of going through the inverter. The diesel generator is being switched off in periods of low demand when the PV system can supply the loads. The switching between the two energy sources can be performed manually or through an automatic controller, Disadvantages with this system is that the supply is momentarily interrupted when the system switches as well as the part load operation has reduced efficiency as the inverter is designed to supply peak loads.

Parallel Configuration allows both energy sources to supply the load at low or medium demand separately, as well as supplying the peak loads combined by synchronizing the inverter. The bidirectional inverter can charge the battery bank when excess energy is at hand from the generator as well as act as a dc-ac converter (inverter operation). This makes the parallel configuration able to supply the system loads optimally and efficiency of the diesel generator can be optimized. However, such a configuration is more complex at the same time as an automatic control rises the price tag on the system.

PVsyst is modelling the generator in a rather simple way and does not really simulate the generator as an integrated system, therefore the configuration that has been chosen for this system is the one that HOMER applies to the simulations, which is the parallel configuration. The settings how the generator is modelled regarding the batteries and whether to have a cycling or load following configuration, also have to be selected in HOMER. This will be further explained in chapter 14.

7.5 The Distribution System

This master-thesis will not have a heavy focus on the distribution-system of the microgrid allocating the power from the hybrid system, as the scope of the thesis has to be limited. However the voltage of the line and major factors that influences the other system parameters will be accounted for. One of the major decisions and problems to solve, is the fact that there are different voltages needed, this because of the heavy machinery in the carpentry demanding 440V and 220V at the same time as all the conventional household appliances demand a voltage of 120. A distribution system with three lines, one with a three-phase 440V and one 220V line that are only distributed from the clustered PV system to the Carpentry and one 120V line which is distributing power to the whole complex is planned.

An other important factor regarding a mini grid distribution network, is that distribution over a certain distance creates additional losses, something that creates a need for up scaling the demand by 10%. [20] This has been done for the total load profile that is presented in chapter 9, which have been used for the scaling of the system.

Below a simple overview over the planned distribution system is displayed. It is planned that the distribution line will follow the pathways (light brown in map) in order to have low interference with the surroundings. The farm and the plant nursery that are situated just outside the scope of the map to the left, will also be connected to the microgrid.

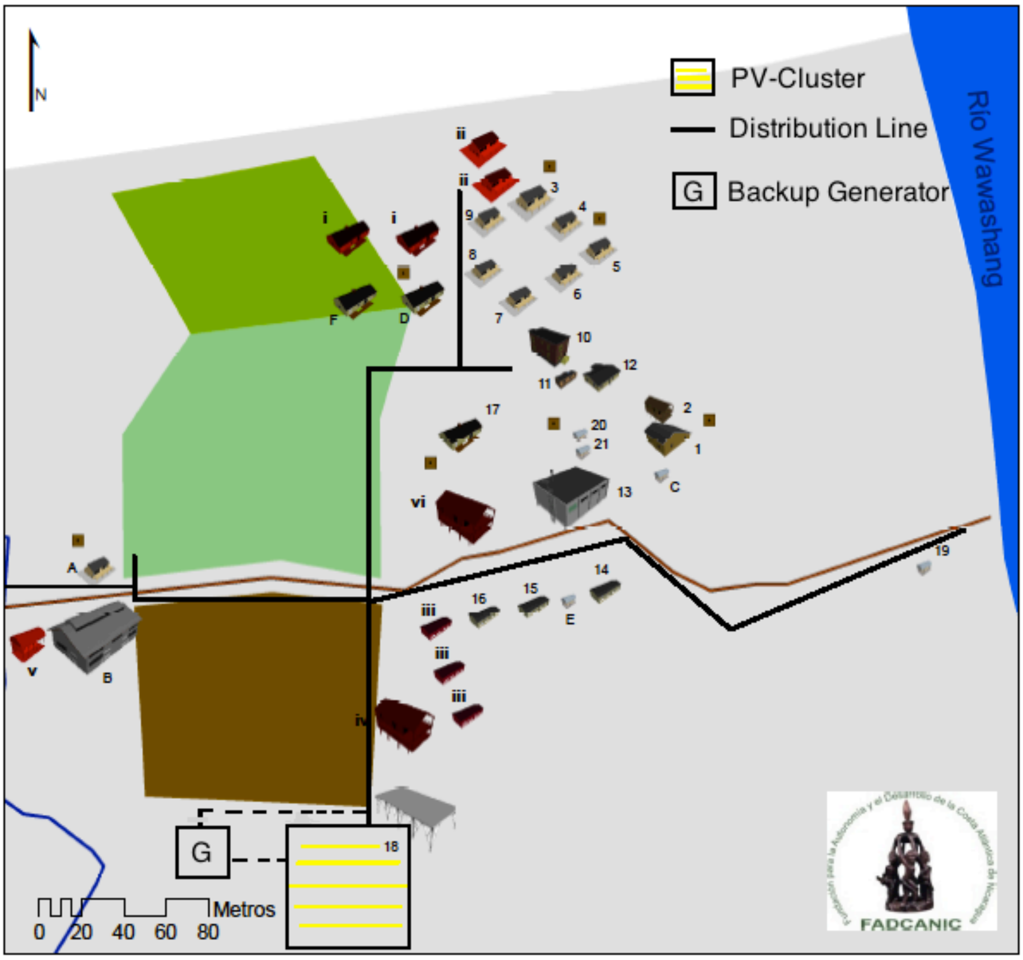


Figure 9 Simplified overview overPV-Cluster and distribution line [10]

8 Load Profile Determination

A major part of this master-thesis and on the authors' behalf the main purpose of the field-trip, was the determination of load profiles for the various buildings of the FADCANIC complex in Wawashang. As the load profiles in general are key factors for the scaling of a system for power supply, the importance of getting accurate and realistic data for usage, is crucial. In the specialization project "Scaling a Stand-Alone PV system as part of a hybrid system in Wawashang, Nicaragua", a rough assumptions for load profiles had to be made. Those assumptions had no connection to the complex, and the basis was taken from other rural villages at the same distance to equator for obtaining a rough image of activity pattern. Basing key data on assumptions do however create a significant uncertainty around the results and the suggested scaling of the PV system. Realizing that, made a field trip to investigate the load profiles in the complex inevitable.

As explained thoroughly in chapter 4, the method of obtaining the load profile in the simplest and cheapest way, turned out to be the OWL electricity meters imported from Britain. The Owl meters were to be attached to the main feed for all electrical installations and placed on various locations in the complex for measuring the usage. A total of 11 load profiles were retrieved, 10 in the Wawashang complex and 1 in Kahka Creek. As a PV-cluster supplying all buildings was planned, the 10 load profiles regarding the current usage in the complex, were merged to become one total load profile, which by a predefined multiplier was modified to yield for future demand. In this chapter the measure points will be pointed out and justified, current load profiles for all locations will be presented separately as well as estimated load profiles for future loads for a clustered PV system are provided. Difficulties, sources of error and reasoning behind the data processing and decision of future load profiles will also be discussed.

8.1 Comments to the Installation Process of the OWL Electricity Meters

As there was no access to information on the configuration of the current systems before arrival in Wawashang, there was limited planning and preparation that could be done before departure regarding the measurements that were to be performed. However an understanding of how the meters functioned and where in the system they should be placed was obtained before arrival. The two main issues that had to be handled was to find feasible measure points for all buildings and make sure the installation of the sensor could be done in a safe way. From the little information given on the current installations, it had been planned that all buildings equipped with either PV-panels or generators should be investigated. See table 4 in chapter 6 for overview over current installations. It was however not certain whether all these buildings had feasible measure points and if the information that had been given regarding the electrical installations was complete and accurate. Mainly the assumptions and understanding regarding the location of the current installations were correct, however there were some differences that made corrections of the original plan necessary. The locations where the plan for data collection regarding determining the load profiles were changed, are presented below. All the other points of measurement went according to the plan.

Originally the idea was to measure usage of both diesel generators at the carpentry area, however there was welding work being done for building vii displayed in the map in figure 8, chapter 6 and it was told that for that reason, only the large 24 kW generator was to be used the weeks in question. The reason for this was that only one of the two generators in the carpentry could operate at one time and the one providing 10 kW was too small for covering the peaks of the welding work. So the 24 kW generator was being used for all work being done at the carpentry in addition to the welding. 27th of February it was informed of utilization of the small generator and a OWL electricity meter was immediately installed to monitor the usage there as well. However the values were too few and spread for creating a profile.

At the building for food processing, the idea was also to have 2 different measure points, as there are two different gasoline generators there. However the only feasible measure point was at the socket at which both generators are connected when they are turned on. Feasible measure point meaning avoiding to open the generators which could be a risky activity. However the data collected from the usage in the food processing building turned out to bee too few as there were only a total of 4 minutes showing usage and basing a load profile based on such few values would be misleading.

When it comes to the student dorms, which were provided with energy through the PV panels on the roof of the professor dorms, the problem with detecting feasible separate measure points was the reason for measuring both areas together. The fact that the measure point is common for both building types, would make it impossible to differentiate between the usage of the professors and students, however the main aim and goal of the load profile detection was identifying a total usage for the whole village. So the compromise made, would not have had severe negative effects on the dataset.

The house of carpenters was until the 21st of February without access to electricity, however the installation of 4x 85 W PV-panels on the roof took place during the field-trip in Wawashang. As there were some extra electricity meters, this location became a point of measurement.

In Kahka Creek originally two measure points were planned, one for the PV system and one for the generator in the carpentry. However it was told that the generator would not be in use the next few weeks because of no activity in the carpentry there and a decision was made to not install the electricity meter there. The decision that the system in Kahka Creek was not a requiring any improvement or expansion, was made after the fieldtrip and that is why also the load profile for those buildings was determined as well.

8.2 Data processing

The part of the work process where the data was extracted from the owl monitors, turned out to be much more time-consuming and complex than expected. The software for the owl monitors is not very user-friendly and are also partly faulty. Even if the voltage has been set for all the monitors it has to be set in the software settings too and in such a way that all monitors will be given the same voltage value even if that is not the case. Through frequent contact with the Owl support centre, it was confirmed that this error could not be solved without multiplying all data with the right voltage and dividing by the voltage in which were implemented in the settings on the computer. Looking at the data provided by the monitors, it was also discovered that the headlines for the different columns of data imported in excel were wrong, as it was supposed to be Wh instead of kWh. However, the most time consuming matter, was to separate and organize all data as the direct export of all data gave an extremely long list of Wh consumption minute by minute for the whole measuring period. There was also a possibility to export data from intervals, however the main problem was that all minute by minute values from list had to be organized for each hour for each weekday for every building. And as the import was time consuming, it was found that that best solution was to handle all data from one single import and divide it into hours and days, and finally representative weekend and weekday profiles. For the three-phase system there was no need for a correcting factor because of reactive power fractions, however for single-phase systems, a factor of 0.95 was chosen to correct for the reactive power of the appliances.

8.2.1 Interpretation of Data

When it comes to the interpretation of data for producing representative load profiles for weekends and weekdays, the dilemma between satisfying the energy demand vs the power demand had to be dealt with. The issue was that for most of the buildings in the complex, there were very varying minute-to-minute values of power consumption within the hour. This variation created a misleading determination of power demands for the specific hours of the day, as summing up energy in kWh for the entire hour could lead to uncovered power peaks during the day. In other words, variation of usage within the hour leads to a relatively low energy demand during the hour, which will give an average of the power. When data is interpreted as a mean, it does not represent the power peaks for high usage some of the minutes within the hour. If a load profile based on that is applied to the scaling of the system, this will lead to the highest peaks of power demand not being covered. A simple example of this problematic can be visualized by looking at a coffee maker demanding 0.3 kW being used 15 minutes of an hour. The coffee maker would energetically imply a demand of 0.075 kWh, converting energy demand to power demand would give and average minute value of 0.00125 kW. Scaling a supply system bases on this information, would strongly undersize the supply system and sufficient production of power for the coffee maker could not be obtained. However, if only looking at the peak power demand , 0.3 kW used for the entire hour, we would get a energy demand of 0.3 kWh which would mean that scaling the supply system regarding that value would make one able to use the coffee maker whenever desired. The last suggested interpretation of usage would however lead to over sizing the supply system significantly, however the supply would be guaranteed.

As the purpose of the detection of current usage was to identify usage patterns to apply to the sizing of an expansion of the current system for handling the future demand, extensive over sizing could be a great way to approach the new demand. As it is planned to multiply all profiles by a certain number for changing the magnitude of supply of the new system, the idea was to keep this number lower because of the over sizing due to maximized interpretation of the data. The way that all data has been processed for all buildings will be referred to as the method of maximization or worst case scenario. For all buildings the minute with the maximum usage for each hour has been detected. This had been done for all measured days for each measure point and dividing those values into weekend usage and weekday usage, the maximum of those values is the basis of the profiles. In other words, the maximum minute value for each hour in one of the buildings the 21st of February is detected and the same procedure is done for 22nd, 23rd and the other weekdays that were measured. Then by looking at all values for each hour of all of those days, the highest hour-value for example for 11 o'clock is detected by comparing all days. The same procedure is done for the detection of the weekend profile.

A positive bi-effect of the worst-case scenario interpretation of the data, is that unwanted outages and unwanted low usage as a result of rationing will be disregarded and most of those data will automatically because of their low values, be excluded for consideration when determining the usage profiles. However there are also negative effects of the maximization approach as unrepresentative high peaks could be applied to the load profiles and if maximum peaks are variable and shifting from day to day, all of those peaks will be visible in the final load profile. However all approaches and interpretation of data will have positive and negative consequences, and as the schedule of activities in the boarding school is quite stabile and the total load profile will be scaled up for the determination of future load profiles, the maximization approach will definitely be the best approach for the datasets regarding this thesis.

8.3 Current Load Profiles for various Buildings

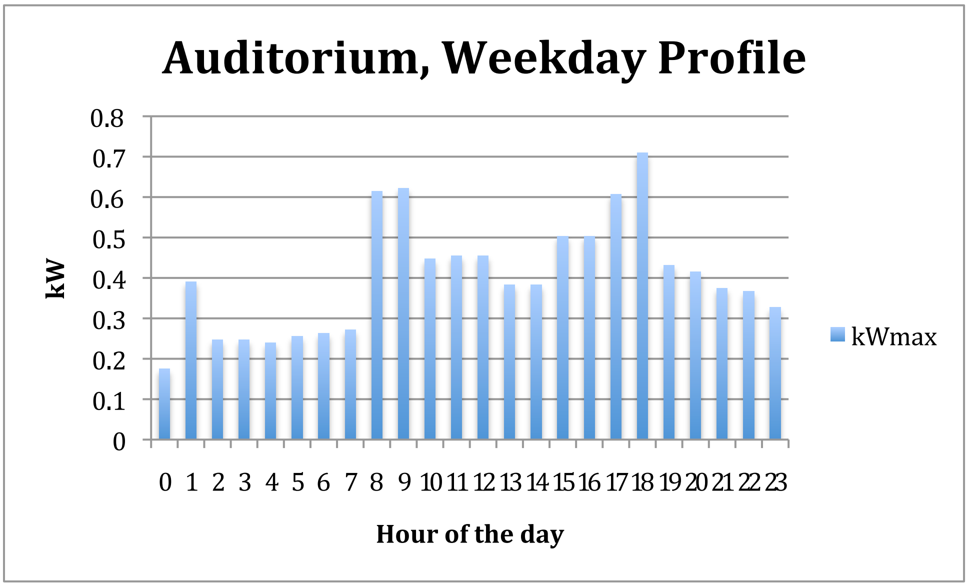
In this chapter the various current load profiles for all measure points will be displayed as well as the function of the building will be stated. The names given to each building might seem odd, however these are the names that the locals have set and that has been used in the communication with them. The normal working week is set to have 6 days, meaning that the first 6 days of the week will belong to the weekday profile and Sunday will represent the weekend. This division may seem rather unusual for European standards, however at the Wawashang complex, Saturday is no different than the other weekdays. However it must be stated that for some of the buildings there were slight differences between Saturday and the rest of the weekdays, however there were more severe cases in the opposite direction where Saturday and Sundays usage profiles were so different that they could not be put within the same category. The reason why it for all buildings had to be stated the same amount of days in the weekday/weekend profiles was that they were to be summed up together and run in PVsyst and HOMER and being non-consequent about that number would lead to miss-scaling. The big generator in the carpentry was the decisive factor for this decision, as it by far has the highest usage and Saturday had a high consumption at the same time as Sundays had a zero consumption. As the magnitude of the demand in the carpentry proved to be so extensive, an assumption that Saturday should count as weekend would severely oversize the demand as Sunday would have been expected to have the same usage as Saturday because of the maximization approach.

For all people living in the complex the day starts at 6am, when the students have to do the daily chores they are given. Breakfast is served at 7.30am, and after that the academic day is starting. At noon there is a lunch break and at 17.00pm there is dinner. After this, the school day is over for all students. One will recognize this pattern when the load profiles below are studied. The measurements were taken in the time period between the 20th or 21st of February until the 1st of March. The exception is the house of technical team, guests and professors, which had a longer measurement period due to testing (17th of February until 1st of March). The raw data that was collected can be found on the CD attached.

8.3.1 The Auditorium

The auditorium is a building that hosts some of the guests of the complex as well as some of the complex managers in its second floor. The first floor is equipped with a small kitchen corner with a gas stove and a fridge. The main part of the first floor of the auditorium is being used as offices for some of the staff and also as a meeting and reception room because of its large size and access to a beamer. Other than the beamer, there is also a fridge, fans and light sources. A varying number of computers and mobile-phones are frequently being charged. In a separate section of the auditorium there are two toilets and three showers being operated, however pressure differences in the water tanks and not electricity are managing the water flow.

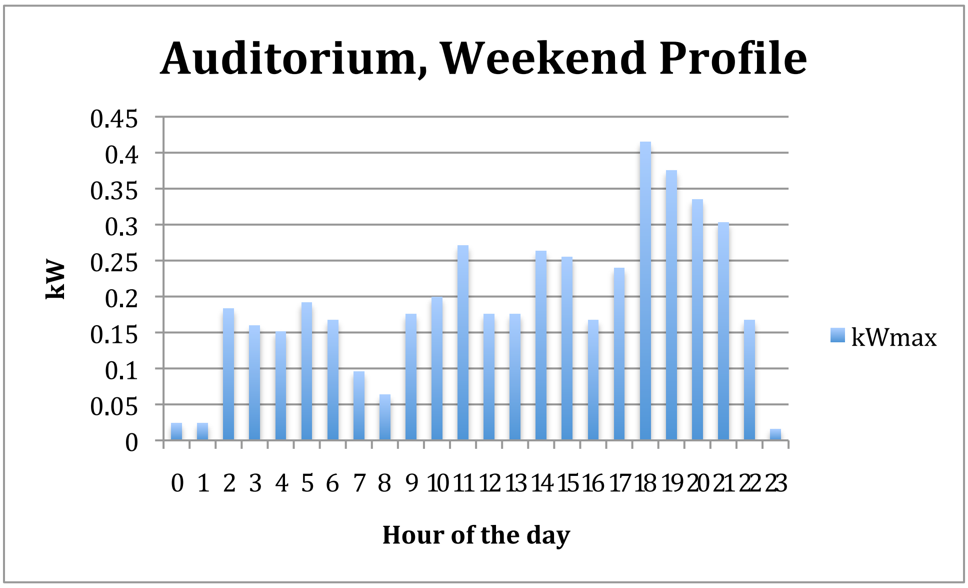
Below, the weekday profile for the Auditorium is represented. As one can see, it looks like there is a bottom load operating at all times as usage never sinks to a zero. At fist eye sight, this could seem to be caused only by the fridge, however by looking at the weekend profile it is clear that the bottom load is much lower than for the weekday profile. This is insinuating that there has to be other appliances accounting for the weekday bottom load. This could be computers left for charging or other office related items which has not been turned off or unplugged. It is in this case important to keep in mind that the maximization approach being applied as interpretation of data could lead to sources of error. This as unrepresentative overuse one evening could be displayed as a normality since only the maximum numbers are being used. The fact that the weekend profile has a lower bottom load, may confirm the suspicion of unrepresentative data being displayed. However one must keep in mind, that the bottom load is relatively low and does not contribute to a significant source of error as well as that the alternative to the over sizing approach also is suboptimal.



Graph 3 Auditorium Weekday Profile

For the weekday profile one can observe that the main peaks occur in the morning at 8 and 9 am, as well as in the evening at 4 and 5 pm. In the morning the peaks are likely to occur as appliances which are not fully loaded after the night are being charged, as well as lights might be in use. It is a little unexpected that the peaks are occurring at 8 and 9 am and not 6 and 7 am when the students and staff are starting their daily program, however even if the day starts earlier for everyone, it might be that electrical appliances and fans are not being plugged in before that hour because the students are busy with their chores which mainly is outdoor activities that does not require electricity. The maximum peak for the weekday usage in the auditorium is exceeding 0.7 kW.

The weekend profile for the auditorium is similar to the weekday profile, however it has a lower magnitude and is lacking the morning peaks. This makes sense as staff and visitors living in the building, are more likely to sleep longer and start their activities later in the weekend. One can also detect that the evening usage has shifted and the peaks relative to the rest of the day are higher compared to the weekly profile, implying that people go to bed at a later time in the weekends. As mentioned before the general usage is lower in the weekends and this is likely to be caused by less computers and office related electrical equipment are being used and people taking the day off or work less hours. However the reason for the electricity demand in the weekend appearing to be lower, could also be caused by the maximization approach. Because the weekend profile has a higher chance of appearing higher than for the weekend profile for the simple reason that the weekend profile takes a much larger amount of hours into consideration whereas the weekend profile only has one measured day. The weekend and weekday profile for the auditorium seems to be quite similar, something which is not very surprising as the guests of the complex are living there and the weekends and weekdays activities for those might not vary very much. The maximum peak for the weekend usage is a little over 0.4 kW.

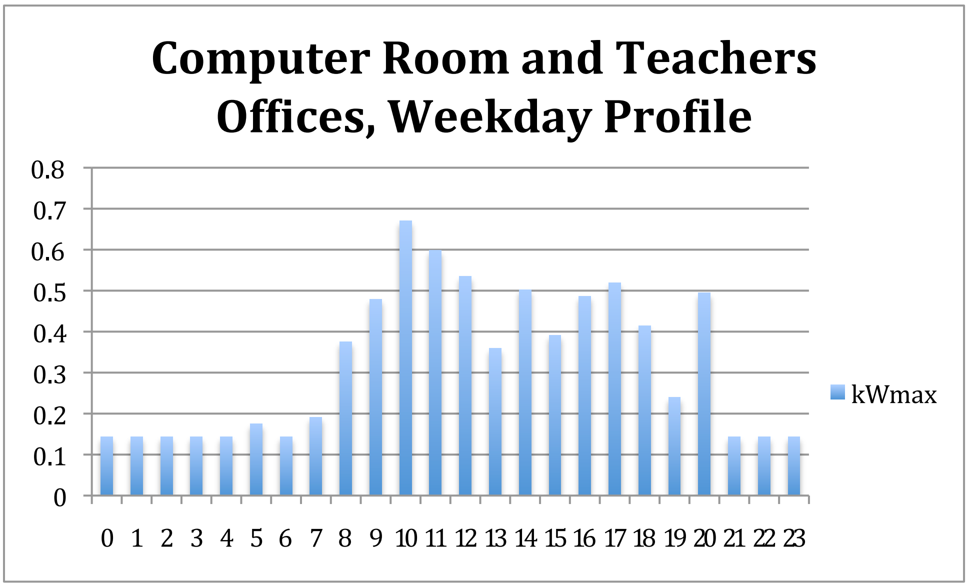


Graph 4 Auditorium Weekend Profile

8.3.2 The Computer room, library and Teachers Office

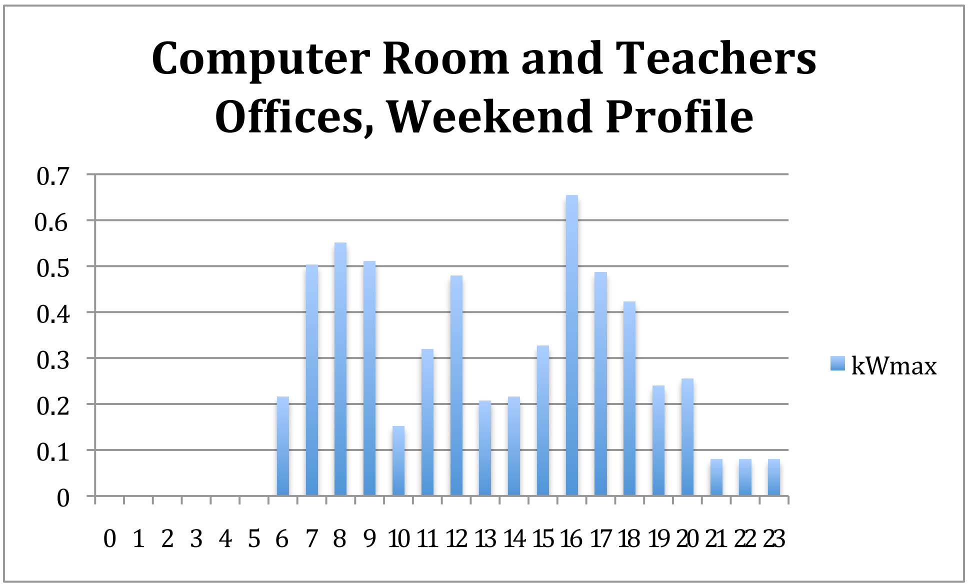
In the two following graphs the weekday and weekend profile for the building containing the computer room, teachers offices and library are presented. The computer room is currently equipped with a small number of stationary computers, fans and light. The teachers offices is equipped with light sources and the teachers with possess laptops, operate those in the offices. From what was observed during the field trip, it is very likely that most of the usage in this building is due to the teachers' offices. Like everywhere else mobile phones are also being charged in this building.

By looking at the Weekday profile one can see that the highest demand is close to 0.7 kW and it occurs between 8am and 8pm, which matches the working pattern quite well. However between 5 and 8 pm the activity in the building is supposedly of a private matter as the official working day is over. The usage profile is not smooth within the hours of high usage. At 10 and 11 am one can see significant peaks, implying that many teachers have off and spend their time in the offices, or that there are many students who are operating the computers or charging their mobile phones in the same building. The bottom load, which is present at all times and amounting to 0.12 kW, implies that there are stationary computers that are not being turned off. It is important to point out that this might not be the norm, as the maximization approach has been applied and it is enough that there was one incident with computers left on in the night for being taken into account in the load profile. However this is not a negative matter as such unnecessary and accidental usage has to be taken into account when scaling a PV system.



Graph 5 Computer Room, Library and Teachers Offices, Weekday Profile

The weekend profile is quite different from the weekday profile for the building containing the computer room and teachers offices. The magnitude of power used is slightly lower, and the highest peaks occur between 7 and 9 am and at 16 pm. We can see that the bottom load is not present, something that is an indicator of that the theory that a computer had been left on one night, is correct. The fact that the usage is lower than for the weekday profile makes sense, as it is implying less activity than in the weekdays which should be the case. The main weekend usage is likely to be due to teachers spending time in the office to plan next week's activities or for using their computers as entertainment. The facilities where the teachers are accommodated are not very large nor well equipped and that might be a reason for spending some of their spare time at the offices also for socializing. The peak demand for this buildings weekend profile, is 0.615 kW which is close to the same as for the weekday usage profile.



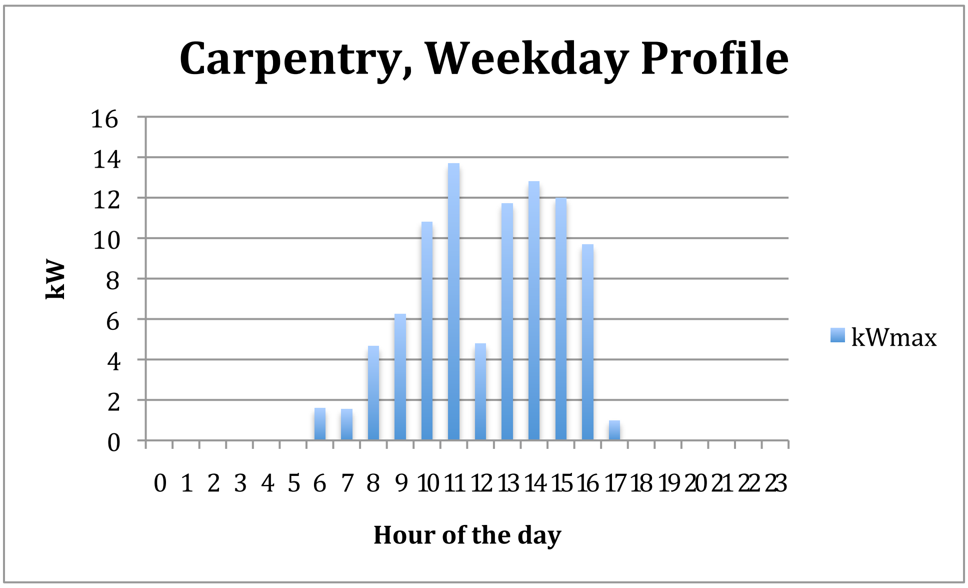
Graph 6 Computer Room, Library and Teachers Offices, Weekend Profile

8.3.3 Carpentry, 24 kW Generator

As mentioned before there are two generators providing energy for the carpentry. However as the small generator was not to be used because of welding-work demanding that the power of the large generator, there were only usable and representative data provided by the monitoring of the big generator. The carpentry is equipped with a number of different hand held machines as well as a small and a big circular saw and a board machine. The latter demanding a great amount of power for being operated. See table 9 in chapter 7.

In graph 7 below, one can get an impression of the usage regarding the large generator in the carpentry. The usage in the carpentry is as one can see in the graph above exceptionally high compared to the other buildings that have been presented so far and is also quite varied. The reason for the varied usage is due to the operation of the different tools in the carpentry. There are both very large machines with an extreme demand as well as small handheld machines with a low power demand. As one can observe from the graph below, the large generator is only running between 8am and 5pm, something that is well corresponding with the working pattern. The low usage at noon, implies a break from using the most power consuming appliances in the carpentry.

Like always one must keep in mind that also in this case there could be misleading numbers appearing in the graph because of the maximization approach. This is for the carpentry especially important, as there is knowledge of that decentralized welding work was being done at a building site at the time. Welding will typically give one large peaks exactly the seconds when the welding machine is being operated, and by using the minutes with the largest usage, it might look like the welding machine is being used at all times within the hour even if the reality is different. However since the carpentry is the building with the largest future demand, this extreme over sizing can be justified. The question is whether the usage at the time of monitoring is realistic and not just a bi-product of the welding work. In other words the issue is whether the heavy machines were overused while welding to avoid energy inefficiency by not using the total potential power of the big generator. The peak demand is close to 14 kW and occurs at 11 am. This is by far the highest usage of all the buildings being monitored.



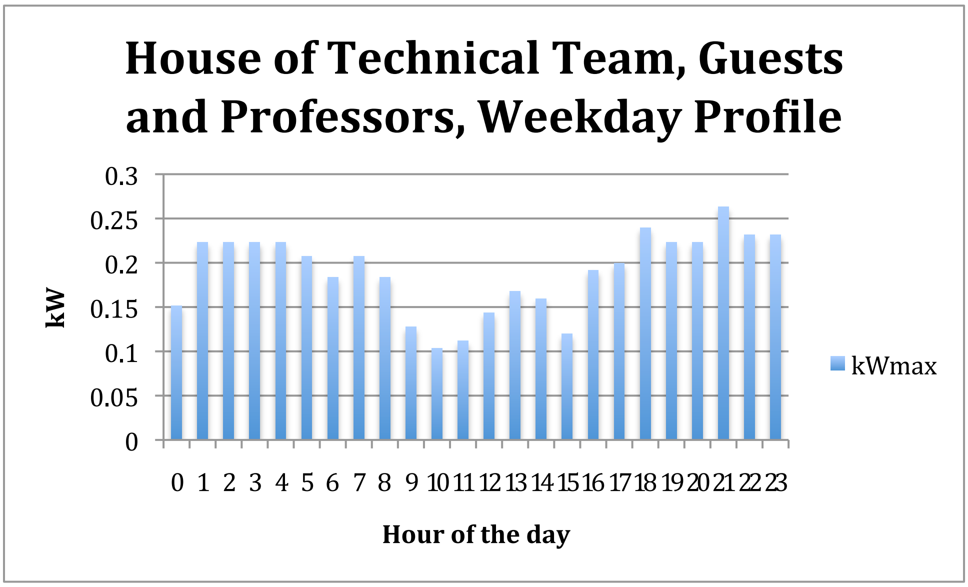
Graph 7 Carpentry, Weekday profile

When it comes to the weekend profile for this specific building, on Sundays there is absolutely no activity and thereby no energy demand in the carpentry.

8.3.4 House of Technical Team, Guests and Professors

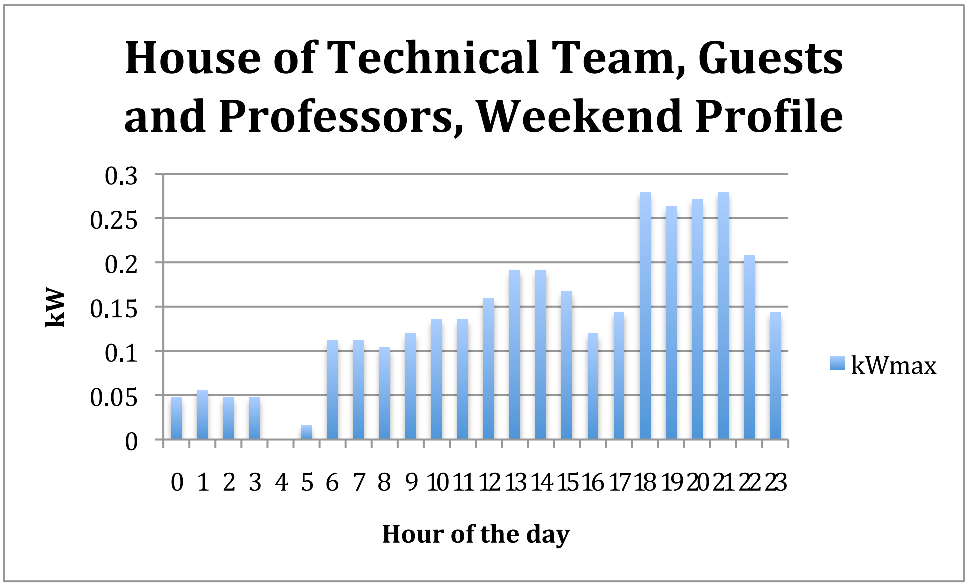
House of technical team, guests and Professors is a building for accommodation of some of the staff, professors and guests of the complex in Wawashang. The building is equipped with fans and light, as well as personal effects like computers, radios and mobile phones are being used.

As one can see in the graph on the next page, the magnitude of usage for this building is very low with a peak just exceeding 0.25 kW at 9pm. One could say close to insignificant in the big picture when comparing with buildings like the carpentry. The profile seems to be matching very well with the usage pattern for the building and one can see that in the middle of the day the power demand is the lowest which suggests that people are outside working and it looks like other than charging some appliances there are close to no other usage. However usage during the night is surprisingly high, however this could be caused by fans being turned on while people are sleeping or appliances left to charge. It might also be that the maximizing approach in this case could be slightly misleading.



Graph 8 House of Technical Team, Guests and Professors, Weekday Profile

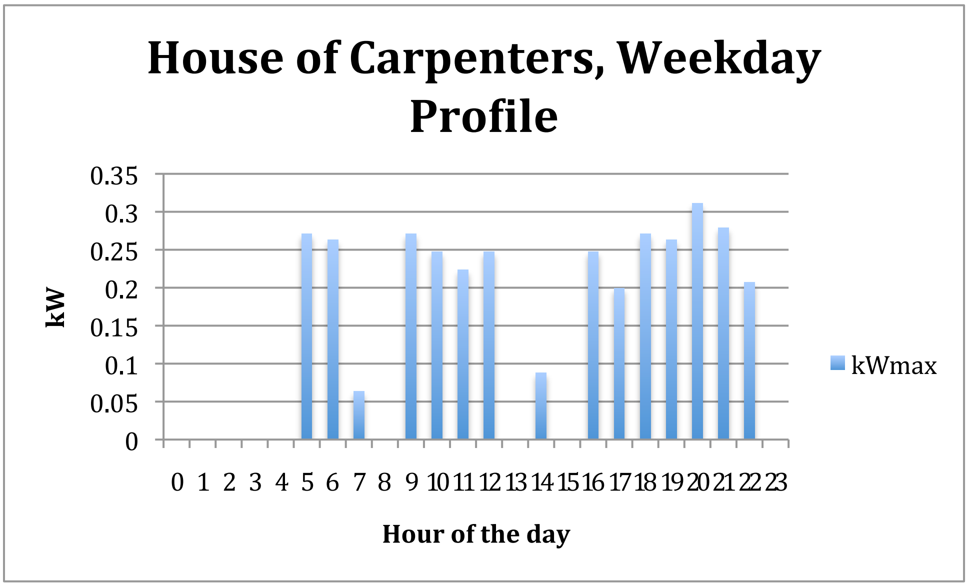
When it comes to the weekend profile of this building one can see that the night usage between 11pm and 5am is quite low compared to the weekday profile. One would think that the usage in the middle of the night would not be very different from the weekday usage, however the reason for this could simply be that there is only 2 days with weekend data and then we will not get the opportunity to maximise the data in the same way as for the weekday profiles. The electricity consumption is in the weekend higher then for the weekday profile between 6pm and 9pm in the evening, implying that the evening usage in the weekends are higher and more indoor activities are taking place. The usage in the middle of the day between 10am and 3pm is slightly higher than for the weekday demand profile at the same time, this makes sense as the people accommodated in the building have time off and thereby more people will spend time there with energy consuming activities.



Graph 9 House of Technical Team, Guests and Professors, Weekend Profile

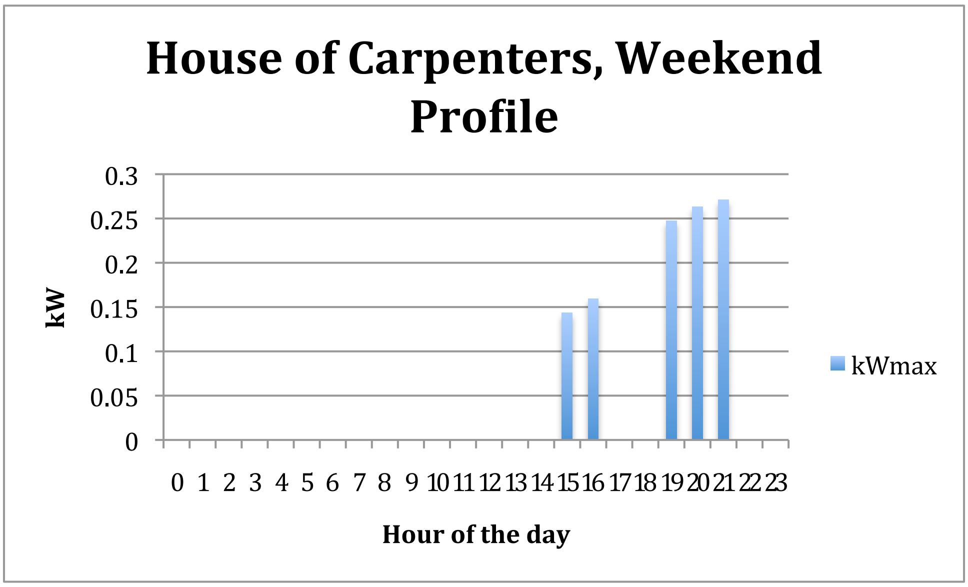
8.3.5 House of Carpenters

The house of carpenters is a building where the teachers for the carpentry are stationed and the building is equipped in a similar manner as the house of technical team, guests and professors. This building was electrified during the stay in Wawashang, and since the system was relatively new one must keep in mind that the people living there are not used to being able to have proper access to electricity. Therefore the power/energy consumption might not be completely representative. This might be the reason why the weekday profile for the house of carpenters is very different than the other weekday profiles represented so far in this chapter. As one can see on the next page, the current peak power demand for the house of carpenters is exceeding 0.3 kW and is occurring at 8pm. The curious thing about this buildings profile is that it is consisting only of similar peaks at three periods of the day and lower usage than that different than zero, only occurs at two points during the day. One reason for this rather curious load profile could be that the maximization approach is making it seem like there are more peaks than there really are. This because in reality it might be that there are only 3 or 4 peaks per day but because they are occurring at different hours of different days the maximization approach takes the maximum hour of all days and makes it look like all of the peaks occur in one day. This may seem like a negative weakness of the maximization approach, however one must keep in mind that when scaling a PV system one must make sure that the system can handle peaks occurring at different times every day, and the only way to prepare the system for that, is by taking them all into account like the maximization approach does. By taking a look at the raw data (CD accompanying the thesis) one can discover that the theory is right.



Graph 10 House of Carpenters, Weekday Profile

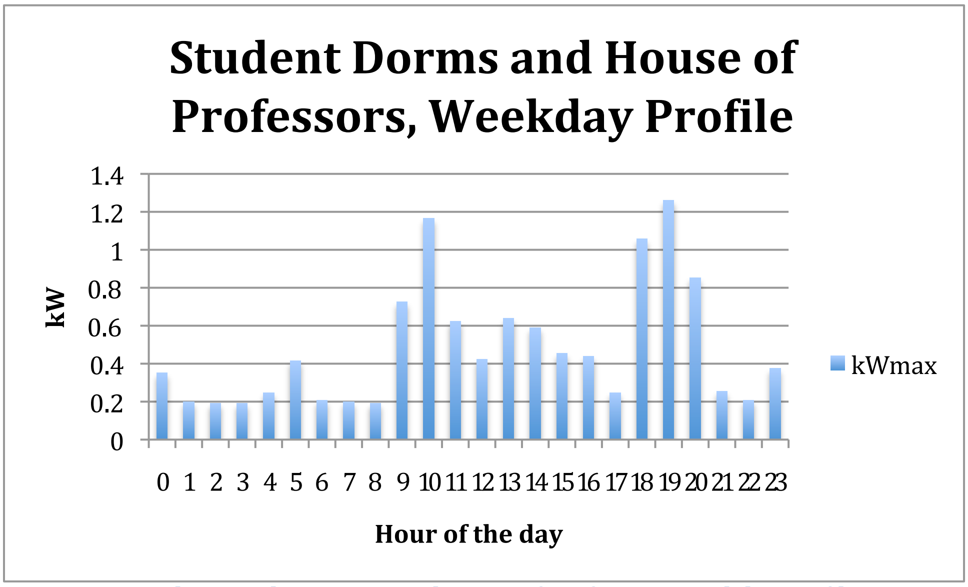
By looking at the graph on the next page one can get a visualization of the weekend profile of the house of carpenters. The fact that there are only 5 hours where electricity consumption has been detected, is also confirming the hypothesis that the maximization approach is disguising the real everyday usage. On Sundays there apparently is only electricity being consumed in the evening and then only a few hours of very low magnitude. The peak is occurring at 9pm with a magnitude of a little over 0.25 kW.



Graph 11 House of Carpenters, Weekend Profile

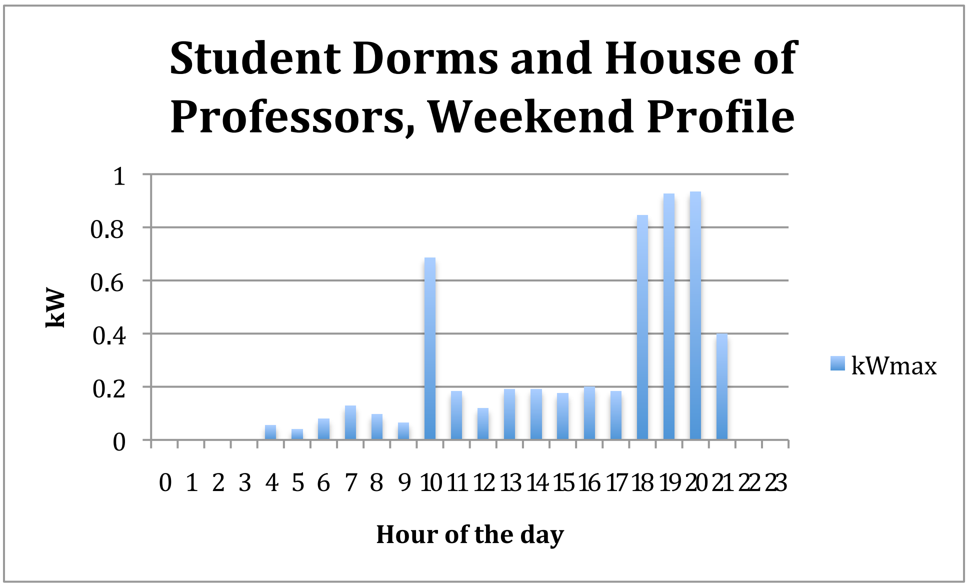
8.3.6 Student Dorms and House of Professors

The house of professors is as mentioned earlier also supplying the different dormitories for the students. However the students only have access to electricity between 6pm to 8 pm. The house of professors is a building that consists of a number of small rooms housing most of the professors. The building is equipped with fans and light, as well as each professor has a laptop, radio and mobile phone. The dormitories are 6 buildings, each with a numbers of rooms in which 4-6 students are sleeping. The dorms are equipped with light and most of the students have their own mobile phone and some of them have radios. In the graph below one can detect the peaks between 6pm and 8pm, something that is very representative regarding that the students only have access to electricity within these hours and that those are the hours when the students have time off. During the fieldtrip it was however also observed that they charged their mobile phones on various locations in the complex during the day. The staff did not like this, however from an energetic point of view this is a good thing because charging their phones in the evening would use the little stored energy in the batteries instead of possible non storable energy during the daytime. The usage is overall relatively low, however the four peaks occurring at 10am and between 6 and 8 pm are quite significant. The highest peak is exceeding 1.2 kW at 7pm. The peak at 10am is rather surprising, as the students at this point of day are not supposed to have access to electricity. It could however be that one of the days of measurement they were given extra access to electricity, and that it is this peak that is represented in the graph.



Graph 12 Student Dorms and House of Professors, Weekday Profile

Below, one can get an impression of the weekend usage of the house of professors and student dormitories. We can easily detect the same trends as for the weekday profile however with a slightly smaller magnitude. The reason for the lower magnitude is not necessarily caused by a lower consumption, however like for many of the other buildings this days consumption will be lower because of the maximization approach and the fact that the chance of a high consumption displayed in the profile, is higher because a maximization over a larger dataset has been applied. Just like for the weekday profile one can see that there is a peak occurring at 10am, a peak that suggests a repeatedly high consumption at this hour, something which again implies that the students have been given access to the electricity. It is suspected that the students have been given access to electricity at 10am, as it is very unlikely that the few appliances the professors have, alone can cause such a large peak. The highest peak occurs at 8pm and has a magnitude exceeding 0.9 kW.

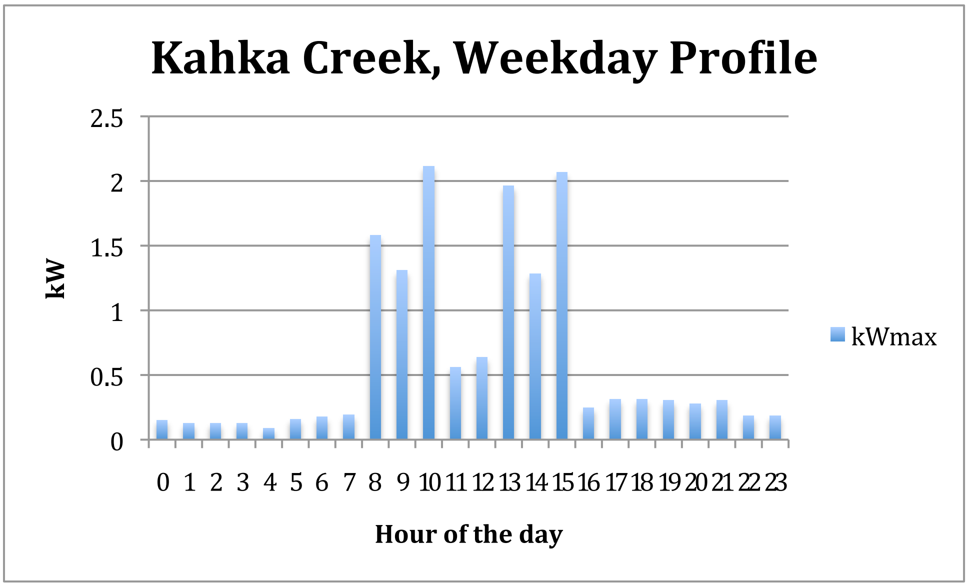


Graph 13 Student Dorms and House of Professors, Weekend Profile

8.3.7 Kahka Creek

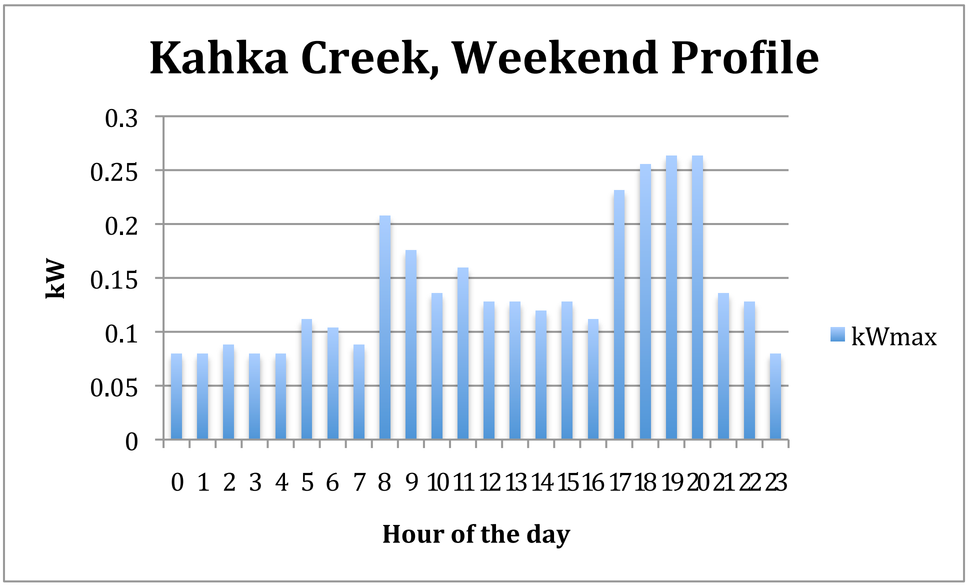
Kahka Creek is as mentioned before in a different location than the other buildings and on the other side of the Wawashang river. Kahka Creek has a mini grid with solar panels and a generator as a supply system for the 3 buildings there, however as it was told that the generator was not to be used within the time of measurement, so only the PV-part of the supply system was measured. The main building, which is a large house with sleeping facilities, kitchen and a living room. The other two buildings is a small classroom and a carpentry with both light and heavy machinery as well as illumination and a generator for power supply. The appliances in the main building are mainly fans and illumination, as well as there is Wi-Fi, computers and mobile phones are in use. The building is normally only housing two of the staff members, however they receive a lot of visitors in connection with the Wawashang complex and a higher number of mobile phones, computers and fans are then expected to be operated.

The surprising factor of the graph below, is that we can recognise some significantly high peaks exceeding 2 kW between 8 and 10pm and 1 and 3pm. When looking at these peaks up in the raw data one can discover that they occurred on different weekdays and only for one or two minutes at the time always. The maximization approach makes these peak values visible even if it could be misleading to say that the continuous power demand those hours are of that magnitude. Then the question is what load it could be, that demands this kind of power for only a couple of minutes some of the days. The only possible explanation is that they have been using some of the lighter machinery in the carpentry even if it was told that when using those, the generator should be the power source. However it is strange that the load is visible only for a few minutes and that this happens repeatedly. There is also an other explanation and that is that the large antenna for the Internet connection is creating disturbances. However this is not very likely as it happens repeatedly and only for some minutes at the time. One can observe that the overall usage apart from those peaks is very low and stabile.



Graph 14 Kahka Creek, Weekday profile

Below the weekend profile of Kahka Creek is displayed. The main usage occurs in the evening as expected, as light and fans are needed, however the power demand is very low with a peak of right over 0.25 kW, which occurs at 7 and 8 pm. The extreme usage peaks which could be seen in the weekday profile, are not to be seen for the weekend usage. This supports the assumption of those peaks being caused due to disturbances and not actual electricity consuming activities.



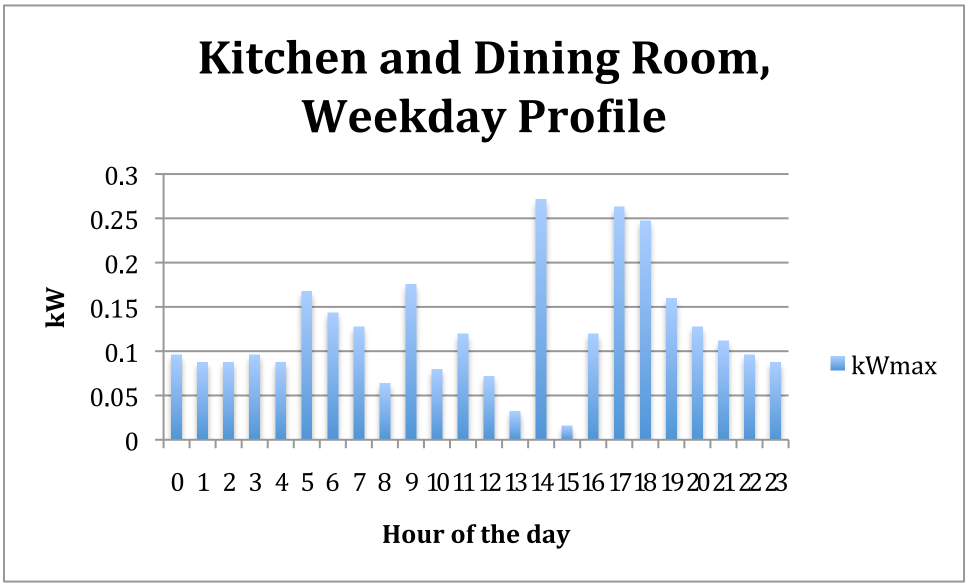
Graph 15 Kahka Creek, Weekend Profile

As Kahka Creek is remote from the Wawashang complex and will not be a part of the PV system there, it had to be handled separately. According to table with future demands of the complex in table, Kahka Creek was also expected to have an increased power demand, however after seeing the system there and studying the energy consumption there, it is hard to defend an expansion of the current system there. The system is installed by BlueEnergy and is very new, sophisticated and the perfect size for Kahka Creek. It is hard to imagine which kind of other appliances could be added to the rather well equipped and modern main building. So in cooperation with the contact person in FADCANIC it was decided to leave Kahka Creek as it is for now and focus on the Wawashang complex. The fact that the load profiles for Kahka Creek will not be further used, is why the mysterious peaks for the weekday profile is not getting further investigated nor modified.

8.3.8 Kitchen and Diningroom

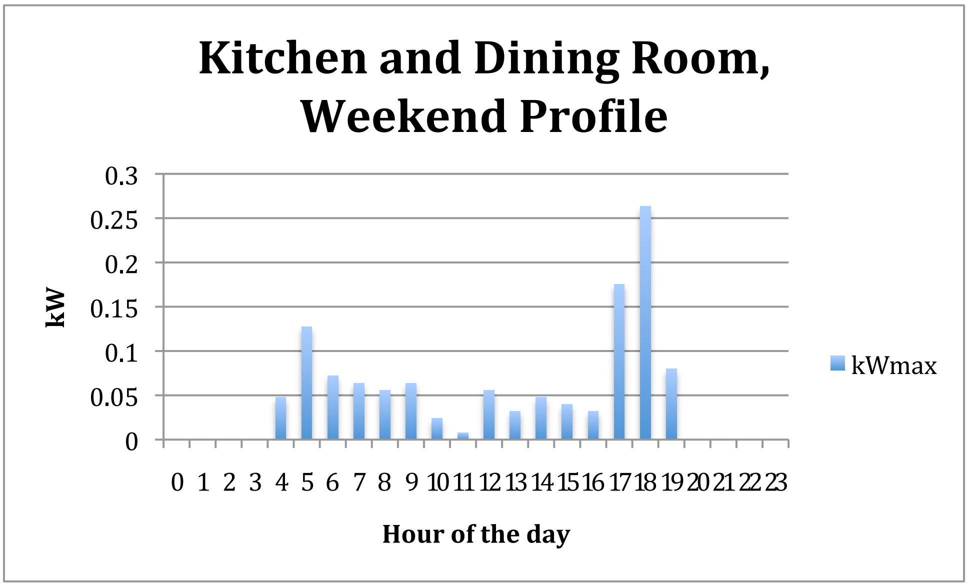
The kitchen and dining room are two separate buildings, they however have the same PV supply system situated on the roof of the dining room and the same battery-pack. In the kitchen, the only electricity consuming appliances are the light sources. The stove situated in the kitchen is wood fired and does not demand any energy. In the dining room, the lights are the biggest contributors to the energy demand, as well as students are charging their phones there from time to time. Earlier there were cold storage facilities, however they are currently out of order. The magnitude of the load profile for the kitchen and dining room is as one can see very low.

The maximum peak occurs at 2 pm and has a magnitude of a little over 0.27 kW. The serving of the meals are taking place at 7.30 am, at noon and at 5pm. The peaks from 5pm to 6pm are coherent with this pattern, as lights are needed for the last serving. The peak at 2pm could be a result of many phones being charged at the same time one day of the measurements and the maximization approach will visualize this episode. There is also energy usage detected between 22pm and 4pm, something that suggests that an appliance was left for charging one of the days of monitoring.



Graph 16 Kitchen and Dining room, Weekday Profile

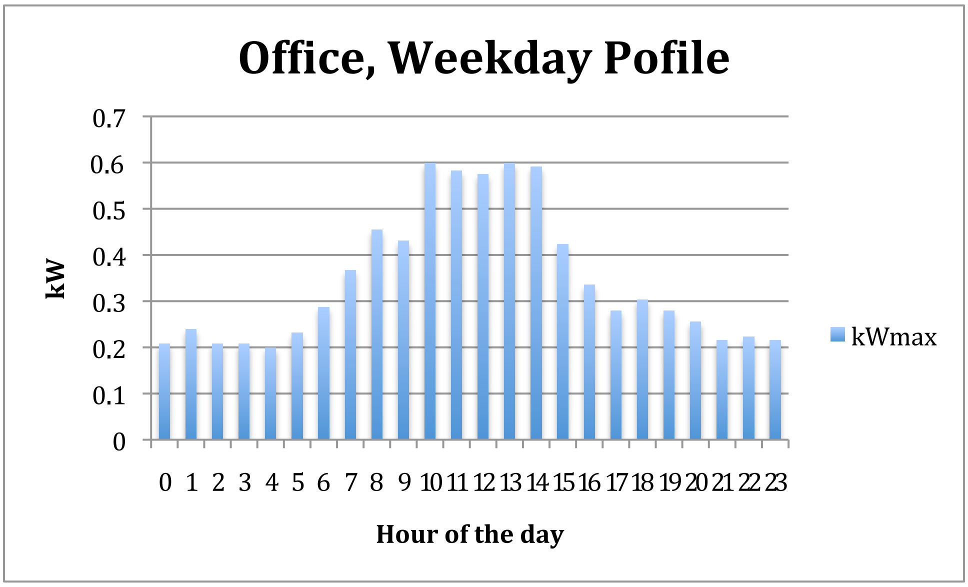
The weekend profile for the kitchen and dining room shows the same trends as for the weekday profile. This is not very surprising as the meals occur at the same time on Sundays as for the rest of the week. The highest peak occurs at 6pm and has the same magnitude as for the weekdays, 0.27 kW. The peak at 2pm is however away as well as the bottom load. This is confirming that the 2pm peak is not a normality but a product of the maximization approach.



Graph 17 Kitchen and Dining room, Weekend Profile

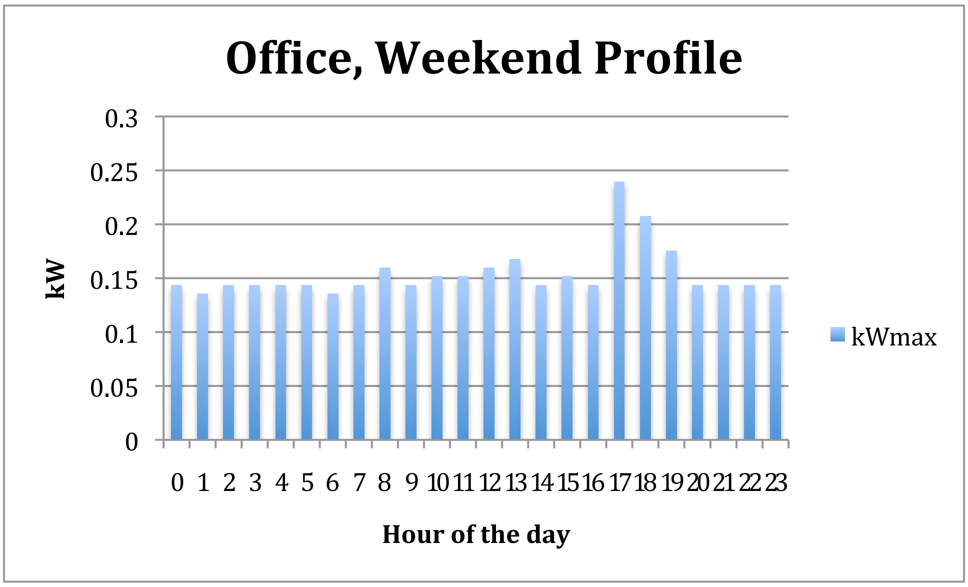
8.3.9 The Office

The office is equipped with a number of stationary computers, a telephone and a printer as well as light sources and fans. The staff members working there also have mobile phones that are being charged in the office. As one can see in the graph below, the weekday profile for the office has a constant bottom load of approximately 0.2 kW, a load which is likely to be stationary computers that are not being turned off. In the working hours between 8am and 5pm there is an approximate demand of between 0.3 and 0.6 kW, with the maximum peak of 0.6 kW occurring at 10am. One can see that during the lunch break at noon, no one turns off any of the appliances being used.



Graph 18 Office, Weekday Profile

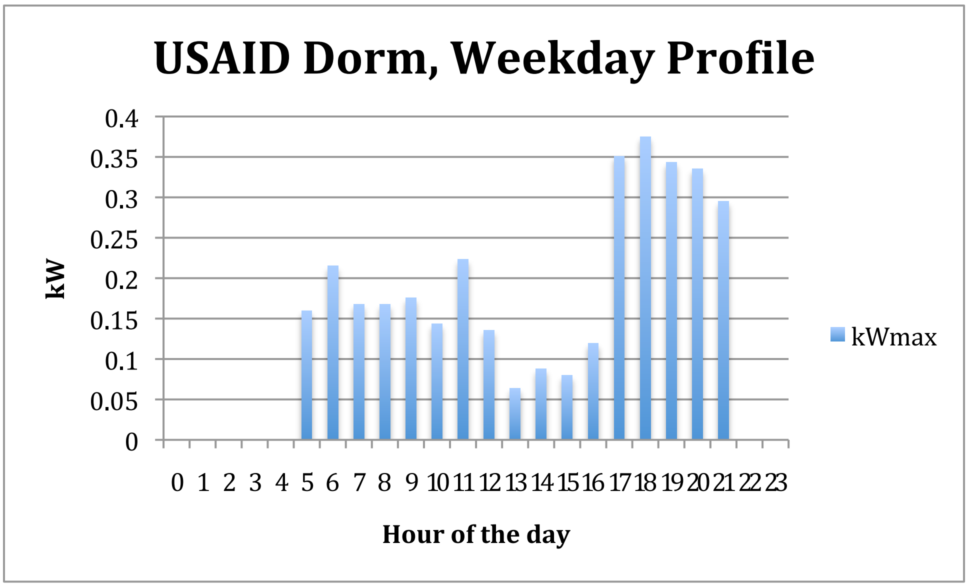
The weekend profile is mainly containing the same bottom load as in the Weekday profile, but it is somewhat lower in magnitude. This implies that some of the stationary computers are always turned on. The three peaks between 5 and 7pm could be someone operating the printer or other appliances due to overtime work.



Graph 19 Office, Weekend Profile

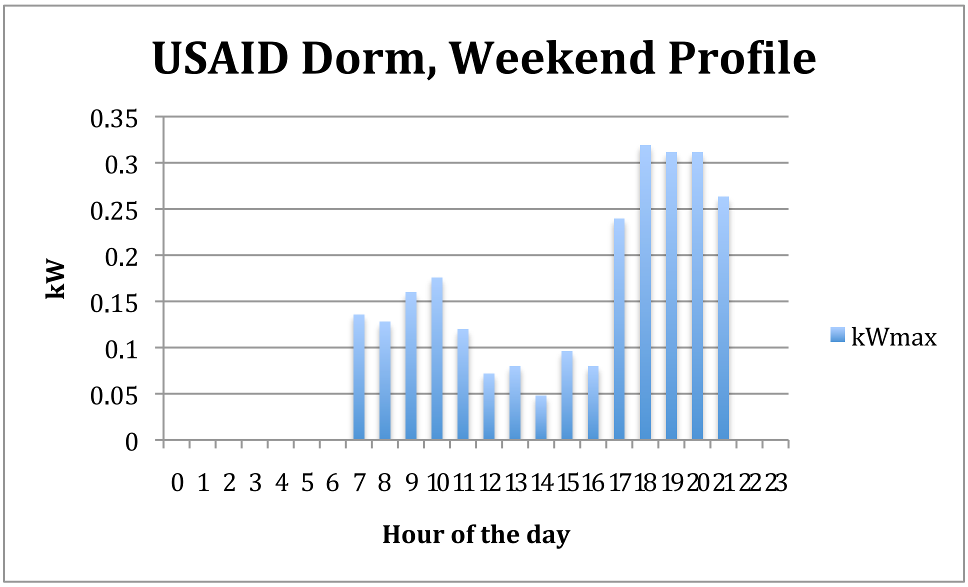
8.3.10 The USAID Building

The USAID building is a dormitory with an own PV-system which is financed by the organisation USAID, thereby the name. The building is mainly functioning as a dormitory for the students, however one of the teachers is also stationed there. The appliances one can find in this building is typically light sources and also presumably a laptop for the professor being accommodated there. Mobile phones and radios are also likely to be a big contributor to the energy demand. In the graph below one can get a picture of the weekday profile for the USAID building. By looking at the other building with accommodation as a function, one can see the same pattern of the highest usage occurring in the evening between 5 and 9pm. In a similar manner, the daytime power demand is low for those buildings. The highest peak occurs at 6pm and reaches over 0.37 kW. The electricity demand is occurring between 5am and 9pm, something that matches very well with the students daily pattern with chores starting at 6am and bedtime and lights going off right after 9pm.



Graph 20 USAID Dorm, Weekday Profile

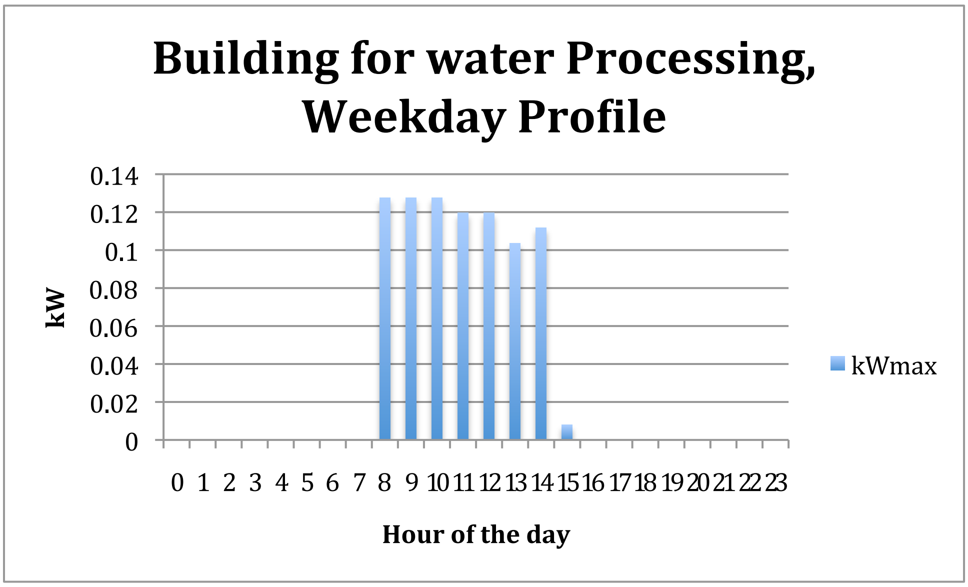
In graph 21 one can see the weekend energy usage pattern for the USAID building. The trends are almost identical as the weekday profile, however the magnitude is a little lower. This is however expected because of the maximization approach and only one day being representative for weekend usage. One can also observe that the electricity consumption is staring at a later point in the weekends and this makes sense as no classes are taking place. The highest peak is a little over 0.3 kW and this peak occurs at 6pm just like during the weekdays.



Graph 21 USAID Dorm, Weekend Profile

8.3.11 The Building for Water Processing

The building for water processing contains a Ultra Violet cleansing system which purifies the drinking water. Except from the purification system, the only other electrical appliance is light sources. Below one can see the weekday profile and one can see that the energy consumption is very, very low and quite stabile at the hours of operation. The highest peak occurs at between 8am and 10am and is barely exceeding 0.12 kW. It is for this building important to underline that the system is not being used everyday, but only 2 times per week one will see something the profile below and the rest of the week the demand for the water processing building is zero.

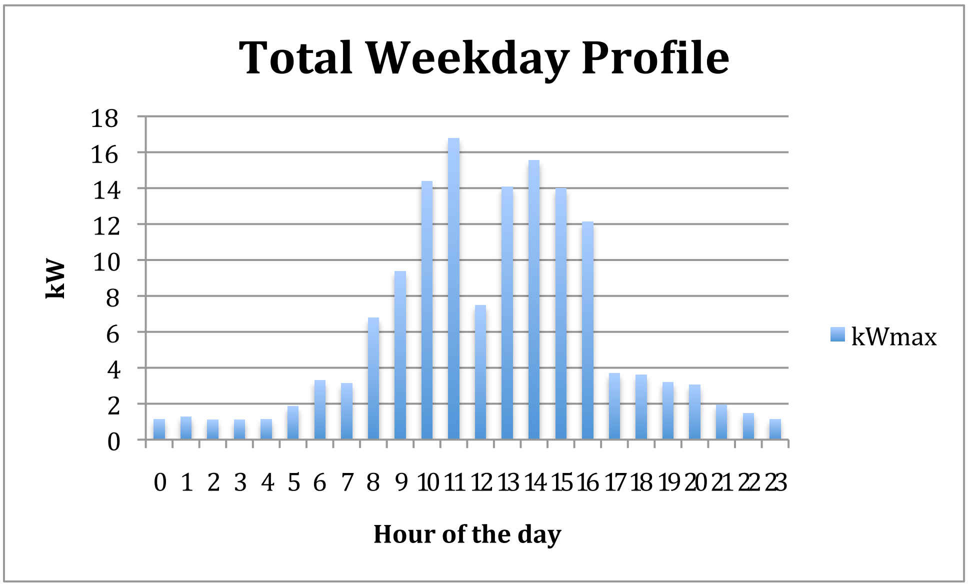


Graph 22 Building for Water Processing, Weekday Profile

The weekend profile for the water processing building is zero and there is no energy demand.

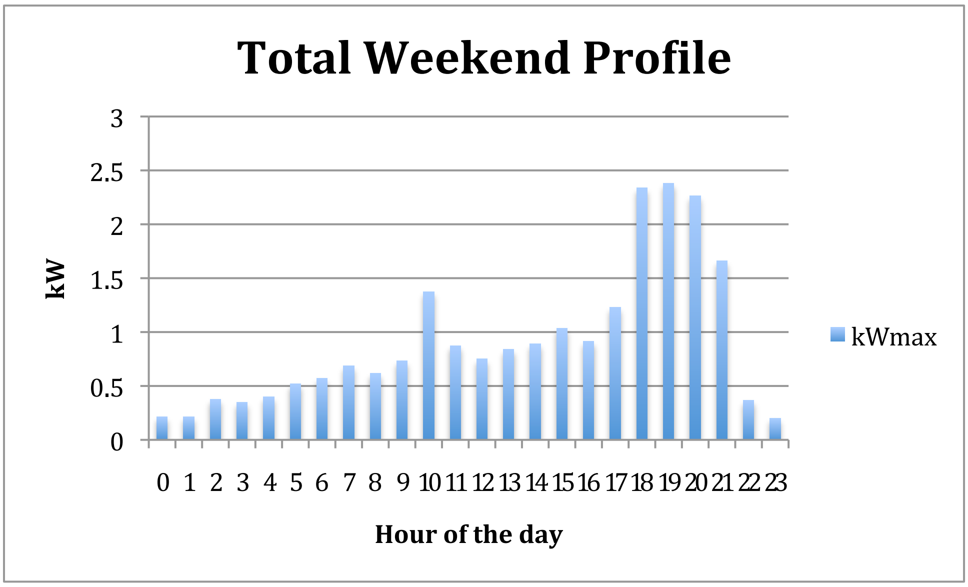
8.3.12 Total Current Load Profiles

Since the goal is to scale a PV cluster for the entire complex, all the relevant load profiles have to be summed up, both for the weekday and weekend profiles, this in order to be able to see the entire power demand in the complex as a whole. For obvious reasons the load profiles for Kahka Creek will not be contained here. In the graph below one can see the total measured demand for the Wawashang complex.



Graph 23 Total Weekday Profile

The graph displaying the total current weekday usage is as expected extremely influenced from the load profile in the carpentry. The carpentry's demand is so high that it at 3 pm it is 6 times higher than the total demand of all buildings excluding the carpentry. This fact tells one that the carpentry is a very important and decisive factor for the scaling of the clustered PV system. The highest peak for the demand of all measured building in total reaches 16.79 kW and occurs at 11am. The lunch break at noon is clearly visible. Regarding that it is a supply system powered by solar energy with generators as backup, it is a very good thing that the highest loads occur during the daytime, as the demand for storage will be stay relatively low.



Graph 24 Total Weekend Profile

By studying the graph on the previous page, one can get a picture of the total weekend profile for the buildings that were measured. The magnitude of this load profile compared to the weekday profile is very low and the main reason for that is that the carpentry had a 0 demand on Sundays. An other factor contributing to that, is a overall low activity in the complex on Sundays. The highest peaks of close to 2.3 kW occur in the evening between 6 and 9 pm. The fact that the weekend and weekday profiles are so different, is a very positive factor for the planned PV system as the battery pack during this period gets the opportunity to get filled up. However spillage due to full batteries in the weekend, might be a problem related to this. Spillage is an issue, which will be returned to in coming chapters.

When it comes to the data displayed in graph 23 and 24, one must keep in mind that the profiles for the generators in the building for food processing and the PV system in the laboratory as well as the small generator in the carpentry for already mentioned reasons are not taken into this profile. An other important factor is that the big generator was being operated unusually much because of the welding work being done. It is therefore important to look at this total weekly load profile only as a very close estimate to reality. It is also important to underline that since the measurements for the different buildings were only made for a little over a week, it is not sure that this week was representative for the rest of the weeks of the year. However this load profile seems to be a good match for the total demand based on the information that was given and the knowledge of the daily pattern that was retrieved during the field trip.

8.3.13 Total Future Load Profile

The last step toward having a complete load profile for future operation of the complex in Wawashang and a key parameter for scaling a electricity supply system, is to modify the current load profile so that it yields for expansion of the complex and increased demand in the future. There are many approaches to make this modification and pros and cons for all approaches as well as the simple reason that there is no right and wrong, emphasizes that it is all just a matter of perceptions and visions. Regarding the data available and the knowledge shared by the locals there were two well suited approaches to apply to the current load profiles towards determining the load profile for the planned PV system regarding future demand. Both of those approaches involve using a multiplication factor for changing the magnitude of the total current load profiles. However whether to use one multiplication factor for each measure point, or to use a multiplication factor for the total current load profile, was the issue that needed to be carefully evaluated.

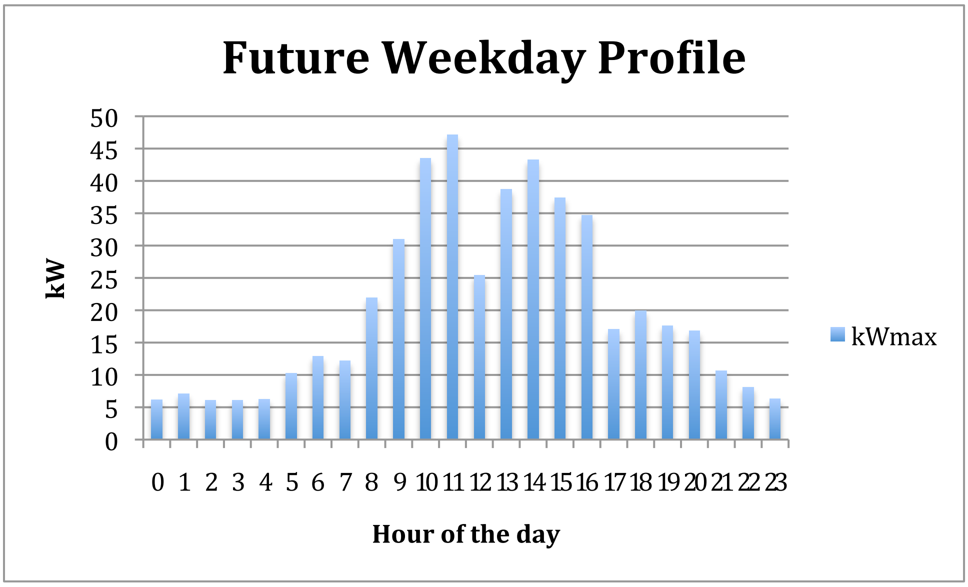
Finding a multiplication factor for each measure point, was the idea that was evaluated first as this was thought to be the best and most accurate approach. The reason for this was that the peak values for desired future demand, were given by the contact persons in Wawashang (see table 8). However, when realizing that these numbers were highly unrealistic when comparing with the measurements made, the reasoning behind these numbers was requested. As feared, the numbers were pulled out from thin air and did not have a very close relation to the reality. So when trying to evaluate each and every building it was concluded with that with those values being faulty, there was simply not enough information regarding the future demand for each building, to be able to justify any multiplication factor for a likely future demand. An other problem regarding the use of those numbers provided is that there only were measurements for some of the buildings of the provided list, as a handful of the buildings there are planned for the future. So how to apply those to the multiplication factor of each building to a planned building, would be an issue. An other reason for choosing a multiplication factor for all the buildings in total, is that the multiplication factor easily can be modified and is easy to understand and work with for the next group of people taking over the Wawashang project.

So then the question is how to find the common multiplication factor to apply to the current usage profiles for the future power demand. The only other relevant information that was given regarding future demand was that by year 2032 there would be a total of **328** people in the complex when used to its full capacity, compared to today's **136** people under the same circumstances**.** The number of students was to rise from 120 to 234. However this information is only applicable for the complex as a whole and cannot be translated to yield for one building at the time. The information of the increasing number of people being situated at the complex is however only the start of finding a common multiplicator. One cannot simply say that the power demand is rising proportionally with the number of people in the complex as many people are accommodated in the same building and one person does not contribute to the demand for an entirely own classroom and dormitory as the same light source, fans and common computers are shared between all students. There are also other reasons for the wanted expansion, which does not have anything to do with the capacity of the complex, like new buildings and more appliances. However the number can to a certain degree be used when reasoning towards the best-suited multiplication factor.

Through our cooperation and communication with the group Blue Energy, their preliminary calculations and estimates around a mini grid in Wawashang, which they did research for some time ago, were presented. They operated with a 30% increase in demand compared to the current electricity consumption, but they did not have a special thought behind that number, as they also struggled with proper numbers being presented. As the uncertainty around the multiplication factor was high, it was decided to ask the contact person in FADCANIC for more realistic numbers. It was then claimed that within 2017 the demand would double. By 2019 it will be tippled and by 2021 it will be four times the current demand. By 2023 they expect the actual amount of power demand to be five times as high as today. As before, the issue regarding where these numbers came from reappeared. A five-doubling of the power demand by 2023 would mean a peak demand of over 83,9 kW, from which the carpentry would demand 68,5 kW. It was hard to imagine how this could be realistic and whether a system of that size could be feasible. It was therefore made an attempt to negotiate that all of the complex except the carpentry would be dimensioned with 5 doubling of the power and the carpentry would be dimensioned with a doubling of the power demand regarding the current demand.

It is important to remember that the maximization approach has already made sure of displaying the highest consumption possible with the reservation that the data was representative and it could be an idea to therefore downscale the negotiated multiplication factor slightly. However it must not be forgotten that the planned buildings and buildings which system did not have a feasible measure point are not included in the up-scaled load profiles. Therefore the over sizing that the maximization approach leads to, will be a buffer to make sure those loads can be served.

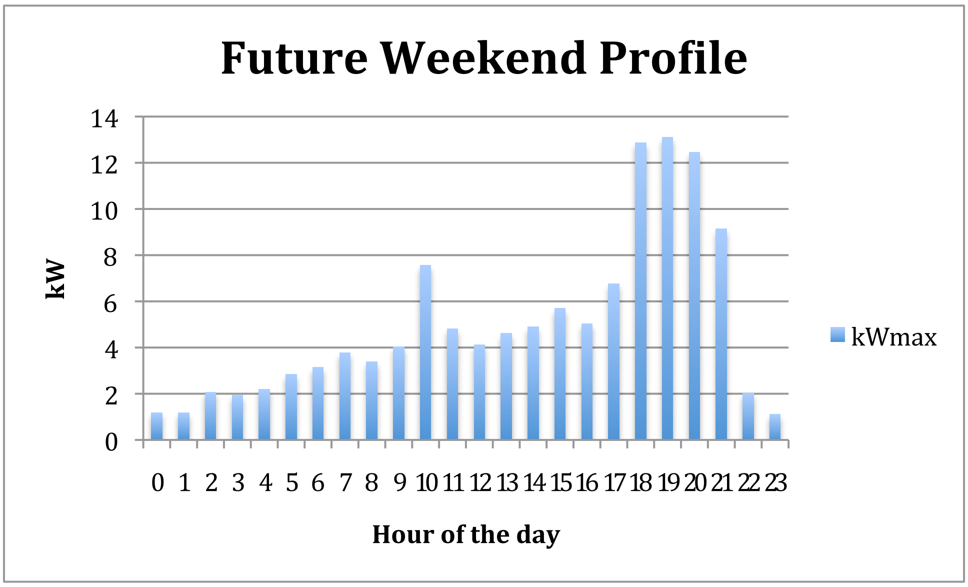
Below the total weekday load profile of the Wawashang Complex is displayed. In addition to the multiplication factor of 5 and 2 for respectively the complex and the carpentry isolated, an additional 10% had to be added for losses due to the distribution of the electricity in the planned micro-grid.



Graph 25 Future Weekday Profile

The peak load demanded is a little over 47 kW and occurs at 11 am. It is 7.8 times higher than the lowest demand, which occurs at 2 am and has a magnitude of a little over 6 kW. The lunch break at 12 is easily detectable and as close to all students and teachers are having lunch, the electricity demanding activities are drastically reduced. The fact that all the peaks of the demand occur during daylight, is reducing the need for battery capacity drastically.

Below the weekend profile for the total weekend demand is displayed. The load profile is very different from the weekday profile and is characterized by a low demand during the day and high peaks in the evening. The highest peak occurs at 7 pm and reaches a magnitude of about 13 kW. This is a demand that is 13 times larger than the 1 kW of electricity demand at 11pm. The fact that all peaks are occurring at night, could have been contributing to a lager battery pack needed, however the evening demand in the weekday profile is higher, so this will not be the case. As one can guess by looking at the enormous differences between the magnitude of the weekend and the weekday profiles, the system will in general be significantly over scaled for weekend usage. The batteries are therefore expected to get filled up during the weekend, something that is a good thing, as it reduces the loss of load. However the extreme over scaling for weekend operation creates a great risk of spillage and unused energy, if the battery pack is not large enough to handle the low usage and high irradiation.



Graph 26 Future Weekend Profile

8.3.14 Sources of Error

When it comes to producing a load profile based on data from many different sources and all sample data require processing and interpretation, as well as the data being collected within a short and not necessarily completely representative timeframe, there are some sources of error that cannot be avoided but however needs to be enlightened, discussed and taken into account.

One of the sources of error could be signal interference with measurements. It was detected during the fieldtrip that the large antennas for providing WiFi, could interfere with the measurements, and create very high peaks, however this was at a magnitude of which was easily detectable and therefore the units that had these issues, were reset and programmed over again. However for Kahka Creeks load profile it is possible that the antenna was causing the extreme peaks that have been pointed out. However as Kahka Creek is not a part of the total load profile, this will not interfere with the simulations that will be performed based on the load profiles.

Unwanted blackout of system because of rationing or system error, could also be a source of error regarding the total load profile. This because the low usage is involuntary and where there actually was a high demand, a low demand is detected and applied to the load profile. However, a great effect of the maximization approach is that mostly those hours with involuntary usage will be disregarded as only maximum values are taken into account.

The fact that the beginning of the period of measurements might not be representative as it was in the beginning of the semester and some of the students had not arrived, is also a possible source of error. However even if the period of measurement might not be representative for normalized usage for some of the days, the maximization approach disregards days with lowest measurements. Therefore the effect of this source of error is minimized.

The Welding work being done in the carpentry might manipulate data, as the maximization approach has been applied and all the peaks will become visible. The fact that the carpentry was the most important building when it comes to scaling the PV-array because of its high demand, could lead to miscalling the system. However it was partly because of the maximization approach that it was suggested that the multiplier for the carpentry should be lower than the rest of the village. An other factor that suggests that the maximization approach is not causing severe miscalling, is the fact that it was explained that the use of the generators in the carpentry is very varying from month to month. Therefore it has to be taken into account that the period of measurement not necessarily was representative and that electricity consumption later on in the semester could be higher.

One of the most common sources of error for all measurements, could be that the weekday profile might appear much lower than the weekday profile because there for many buildings just were one Sunday measured, and the weekday profile were maximized over 6 or 7 days. In that way its much more likely to get high numbers for the weekday profile.

It might seem like there are a significant number of sources of error connected to the maximization approach, however it is important to remember that there is no optimal way to process such data. If energy demand rather than power demand would have been regarded, severe under scaling of the system would be risked, as there was such varying minute to minute data. Over scaling rather than under scaling is definitely an advantage regarding that a future profile is determined.

9 Financial Aspects

Production, improved health and a better education [21] are important and significant improvement factors of electrification and expansion of electrical systems, however the cost and financial aspects of electrification must also be considered when dealing with rural electrification. As the areas with little or no access to electricity often are rural and in low resource areas, it has to be considered who will take the bill for the installations planned. The state, the villagers and organizations are the possibilities that seem the most likely. The world banks report [21] proves that the rural inhabitants show a high willingness to pay, but it insinuates that limited resources and a fair payback plan are the missing factors. However it is pointed out that costly stand-alone systems are financed with better conditions, like extended payment period or credit. The report also claims that in the later years, stand-alone systems providing renewable energy are popular projects to support. However the report also claims that off-grid schemes have fewer advantages because they have higher costs and fewer benefits.

The aspect of responsibility and fairness regarding the financing a rural PV project will not be further mentioned in this project as it is outside the scope of this project. In the coming subchapters the alternative cost to the microgrid will be presented and discussed.

9.1 Cost Minimization

Scaling and designing a PV system, is not only about finding the most efficient, elegant or innovative solutions. The costs involved with a PV system purchase are for many costumers the most important factor besides reasonable supply. The reason for this is that when wanting to purchase a PV system, people have expectations that the system will be either more productive or cost-efficient than the alternatives. Regarding the system described in this project, perhaps the most relevant alternative for electricity supply, would be to extend the national grid from the closest connection point, Kakabila, to the rural area of Wawashang. The goal regarding financial aspects for this project will be to keep the costs below the costs of such a grid-extension. This is not expected to be very hard, as Wawashang lies over 65 km away from the grid and an extension of this magnitude would be quite costly. When it comes to reliability of supply, the Nicaraguan electrical grid is not known to be very reliable and is characterized by power outages and overload due to people attaching to the grid secretly. All in all it should not be very hard to provide a system in Wawashang which on all areas would function better or just as good as the national grid.

Contradictions between technical and economical optimization, create dilemmas and make it hard to emphasize one important factor over the other. HOMER performs a cost minimization of the scaling of the system and PVsyst focuses of technical optimization. Normally there are two those two approaches that could be applied to the strategy of the scaling process, however in this thesis a third strategy, which is feasibility, demands a forced focus. The reason for this is that the feasibility of executing the plans in real life and accessibility of modules, batteries and other equipment is connected with many restrictions as it is in a rural area. Designing a system that is actually practicable is a very high priority, as a design that is only technically optimal but not feasible, does not have any value for the Wawashang complex. This is the reason why the specific modules, batteries and other equipment were chosen even if more high-tech and efficient modules and equipment could have been chosen and modules with longer life time could be available. This makes thesis will lie in-between a technical optimization and economical optimization. It will be returned to the specific equipment that was chosen in chapter 10.

9.2 Alternative Cost

When designing a microgrid, it is compulsory to take a look at the alternative cost regarding the evaluation of the financial aspects. If it can be proven that the alternative cost is larger, there are additional incentives for the establishment of the microgrid. The alternative to the microgrid is a 65 km grid extension from Kakabila and according to the article, *Simulation of off-grid generation options for remote villages in Cameroon*, the cost of single-wire grid extension in developing countries is evaluated to be 9000 US$/km.[22] The annual operation and maintenance cost is 180 US$/year/km and grid power price is something in the area of 0.55 USD/kWh. [23][24] Already by looking at the magnitude of the cost related to the grid connection, one get an idea of that it would be very costly way of electrification and the investment alone would require 585 000 US$, and then operational costs and actual spot price comes on top of this.

It should however be noted that the information regarding the cost related to a grid extension, is from an article from 2009 and the area in question is also different from in the article, so the magnitude of these costs should be looked at as a somewhat rough estimate. An other important factor regarding the alternative to the microgrid, which is not of an economical matter, is whether the gridline in question could handle the high demand from the complex in Wawashang as it only is a branch of the national grid and the capacity is not necessarily large enough to serve the complex.

Even though it is expected that the option of grid extension to Wawashang is suboptimal, it is interesting to look at the total net present alternative cost connected to it. Regarding the calculation of the net present value of the future cost of the electricity and maintenance costs, a discount rate claimed by the Central Bank of Nicaragua (31 December 2010 est.) of 3% was applied. The 136 600kWh/year that has been applied to the calculations, is the number of kWh per year which are delivered by the system according to PVsyst. In later chapter this number will be further presented and discussed.

Supply system	Distribution system	Net Present value of grid power cost	Maintenance Costs	Total Cost
Grid extension	9000 US$*65= **585 000 US$**	NPV of 0.55$/kWh* 136,600kWh/y*20y= **1 179 162 US$**	NPV of 180 US$/km * 65 km= **185 766 US$**	**1 949 928 US$**

Table 10 Alternative cost

As one can see, there are severe costs related to a grid extension and paying the spot prices and maintenance costs connected to the national grid. A total cost of 1 949 928 US$ has been identified and this cost will be compared to the cost that will be stated by HOMER in coming chapters for an evaluation of the feasibility and optimality of the system. However it should be kept in mind that the costs that will be presented in HOMER this is excluding distribution, fence costs and maintenance costs. That is because numbers related to those posts is impossible to find and as it is expected that those cost categories will be kept low as the system is quite small and a lot of the work could be done by the work force already present in the complex.

However, even though the grid extension would prove to be cheaper, an important factor to keep in mind, is that extending the national grid to remote and rural area with little resources and low population. In many cases is an unfeasible and extremely expensive solution looking at cost per capita and this is leading to a demand of other stand-alone or microgrid solutions for electrification. An other important factor is the environmental aspect. The electricity mix in Nicaragua is mainly provided by the exploitation of fossil fuels and regarding the environment, a microgrid distributing energy from solar power would by far be preferable.

10 PVsyst Simulation Settings

PVsyst is a PC software package for the study, sizing, simulation and data analysis of complete PV systems. The basic constraints when sizing a stand-alone PV system are the availability of solar energy during the year and meeting the user's needs. The goal of the scaling, is to optimize the size of the PV array and the storage capacity, obtaining an efficient and well functioning system in order to meet the energy requirements in the technically best way regarding the system settings. It is of high importance that the sizing and determination of the different parameters for the PV system is done in a proper way to avoid shortcomings of energy delivery or potential waste of the produced energy in a oversized system with too low battery capacity. However, one have to be aware of that the simulations in PVsyst never will give a full picture of the reality, as there are numerous unsecure factors especially regarding the irradiation in the area and the load profile which have been determined based on historical data applied to future estimations. All the system parameters that have been applied to the simulations except for the load profile and irradiation data, which have already been discussed, will be presented and justified in the coming subchapters. The parameters that were implemented into PVsyst are the same parameters that will be used for the HOMER simulations as far as the software allow it. The common variables will only be presented in this chapter.

10.1 Autonomy and LOL

The autonomy time represents the period of time the system is able to deliver the required energy just from energy stored in the battery. The autonomy time chosen for this system is three days, both for the system with and without backup. This practically means that after no irradiation for 3 whole days, the batteries will be disconnected due to low charge level and potential damage of the battery. An autonomy time of 3 days is the default value in PVsyst and a very common choice for the scaling of a PV system. A lower amount of autonomy time results in an inflexible and unreliable system, that practically might be an unfeasible solution. A higher amount of autonomy days could lead to over sizing the system.

When it comes to LOL, or "Loss of load" probability, 5% was the determined value. This means that 5% is the accepted fraction that the users energy demand do not have be supplied and it is the time fraction when the battery is disconnected due to low charge. This value needs to be implemented as it helps define the PV array needed for a certain battery capacity. The chosen value of 5% is a very common value to choose for homes and is the default value when using PVsyst. Hospitals and other buildings where it is extremely important to never be without access to electricity, have a LOL of 0%.

10.2 Operating Temperatures

When implementing meteorological-data, operating temperatures also had to be implemented for detecting limitations of the system and to in a better way be able to map the losses and efficiency of the system. The input parameters VmppMin , VmppMax and VabsMax , helps determine the possible number of PV modules to be connected at the input and the inverter power needed. As higher temperatures within the PV-system is worsening the efficiency, it was of high importance to find the right values. Below the temperatures are explained and stated. The temperatures are all ambient temperatures with an additional 30 °C [25] added for approaching cell temperature, except for the lower temperature for VmaxAbs, which is supposed to be the minimum ambient temperature according to PVsyst manual.

VmaxAbs, is the lower temperature for limit parameter that is used when determining the maximum possible voltage of the array. The absolute maximum voltage, the open circuit voltage, at the lowest temperature has to stay below the absolute maximum inverter input voltage. Furthermore it should not overcome the maximum system voltage specified for the PV module. Lower temperature for VmaxAbs limit was set to 15°C [26]

The winter operating temperature for VmppMax design parameter, describes the minimum cell temperature during operating conditions in winter. The maximum array operating voltage has to stay below the maximum inverter voltage. Winter operating temperature for VmppMax design = 45°C [26]

The usual operating temperature under 1000 W/m is as the name says, the usual operating temperature of the array under solar irradiation of 1000 W/m. Usual operating temperature under 1000W/m^2, is set to 56 °C [27]

The summer operating temperature for VmppMin design parameter describes the maximum cell temperature in operating conditions and is used to determine the array minimum operating voltage. The minimum array operating voltage should be above the minimum inverters operating range. Summer operating temperature for VmppMin design is 68 °C [26]

10.3 Albedo

The albedo is the proportion of the incident light or radiation reflected by the surface surrounding the PV panels that theoretically would get a second chance to hit the PV array. The albedo being 0 implies a vey dark surface surrounding the PV array and an albedo of 1 is applied when a surface is very bright white or metallic and has a high degree of reflectance. The albedo chosen was 0.25 [28], as this is the albedo of the grass that will be surrounding the area around the PV array. The albedo for the actual area had to be determined in order to later on be able to have a accurate irradiation in the area due to influence of the indirect irradiance caused by the albedo effect. It is however mostly when there is snow or high reflecting substances around the PV array that the albedo will have a significant effect on the production of the PV array.

10.4 Batteries

When it comes to the batteries that were chosen for the system, the accessibility and deliverability of the batteries, was a main decisive factor when choosing brand and model. The current batteries in the complex are mainly 6V 210 Ah Trojan batteries. The Trojan batteries have a good reputation and are the only ones that can be easily obtained and delivered by a distributor in Managua (Ecami), so the 6V Trojan batteries with the highest accessible capacity of 420 Ah, were chosen for the new system.

As the battery Trojan 6V 420Ah was not available in the databank of PVsyst, an other type of 6V batteries were chosen. Rolls batteries with 453 Ah were the batteries that were chosen as the characteristics of this battery was quite close to the Trojan model, for which a price was available and it is known that the batteries could be delivered from Managua. The fact that the price is known is very important as the same parameters will be run in HOMER for economical optimization and at that point having the prices available is crucial for being able to obtain meaningful results. So even if it might not be an optimal solution, it is much more important that the parts of the system can be delivered, rather than scaling an optimal system which could never be implemented. There were also price information on the Trojan batteries with 210Ah capacity, however over the double amount of batteries would then be needed and the system in general would have been a much more complicated configuration as well as more extensive maintenance would be demanded.

The battery pack was set to be 48V as this is an appropriate voltage for the system in question and as the voltage has to be a number which can be divided by 6 because of the single battery voltage. In figure 10 the nominal capacity at 453 Ah is shown for three different currents and durations implying the characteristics of the battery. 91 A and 6.2 hours, 45A and 12.5 hours and 9A for 58.3 hours are displayed.

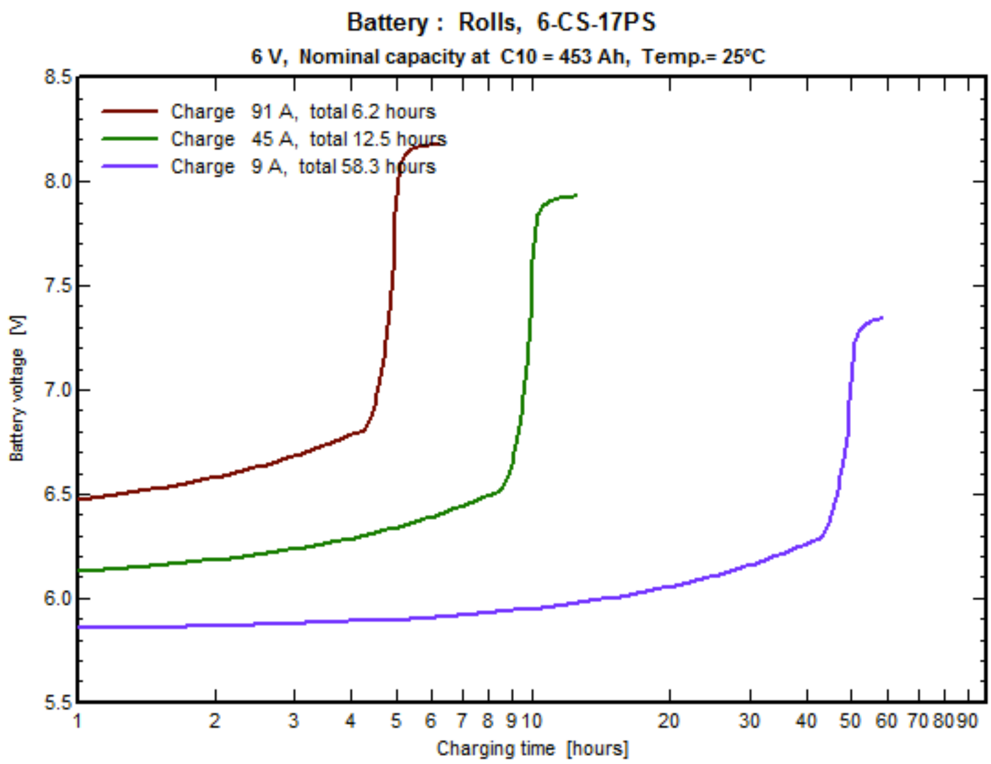


Figure 10 Nominal capacity at 453 Ah, Rolls 8-CS-17PS

Even if it was not possible to implement the already present batteries in the complex into PVsyst and configure a system consisting of the 210Ah batteries that are currently there and fill up the capacity with the 453 Ah batteries modelled in PVsyst, in reality this could be a possibility as a saving measure. This would have to be configured by having two different battery packs with the two battery types. However there are many downsides to such a measures like life time of the batteries being different and the fact that the configuration of the system getting more complicated. This matter will not be further discussed as it is not implementable into the software and thereby cannot be investigated.

10.5 PV-modules

Accessibility was in a similar manner to choosing the batteries, the main restrain of choosing the modules for the PV-cluster. As the location of Wawashang is very remote, large costs could be involved in transporting the modules from far away. To take the economic aspect into account, polycrystalline modules were chosen over mono-crystalline and Thin-film PV. This as polycrystalline is substantially less costly than the other two, and as the choice of PV modules has a large effect on the price tag of the project. According to BlueEnergy, a distributor called Ecami in the capital of Nicaragua, Managua, has been identified. The polycrystalline modules chosen were Kyocera model KD215GX-LPU with a power potential of 215 W and a voltage of 24. This because it was the modules that BlueEnergy was recommending and of course as it is the only modules of that size which are known to be deliverable to the complex as well as the price is known. The alternative were the modules that have been used earlier by FADCANIC which also had a known price, however the peak power of this EGE 100W 12 VDC were simply expected to be too low for being implemented in a PV cluster as large as the one planned. According to PVsyst close to the double amount of PV-modules would be needed and thereby the double area would be demanded for the cluster. So the Kyocera 215W were obviously the more suitable modules for the purpose and therefore chosen. Below one can see the module characteristics of the Kyocera model KD215GX-LPU.

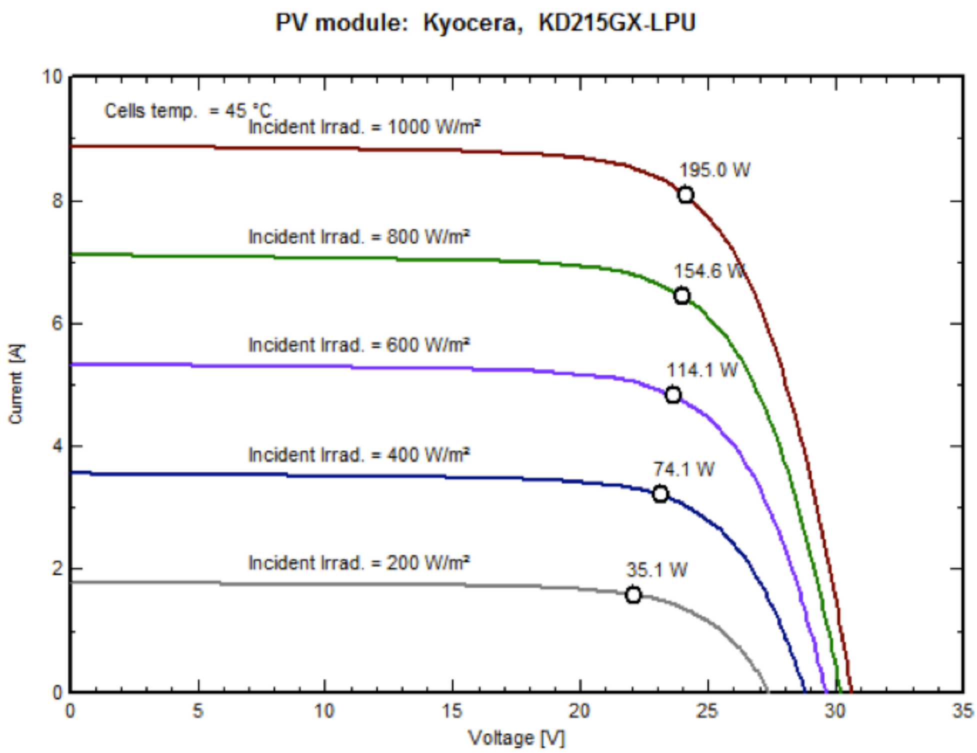


Figure 11 Caracteristics curve for module type 215 W from Kyocera

The dotted point is the maximum power point, voltage * current (Vmp*Imp) and is the optimal operation point of the module. Above one can see the optimal point for 5 different irradiation scenarios; 1000W/m^2, 800 W/m^2, 600 W/m^2, 400 W/m^2 and 200 W/m^2. In the same way as for the batteries the problem of including the PV panels that are already present in Wawashang yields and the modules will not be taken into account for any simulation. However unlike the battery pack which practically could be supplied by some of the batteries that are already in the complex, PV modules with different characteristics and power potential cannot be placed in the same PV-cluster. The opportunity of scaling multiple clusters could seem to be a good approach, however load profiles, which have to be implemented into both simulation software, cannot be modified so that the loads could be divided between the clusters, therefore this is not a feasible solution.

10.6 Shade

Shading is a factor which could severely impact the efficiency of a PV array. Especially if there are objects like trees or other buildings that only cast a shade on a small part of an array. If one part of the array is shaded, no currents are generated and the cell is reversed and it starts absorbing energy from the circuit just like a load. Even if bypass diodes are minimizing this problem by not letting large voltages to build up across the cells, there are not enough of these bypass diodes in a module to keep a solar array unaffected by shade.

There are two different types of shading that could be implemented in the simulation software PVsyst. Horizon or far shading and near shading are the two types and as the names says, they are differentiated by the distance to the shading object. Horizon shadings are acting globally on the PV plane, which means that either the whole array is shaded or no part of the array is shaded. As the area Wawashang is quite flat, there will be no horizon shadings implemented in PVsyst.

Near shadings are only partially casting a shade on the PV panels and it is changing during the day. The fraction of shading is called shading factor and in PVsyst one can construct a 3D representation of the area and map the shading objects in order to detect the shading factor both for liner shadings or shading according to module strings. At the site where the PV cluster is planned, there is no objects interfering with the irradiation reaching the PV-modules and the area thereby does not have any shading factor.

10.7 The Regulator: Inverter + controller

After choosing the batteries and PV-modules in PVsyst, the regulator must be chosen. The term regulator in PVsyst includes a controller and a converter as well as other components for controlling the operation of the PV array. The controllers task in a PV system is to protect the battery from being overcharged and over discharged, as this damages the battery. In PVsyst the term converter is used when it is actually an inverter which is in question. Because as a converter usually converts AC to DC, the inverter converts the DC output from the PV array to AC and only the latter conversion is needed. In PVsyst no specific controller must be chosen as the common term regulator is used and the controller is embedded in that term. One can however in a similar way to the battery and module selection choose different converters (inverters) from different companies, and also choose between MPPT converter, DC-DC converter, or normal fixed voltage inverters. A so called default converter can also be chosen to simplify things, and then PVsyst chooses default data on a suitable MPPT, DC-DC or normal converter for you. A maximum power point tracker (MPPT) is a power electronic DC-DC converter inserted between the PV module and its load to achieve optimum matching. By using an intelligent algorithm, it ensures that the PV module always operates at its maximum power point, as the temperature, insulation and load vary. [29] For both systems being analysed, a default MPPT converter was chosen, as it contributes to optimize the system and it was set to be a default to simplify the simulation. Below a general component diagram taken from PVsyst regarding the configuration of the system is displayed.

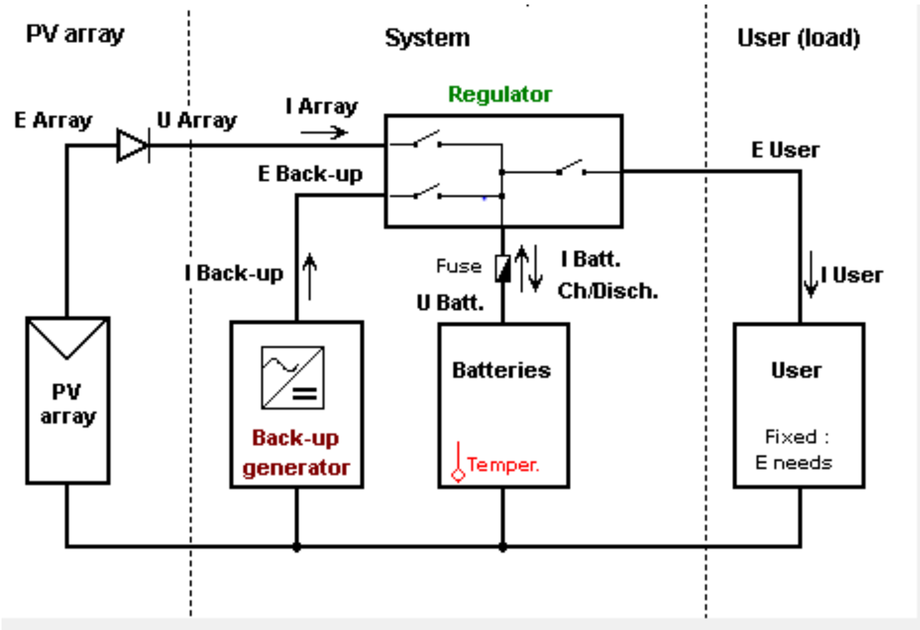


Figure 12 Component diagram

As one can observe, the coupling of the back-up generator is also identified in the overview above. However in chapter 7, the configuration of the system regarding the diesel generator is better described and the coupling of the back up generator in the figure above is not necessarily a great illustration of the configuration which will be applied for this project as the power from the backup generator will not go through the inverter. However the figure is a great map over how the inverter works and how it is coupled regarding the other components of the PV-system.

Unlike the batteries and the PV modules, no specific brand or model regarding the regulating components has been chosen. The reason for this was the uncertainty around whether one large inverter should be chosen or if string inverters conditioning each single array string should be applied. As shade is not expected to be an issue for the planned PV-array, one large inverter could be beneficial. However it is not known whether the distributor in Managua could provide such a large inverter. As no suitable inverter was found in the list in PVsyst, the default inverter was chosen.

10.8 Azimuth

The azimuth is a factor that can have a large impact on the power production of the PV array. The azimuth tells one the angle between the geographical south and the modules and optimally this angle is 0°. It is important to understand that the magnetic South Pole and the geographical South Pole are slightly deviating, even if in theory they should be the same. In the legend for the detailed map in table 4, the azimuth is stated. However this measurement has been performed by a normal compass and thereby the orientations stated are in regard to the magnetic South Pole and not the geographical one. This means that the values stated in table 4, are slightly deviating from the geographical South Pole. However as the field where the PV cluster is planned is very large, the modules can be turned in any direction desired and be chosen according to the geographical south. As it is the optimal angle and it is a free choice in which direction the modules are mounted, an azimuth equal to 0° is chosen in PVsyst.

10.9 Tilt Angle

The tilt angle is the angle of which the solar array has been tilted vertically for optimal collection of the solar irradiation and is also an important issue for optimal operation of the PV-array. There are many options of the design of the PV-system when it comes to the determination of module angles. Fixed inclination angle that can be modified for summer, winter or conditioned to suit both circumstances as well as a tracking array following the suns motion on a dual or single axis, are common configurations. Even if an array tracking the suns motion is a more productive one, fixed inclination angles have advantages like simplicity, no moving parts and low cost. As it would be very costly to get skilled professionals to the rural area for repairing the array and moving parts are causing more frequent problems with the array, the system in Wawashang was determined to have a fixed angle both in regards to summer and winter season, so that no interference except for maintenance and cleaning of the modules is necessary. Even if it could be interesting to look at the design of the system regarding a tracking array, there is no cost information nor knowledge on deliverability to Wawashang and as keeping a realistic and applicable system is the main focus, tracking arrays were not further explored.

There are many different ways with varying accuracy for determining the angle for a whole-year optimization of the array. Being extremely accurate is not that necessary as only whole numbers can be implemented into Pvsyst. The angle is as a rule of thumb said to be approximately the same as the latitude of the place they are being mounted, however there is a simple equation for determining a more exact optimal angle. [30]

$$\beta_{opt} = 3.7 + 0.69|\phi|$$

Wawashang having the latitude of 12.65 gives a β_{opt} of:

$$\beta_{opt} = 3.7 + 0.69 * 12.65 = 12.42$$

As one can see this is very close to the latitude and the rule of thumb would have been a very good approximation. In PVsyst only whole numbers can be chosen and a tilt angle of 13° was chosen in PVsyst, as a larger angle is better for winter irradiation conditions for locations in the northern hemisphere.

11 Results of simulations in PVsyst

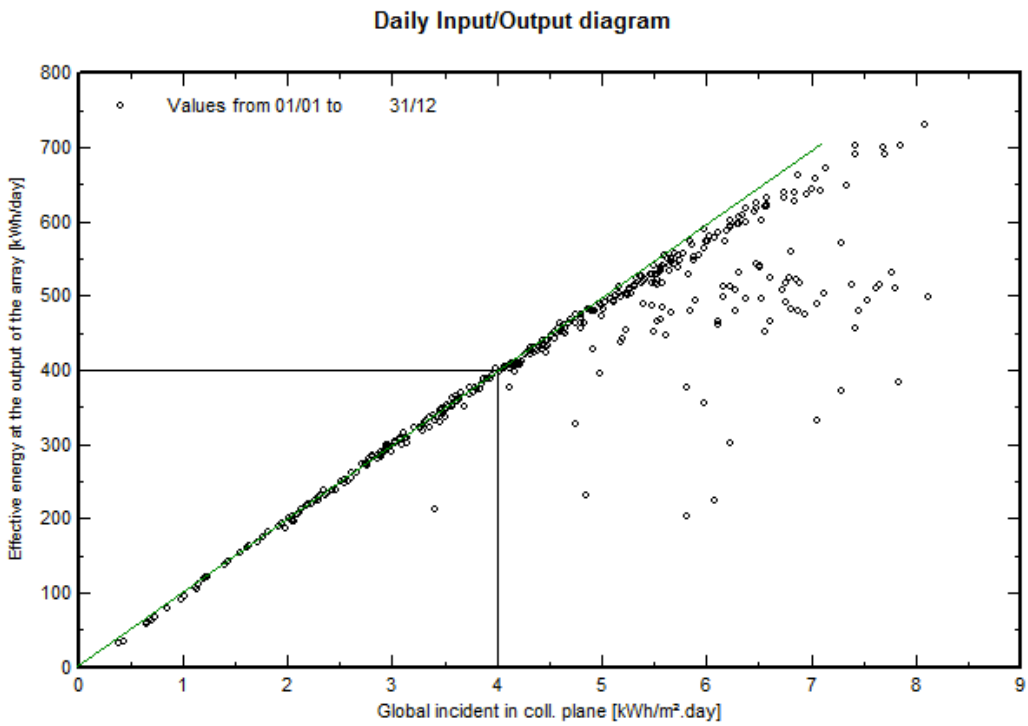
When performing a simulation with PVsyst, one can access a full report containing comprehensive data. [Appendix 2 and 3] In this chapter the main results from the PVsyst simulations will be presented in form of graphs and tables from produced by PVsyst, some modified to indicate trend lines. This chapter will contain two simulation sets, one with and one without a diesel backup generator. In this way, the optimality around whether to include a diesel generator as a backup can be identified. An input/output diagram along with tables on solar fraction, an overview over state of charge, daily array output energy, loss diagrams, normalized production and loss factors and performance ratio will be presented and explained. All the above-mentioned results will be discussed and compared against each other regarding the two simulated systems.

13.1 System with Backup Generator

According to PVsyst the system with a backup generator is optimally configured with 574 modules where 2 modules are in each string and there are 287 parallel strings over an area of 852 m^2. As the sports field has an area of 5400 m^2 , the area of 852 m^2 will not affect the feasibility of the system. The battery pack consists of 480 batteries in strings containing 8 batteries and 60 parallels are needed. A 10 kW diesel generator is set as backup to the PV system and a default converter is also included in the system. The users need is set to 397 kWh/day, the array global power amounts to 123 kWp and the available energy amounts to 150.6 MWh/year. In this chapter the main results from the PVsyst simulations for the system with a backup generator will be presented and briefly commented.

13.1.1 Daily Input/Output Diagram

Input/output diagrams imply the system production as a function of the input irradiation. Ideally the uptake of the PV array should increase linearly with the irradiation at all times, to demonstrate an optimal utilization of the irradiation in the arrays. The input/output diagram allows one to get an idea of how well functioning the system is and it immediately gives indications about the inefficient days. The input/output graph should be as steep as possible implying beneficial uptake fraction of the solar energy, in other words implying good module efficiency. The x-axis shows the global incident irradiation per m^2 per day (kWh/m^2day), and the y-axis displays the total correlated effective energy at the output of the array (kWh/day). All the dots, there are 365 of them in the diagram, represents the average incident irradiation of each day and the corresponding uptake of the array.



Graph 27 Daily input/output diagram

The input/output diagram for the system illustrates a well functioning and efficient system indicated by most of the dots kept on the steepest line. There are however some days that differ from the trend, but the main part of the days lay on the close to linear line with a gradient close to 100. When the daily global incident irradiation and corresponding effective energy is on the linear line, the degree of efficiency is:

$$\frac{4kWh}{m^2} * 852m^2 = 3408$$

$$\rightarrow \frac{400\frac{kWh}{day}}{3408\frac{kWh}{day}} = 11.73\%$$

It might sound little, however this is not a bad output regarding the cell efficiency of the modules being 14.49 % [31] at optimal operating conditions according to the manufacturer. Commercial polycrystalline modules typically have a efficiency degree of 14.13%. [32] However one must take into consideration that the 14.49% are under ideal test condition and with the operating temperatures being applied in this thesis, lower efficiency of the modules has to be expected. That is why an efficiency of 14.49 % is considered a good number of efficiency.

13.1.2 Solar Fraction

In this sub-chapter, perhaps the most important and interesting outcome of the analysis related to the supply of the PV-cluster, will be displayed. In the tables containing balances and main results, one can get crucial information on how well the systems are functioning and if they are meeting the users demands. When it comes to delivery, reliability and liability, a very important factor to study is the solar fraction (SolFrac in PVsyst). The solar fraction represents the fraction between the amount of energy supplied to the user and energy demanded by the user. In other words it is a fraction representing the relationship between supply and demand. A fraction of 1 means that all demands are met and a fraction under 1 it means that there are parts of the demand that will not be served. However it is important to be aware of that this is a stand-alone mini grid system and solar energy cannot in any way be controlled, and only to a certain degree be predicted. The probability of loss of load is set to 5% meaning that an amount of undelivered energy up to 5% was initially accepted, however higher deficits are expected for some months because of the unpredictable irradiation.

	GlobHor kWh/m²	GlobEff kWh/m²	E Avail MWh	EUnused MWh	E User MWh	E Load MWh	SolFrac
January	133.0	141.1	13.25	0.415	12.41	12.42	1.000
February	143.8	148.9	13.71	1.455	11.08	11.09	0.999
March	169.6	168.4	15.97	2.836	12.40	12.42	0.999
April	174.3	165.3	15.53	3.158	11.64	11.65	0.999
May	156.9	144.2	13.69	0.838	12.41	12.42	1.000
June	121.2	110.6	10.24	0.760	11.97	11.97	0.746
July	115.0	106.4	9.97	0.223	12.09	12.09	0.827
August	124.6	116.9	10.89	0.010	12.42	12.42	0.882
September	131.4	127.0	11.84	0.234	11.65	11.65	0.890
October	128.7	130.4	12.31	1.287	12.41	12.42	0.826
November	118.5	122.7	11.24	0.005	11.97	11.97	0.977
December	121.8	130.5	11.98	0.328	12.09	12.09	0.827
Year	1638.8	1612.7	150.62	11.548	144.52	144.59	0.914

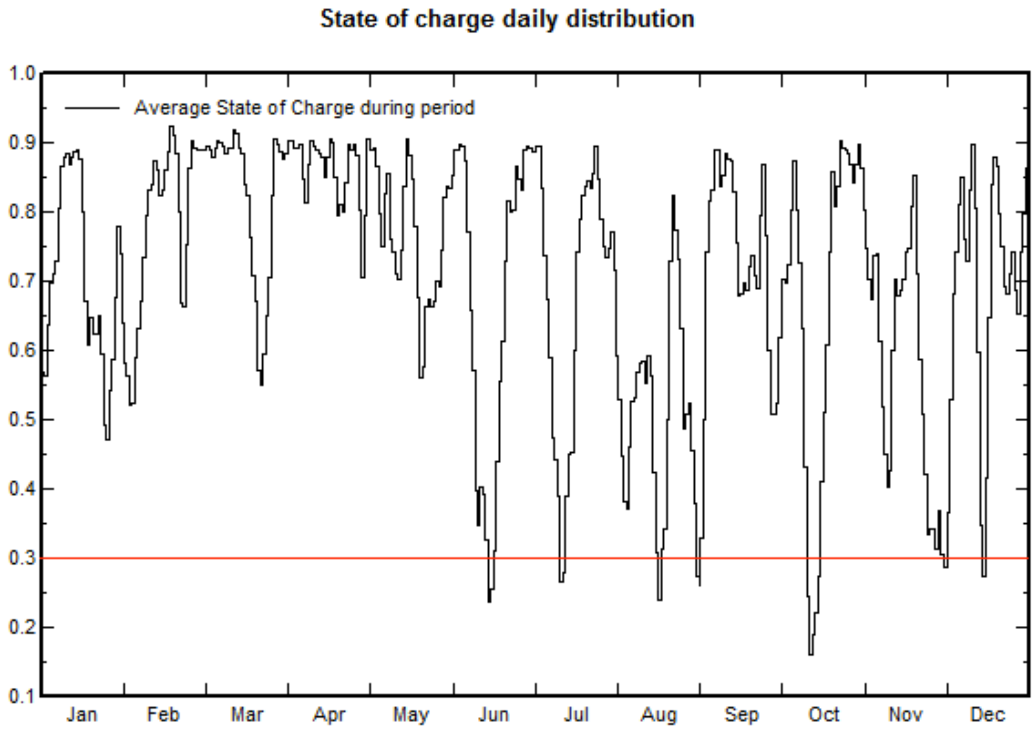
Legends:				
	GlobHor	Horizontal global irradiation	E User	Energy supplied to the user
	GlobEff	Effective Global, corr. for IAM and shadings	E Load	Energy need of the user (Load)
	E Avail	Available Solar Energy	SolFrac	Solar fraction (EUsed / ELoad)
	EUnused	Unused energy (full battery) loss		

Table 11 Main result PVsyst

For the planned PV cluster, one can find that June, July, August, September, October and December have a solar fraction below 95% meaning a LOL of over 5%. The month with the largest supply deficit is June, where 25.4 % of the energy demanded will not be delivered by the PV system. This means that that month 25.4 % of the energy has to be supplied by the 10 kW backup generator. The average yearly solar fraction is 0.914, an average that is only 3.6% away from the targeted 5% LOL, however this is only regarding the PV modules alone. The nearly acceptable yearly average, however, does not solve the problem of the severe energy shortage in the above-mentioned months and the diesel generator will have to supply the missing energy making the system having a system delivery fraction of 1 even if the solar fraction is 0.914 on a yearly basis. As mentioned earlier PVsyst has a focus on only the PV modules and the diesel generator cannot be accurately modelled other than as an alternator and rectifier element, ensuring the recharging of batteries when the solar energy is insufficient to satisfy the user's needs. As it will be stated in coming chapters, HOMER allows a more exact modelling of the backup generator and allowing a LOL of 5% will yield for the whole system and the generator will not lead to a system delivery fraction of 1, however only improve the delivery for certain months.

13.1.3 State of Charge

For stand-alone systems, battery usage is an important factor for optimal operation and for obtaining a long lifetime for the components. The state of charge is the term of available level of capacity in the battery. A fully charged battery will have a 100% state of charge in contradiction to a fully discharged battery, which will have a state of charge level of 0%. [32] To ensure that the battery is not taking any damage, it should be ensured that at the end of "days of autonomy" the battery should not have a state of charge lower than 30%, ideally between 30-50% [33]. A too high state of charge could also be damaging.

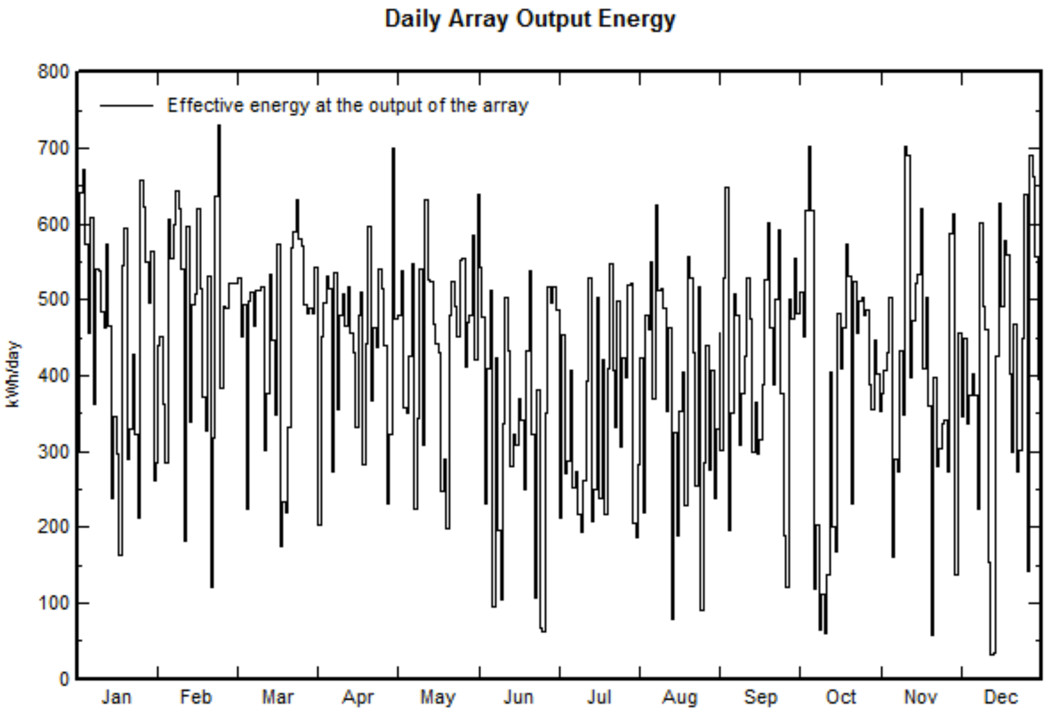


Graph 28 State of charge daily distribution

The modified overview shows us that the PV cluster at 7 times fails to stays safely above the critical level of 30%. Those inverted peaks occur in the middle of June, July, August, September, October and December, months, which mostly are the winter months in Nicaragua. The first three months mentioned are approximately down at a state of charge of around 25%, however in October there is a very low state of charge in the first half of the month going as low as about 15%. This implies that PVsyst`s limits for disconnecting the batteries are lower than it is stated in the literature. These low points are contributing to shortening the lifetime of the batteries and should be avoided. In the first 5 months of the year as well as end of October and beginning of December the batteries are frequently getting filled to a certain level of about 90% of which the batteries are close to fully discharged and controller disconnects them from the loads to keep from damaging the battery-pack. The batteries being disconnected, could lead to spillage, a situation that is an unwanted effect of over production. However due to the seasonal variation of the solar power, this is unavoidable when a PV system is scaled, as a too big battery pack leads to higher costs and more incidents with too low state of charge.

13.1.4 Daily Array Output Energy

The daily array output curves inform one of the kWh that are being produced in the system at all times. As one might guess, this is closely related to the daily input/output diagrams, however in graph 29, one can get a better indication on the seasonal variations and timing of energy production.



Graph 29 Daily array output energy

From the overview above one can easily see that this graph is cohering well with what was stated about the sate of charge. June, July, August, September, October and December are all months that are characterized by very low production at some points of the period. These were also the months that where reaching unhealthy low levels of state of charge. The minimum level of production is reached in December and it is as low as 25 kWh/day. The month with the highest production is February with close to 740 kWh/day for the whole array. However by looking at the overview over state of charge in graph 28, one can see that completely filled up batteries is a frequent problem in February, implying that the extreme energy production in February is not being exploited.

13.1.5 Losses

When it comes to losses, default values of losses are implemented in the simulation, containing losses from converters, PV-modules, batteries and other components in the system. However, further losses can be added to the system. An example of this is mismatch losses connected to non-uniform shaping of the array and the fact that the PV system only woks as good as the worst module performs. One can also add additional wiring losses, and change the loss values of all components. However it has been chosen to stay with the default losses as research shows that these are quite carefully chosen and realistic, and also because the array is not expected to be influenced by any shadow. One must also keep in mind the 10% increased load profiles due to distribution losses that has been taken into account.

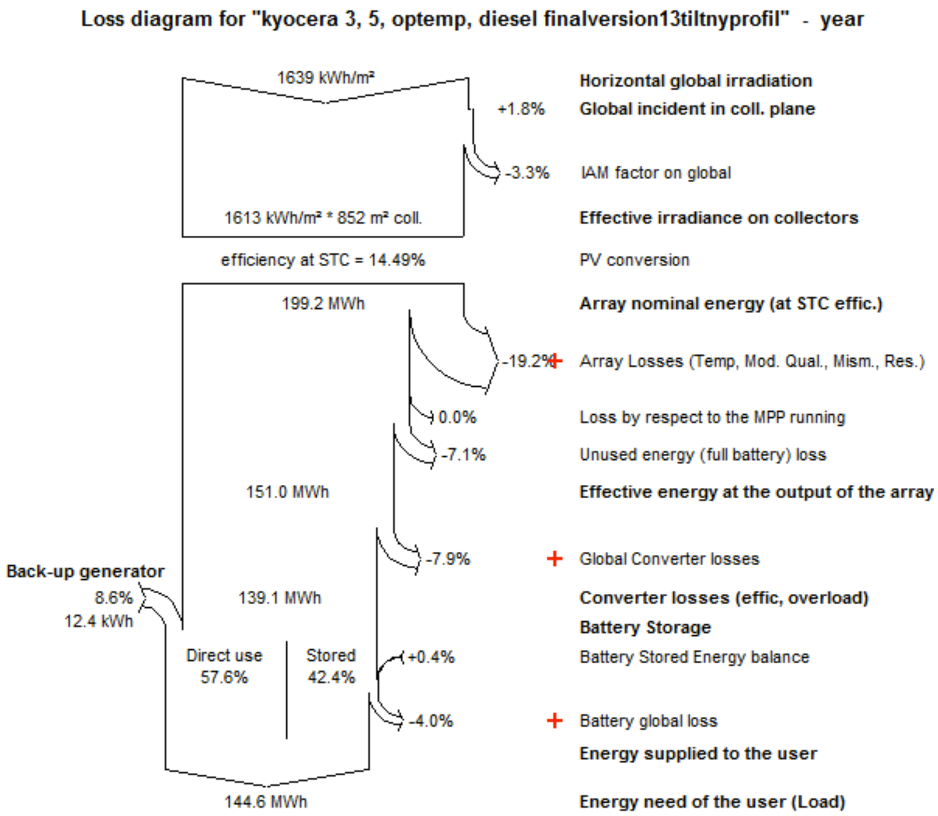


Figure 13 Loss diagram

Looking at figure 13, one realizes that there are many ways of looking at losses regarding PV systems. One can for example look at total energy reaching the PV modules, or avoid taking the efficiency of the modules into account. Including the losses due to module inefficiency is not a very common thing to do, as PV modules commonly have a poor degree of efficiency. An interesting comparison factor for this system, is the losses occurring between the energy taken up by the modules and energy supplied for the user. Figure 13 shows us that array nominal energy for the system is 199.2 MWh and Energy supplied to user is 144.6 MWh. This implies a loss of 27.4%. An other interesting factor is the contribution from the backup-generator which is 12.4 MWh (not kWh as it says in the figure) and a total of 8.6% of the energy needed by the user. This number is a perfect match with the missing energy which we identified in the table displaying the solar fraction. The solar fraction was 0.914, implying a supply deficit of 0.086, which makes up a percentage of 8.6, hence the percentage being displayed as a contribution from the back-up generator ensuring a 100% energy delivery for the scaled system. 57.6% of this energy is being directly supplied to the load and 42.4% are being stored for later use.

13.1.6 Normalized Production and Loss Factors

In the following overview over normalized production and loss factors, one can see the different groups the produced energy is divided into percentagewise. Unused energy because of full battery is one of the groups and as anticipated from the overview over the battery state of charge, the first five months are characterized by high losses due to batteries getting filled up. However extending the battery capacity would get expensive as well as the system would be miss scaled for most periods of time. It is important to realize that these are monthly values and it might just be a short period of time where the batteries are full and losses are created, as in other times of the month the batteries are almost empty and have to be disconnected. PVsyst is scaling an optimized system and finds a balance between the two extremes.

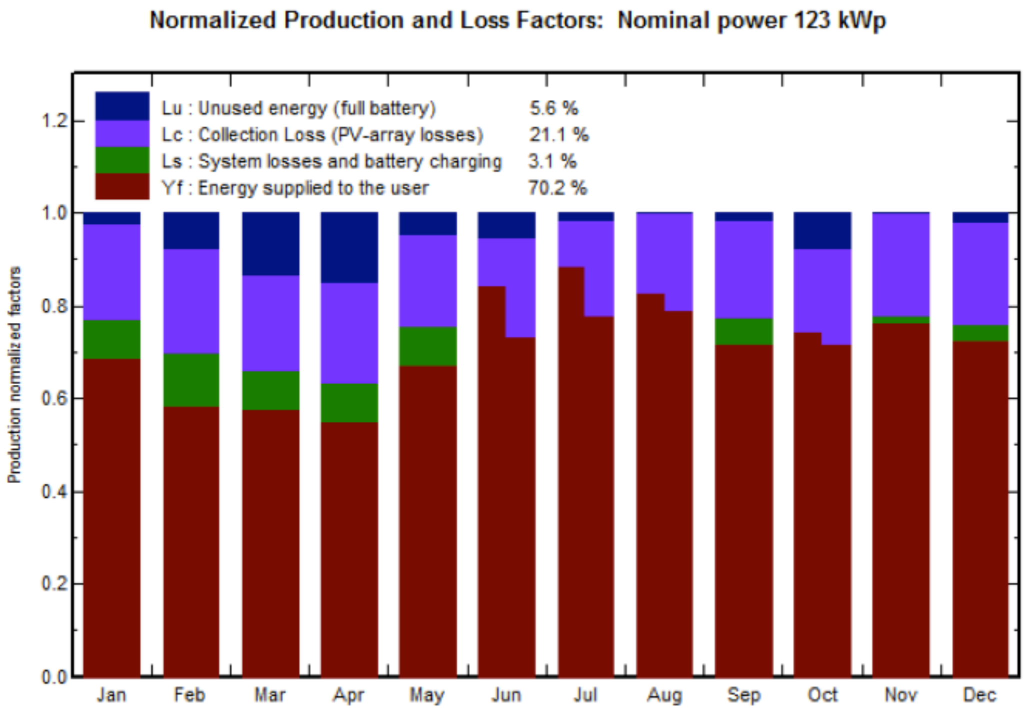


Figure 14 Normalized production and loss factors

Other groups are PV array losses and system losses. Array losses are pretty even over the year, something which is not very surprising as the modules are the same and as no shade is interfering with the system. The red bars indicating energy supplied to user is the highest in June and July, something which might not seem to be cohering very well with graph 28 and 29, saying that June and July is the time when the batteries are emptied and the production is the lowest. However this only shows a percentage, and one have to remember that the diagram bar representing June is much, much smaller than the one for March, as the production in general is much lower. And it makes perfect sense that the months of low production losses due to unused energy are much lower in months with low production, than for the other months. Losses due to battery charging are also eliminated because the loads are being supplied directly as there is not enough excess energy to charge the batteries. The dark purple part of the bars, showing wasted or spilled energy is the largest in April, this fact is confirming the assumptions regarding the state of charge overview where large parts of the month had fully charged batteries. Now that one knows that the unused energy for that moth was high, one can with full certainty say that this month is characterized by a large amount of spilled energy due to full batteries.

13.1.7 Performance Ratio

In the overview below, the performance ratio (PR) is displayed. PR is numerically equivalent to the energy, which would be produced if the system was always running with its nominal efficiency. PR includes losses and is not directly dependent on the meteorological input or plane orientation. PR is related to the system quality, and allows a comparison between installations in different locations and orientations. In figure 15 the solar fraction is also displayed, however this solar fraction is including the power from the backup generator and is misleading regarding the PV array itself, therefore the solar fraction in table 11 should be used instead. For this system design, one can see that the yearly averaged performance ratio is 70.2% which is a quite acceptable number regarding that the highest performing PV plants only can achieve up to 80% PR [27]. However in the full report in appendix 2, one can detect that the performance ratio only for the PV system, not including the backup generator is 64.2%, and it is this performance ratio that has to be used when comparing the two systems. April is the month with the lowest performance ratio amounting to about 5.5, this even if this is a month with a high irradiation and a solar fraction of 0.999. The reason for the low PR is the massive spillage that occurs within this month that was detected in figure 14.

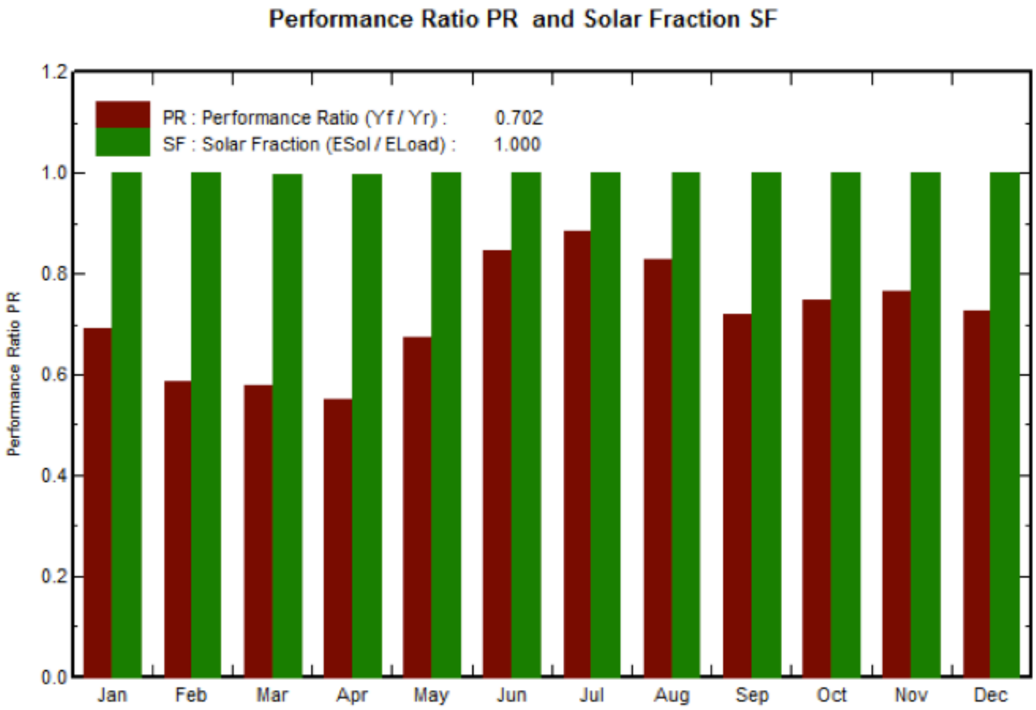


Figure 15 Performance ratio (PR)

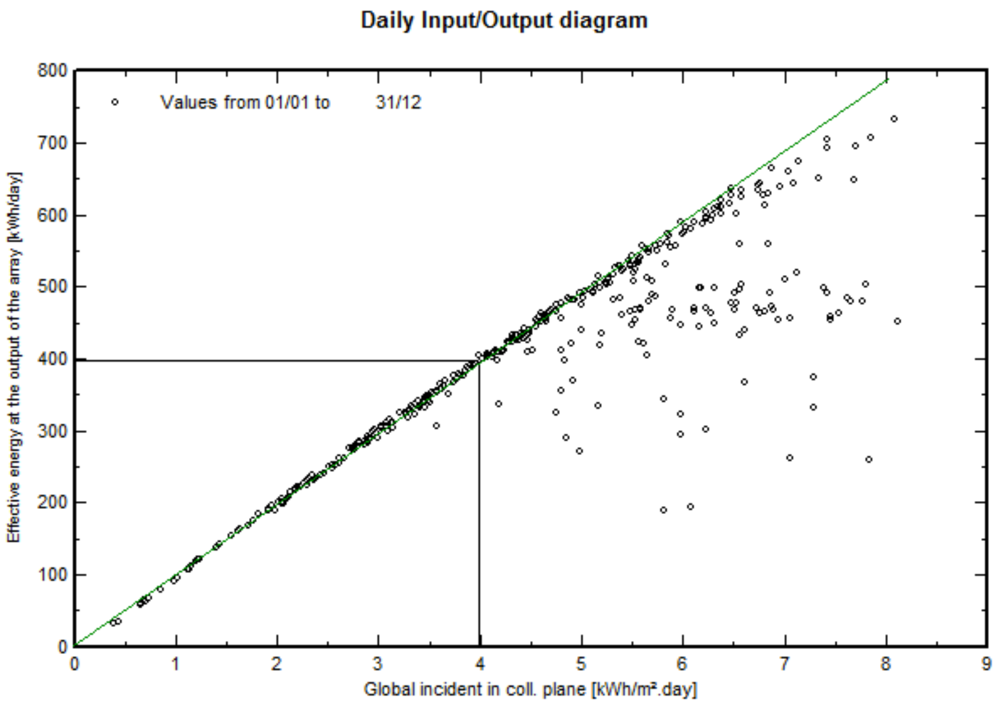
13.2 System with No Backup Generator

The system simulated with no backup diesel generator optimally consists of a 855 m^2 PV array with 576 modules in 288 strings of 2 modules each. A battery pack of 8 batteries per string and 60 strings, amounting to 460 batteries, is needed for energy storage. The users need is set to 397 kWh/day, the array global power amounted to 124 kWp and the available energy is 158.8 MWh/year. By comparing this system configuration with the design for the system with a backup, one can see that this system requires 2 more PV modules resulting in 8.2 MWh of additional available energy per year, however the battery storage facilities are identical. It makes sense that this system, solely relying on solar power, needs a larger and more powerful array to obtain an acceptable amount of delivered energy to the user regarding the predetermined LOL, as this system does not have a backup supply.

The reader has to be aware of that comparing the two simulations in PVsyst should not be done without keeping in mind that PVsyst always simulates with a certain degree of randomness. By simulating the exact same parameters the author discovered a certain deviation between the results, something that implies that PVsyst is operating with a certain degree of randomness either regarding the synthetic irradiation data, or a random factor is applied to the load profile. The PVsyst results for the simulation of a system with no backup supply will be displayed in the following subchapters.

13.2.1 Daily Input/Output Diagram

Input/output diagrams imply the system production as a function of the input irradiation and in a similar manner to the system with a diesel generator as backup, a linear line is desired. For this system one can clearly see that for low irradiations the production and irradiation have a close proportional relationship. However for higher irradiation magnitudes, at some points the production is fairly low. However the daily input/output curve is close to identical to the system with a backup system, something that is not surprising, considering that the systems have the same type of modules and the same base for irradiation data. However the randomness for some of the variables creates a slight difference.



Graph 30 Daily input/output diagram II

When the daily global incident irradiation and corresponding effective energy is on the linear line, the degree of efficiency is:

$$\frac{4\,kWh}{m^2} * 855 = 3420$$

$$\rightarrow \frac{400\,\frac{kWh}{day}}{3420\,\frac{kWh}{day}} = 11.69\%$$

This is a little lower than for the system with a backup generator, however one have to consider that this investigation has been performed through graphical analysis and the accuracy might not be a 100% reliable as well as the randomness factor induces a slight deviating tendency. However all in all, this looks like a healthy and well functioning system just like the system with a backup generator and the majority of the measure points lie on a straight line with a gradient of 100.

13.2.2 Solar Fraction

One of the most important characteristics of a system, is the ability to deliver energy to cover the demand. Therefore the solar fraction is a very good indicator of the reliability of a PV system. Below the solar fraction is given on a yearly basis as well as for each month of the year.

	GlobHor kWh/m²	GlobEff kWh/m²	E Avail MWh	EUnused MWh	E Miss MWh	E User MWh	E Load MWh	SolFrac
January	133.0	141.1	13.79	0.653	0.000	12.42	12.42	1.000
February	143.8	148.9	14.65	2.511	0.000	11.09	11.09	1.000
March	169.6	168.4	16.76	3.594	0.000	12.42	12.42	1.000
April	174.3	165.3	16.49	4.084	0.000	11.65	11.65	1.000
May	156.9	144.2	14.35	1.411	0.000	12.42	12.42	1.000
June	121.2	110.6	10.65	0.492	1.999	9.97	11.97	0.833
July	115.0	106.4	10.47	0.025	1.242	10.85	12.09	0.897
August	124.6	116.9	11.53	0.119	1.454	10.96	12.42	0.883
September	131.4	127.0	12.48	0.007	0.000	11.65	11.65	1.000
October	128.7	130.4	12.81	1.263	1.839	10.58	12.42	0.852
November	118.5	122.7	12.02	0.440	0.000	11.97	11.97	1.000
December	121.8	130.5	12.79	0.539	1.485	10.61	12.09	0.877
Year	1638.8	1612.7	158.79	15.139	8.019	136.57	144.59	0.945

Legends:				
	GlobHor	Horizontal global irradiation	E Miss	Missing energy
	GlobEff	Effective Global, corr. for IAM and shadings	E User	Energy supplied to the user
	E Avail	Available Solar Energy	E Load	Energy need of the user (Load)
	EUnused	Unused energy (full battery) loss	SolFrac	Solar fraction (EUsed / ELoad)

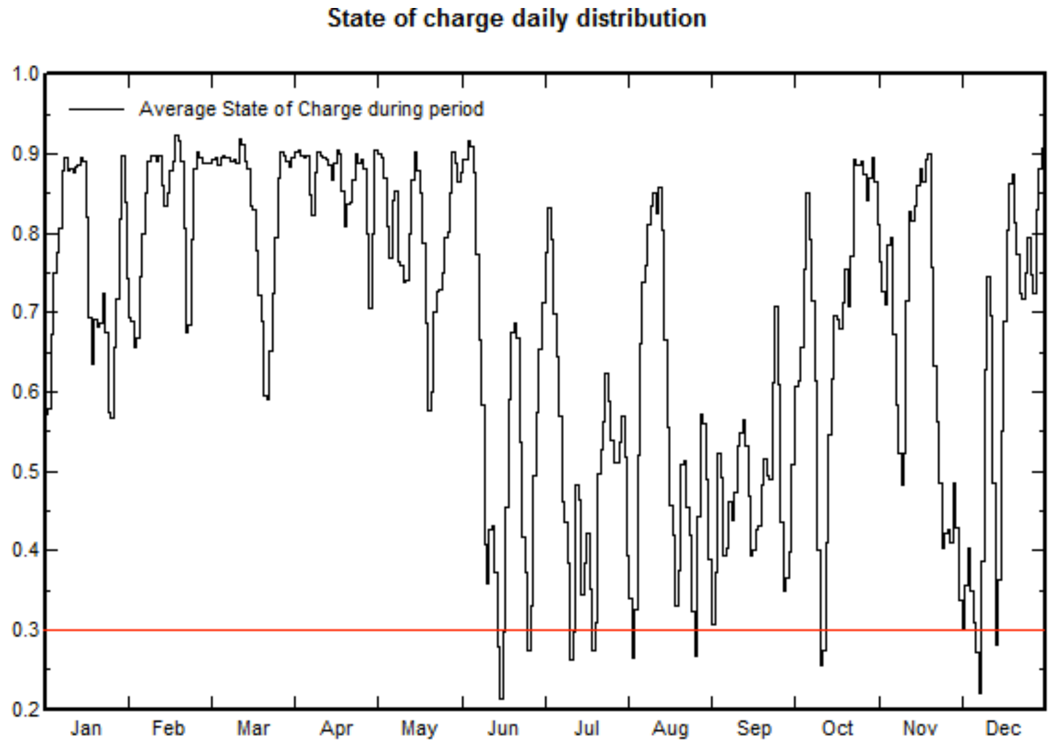
Table 12 Main result PVsyst II

June is the month with the lowest solar fraction, hence the fraction between delivered and demanded energy is low. June has a solar fraction of 0.833, giving a delivery deficit of 16.7%. This is a quite significant deficit regarding that there is no backup generator to handle the deficits and it is 11.7% more than the yearly-accepted LOL. Other months with delivery problems are July, August, October and December with a solar fraction of respectively 0.897, 0.883, 0.852 and 0.877. The yearly solar fraction amounts to 0.945, which gives a delivery deficit of 5.5%. This is 0.5% higher than the accepted LOL of 5%, however in PVsyst LOL has to be a whole number and it seems like PVsyst has accepted this system, since it is within a range where the LOL can be rounded down to 5%. However as it has been stated, there are quite severe delivery deficits during 5 months of the year even if the yearly LOL is at an acceptable level. The fact that for some moths of the year there are severe delivery problems will have a great influent of the decision of which system configuration is the optimal one.

Comparing the solar fraction of this system to the system with a backup, one can discover that the solar fraction on a yearly basis is higher for the system with no backup generator than for a system with a backup generator. This is due to the extra modules that this system is suggested to have. The reason for this is that for the system with a backup solution, a higher accepted delivery deficit regarding the energy produced by PV panels has been accepted, as the diesel generator can help supplying energy to the loads and thereby raise the delivery fraction of the system to get a 100% delivery rate. From a technical point of view, it is quite clear that the system with a backup system is the one with the highest delivery rate and thereby is the optimal one. However it will be returned to whether this system will be the right choice regarding the other optimization aspects and whether it is the right system for Wawashang.

13.2.3 State of Charge

In the graph below, the state of charge daily distribution is displayed over a period of a year.

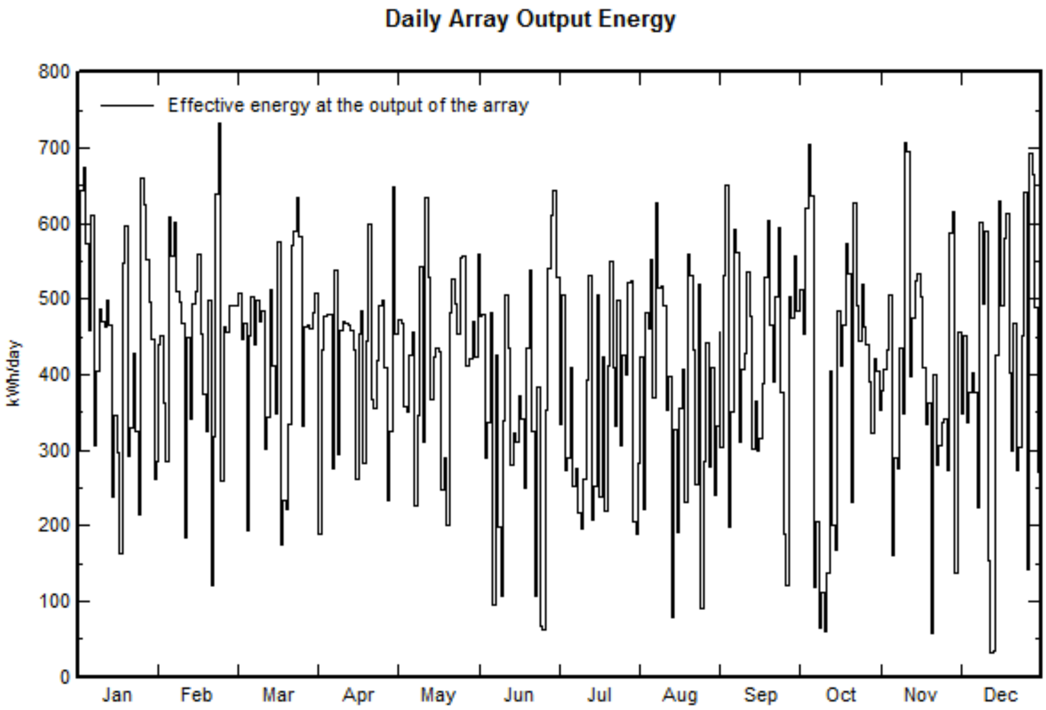


Graph 31 State of charge daily distribution II

It is detected that 9 times between June and December, the state of charge goes below the critical level of 30%. This is 2 more times than for the system with a backup solution. June, July, August, October and December are the months where the critical level is crossed and it thereby is implied that there is a delivery problem for this system as the batteries are being disconnected when the state of charge reaches such low levels. This is cohering very well with the solar fractions that were stated for these months. The lowest point that is reached is close to 20% in June opposed to 15% in October for the system with a backup system. This system seems to have a more frequent occurrence of state of charge below 30%, however the other system reaches lower levels in general. This could be a result of the randomness in the simulations however also a result of less modules and the same battery pack for the system without a backup. Also for this system, spillage seems to be an issue, as during all months except July, August and September, at many points the batteries are being filled up to the critical level of 90% where the batteries are being disconnected due to preventing damage because of overcharging. In general, regarding the battery-pack of this system, the system with no backup seems to have a more unhealthy battery pack as lower levels are reached, however if the spillage turns out to be more severe problem for this system, that will not be the case.

13.2.4 Daily Array Output Energy

Below the production of the PV array given as kWh/day is presented on a seasonal basis.



Graph 32 Daily array output energy II

As one can see, the production of the PV array is very varying during the year, not only on a seasonal basis however there is also a great variation within the different months. The highest production reached occurs in February and amounts to ca 740 kWh/day. The lowest production occurs in December and amounts to ca 25 kWh/day. Needless to say, this shows an extreme variation, causing issues around the scaling of the system, as golden mean between spillage and low battery capacity has to be found. The characteristics regarding the production of the system, is as expected in tact with the irradiation data in table 2, showing a close relation between seasonal irradiation and production. Unlike the input/output diagram that shows irradiation relationships per square meter, graph 32 shows the energy production regarding the entire array. Because of that, it was expected that since it is a larger array, the irradiation would prove to be slightly higher in this overview than the graph showing daily array output energy for the system with a backup. However production from 2 extra modules is hard to detect in such a graph, and the randomness factors also have an influence n the matter.

13.2.5 Losses

The losses related to the system with no backup system is displayed on the next page.

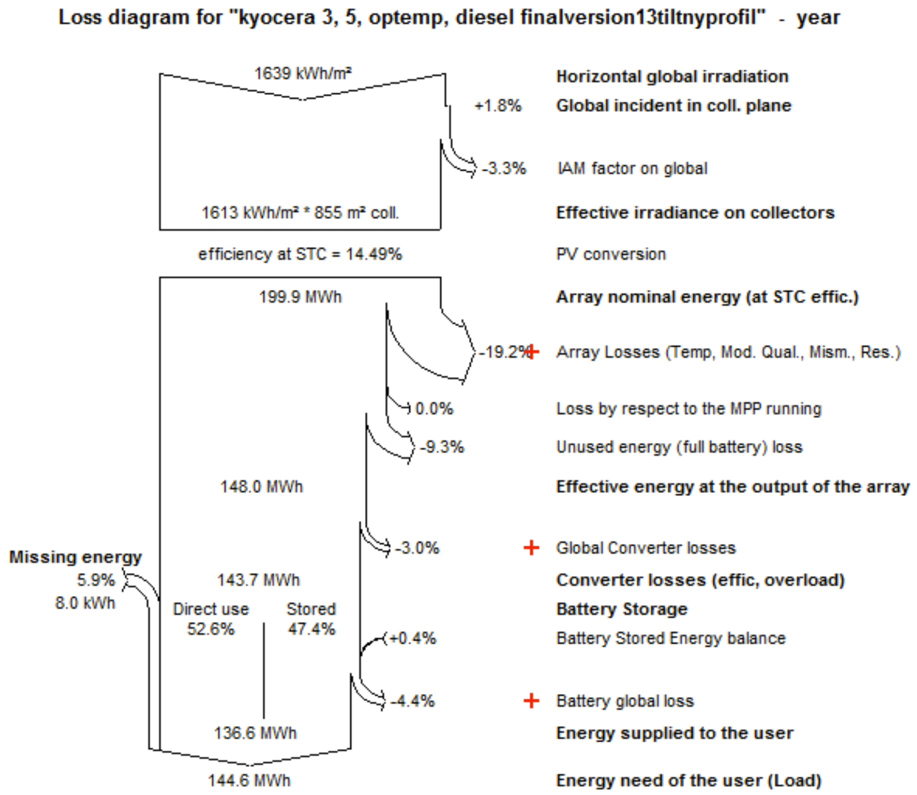


Figure 16 Loss diagram II

The array nominal energy of the system amounts to 199.9 MWh and the energy supplied to the user is 136.6 MWh, this implies a system loss of 31.6%. The missing energy of the system is smaller than for the system with the backup and amounts to 8.0 MWh implying a deficit of 5.9%. As expected this number is very close to the one we saw in the overview over the solar fraction where a deficit of 5.5% was stated. The losses due to unused energy and spillage is higher for this system, than for the one with a backup, with 9.3 % vs. 7.1%. The reason for this is likely to be the larger array with the same storage facilities. The amount of direct use vs. stored energy is 52.6% vs. 47.4%, which in comparison to the system with a backup generator shows that 5% more of the energy is getting stored instead of being used directly.

It is in this overview the main difference between the system with and without backup is identified. Because as the system with a backup generator can deliver all the 144.6 MWh needed by the users by producing the missing energy by using the diesel generator, the missing energy in the system without backup remains undelivered. However for both systems the production boundaries set are mainly being followed with a yearly LOL of 5% accepted. The difference is just to which degree they are being fulfilled and whether large amounts of unused energy some months are being hidden by a high solar fraction other months, making an acceptable yearly average.

13.2.6 Normalized Production and Loss Factors

In the overview below the normalized production and loss factors are shown, making a great visualization of the different groups and fractions of the produced power.

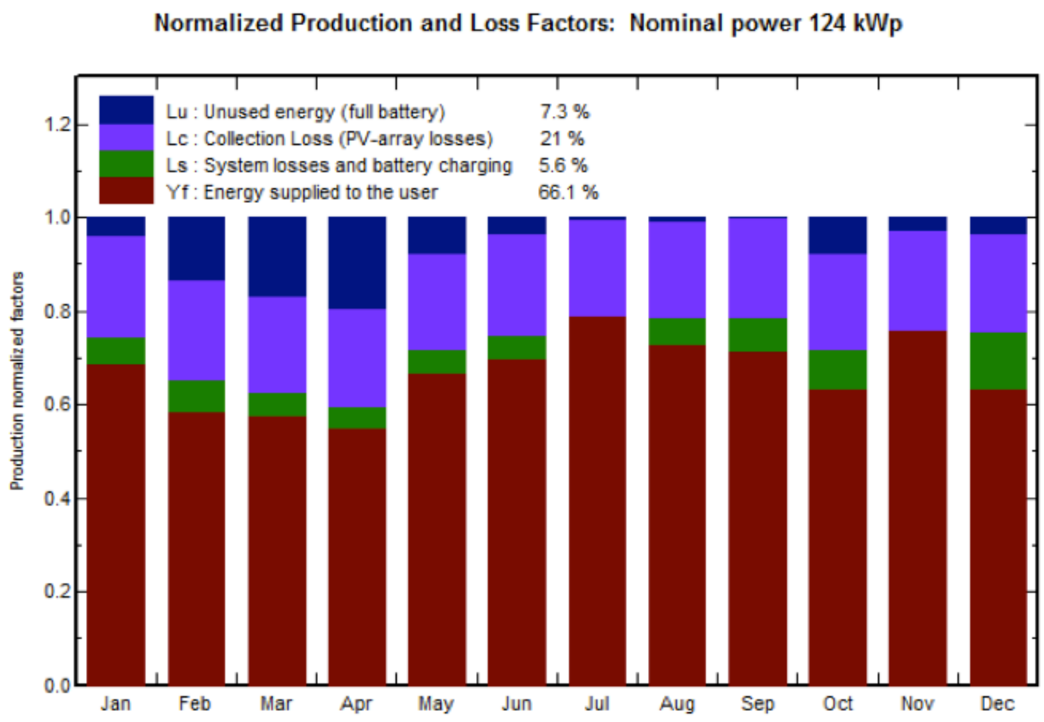


Figure 17 Normalized production and loss factors II

Just as expected from the study of the graph showing the state of charge, the dark purple bar states that the first 6 months as well as the last 3, are characterized by spillage due to fully charged batteries. In July the highest fraction of the produced power is supplied to the user, something that is expected regarding the low production this period and empty batteries minimizing spillage and losses related to battery charging. The Normalized Production and Loss factor overview for the system with no backup is close to identical to the system with a backup system. However the fraction of energy supplied to the user, is lower than for the system with the backup, with 66.1% vs 70.2%. This is a result of the larger losses regarding the battery-pack for this system, both regarding unused energy and battery charging losses that are respectively 1.7 % and 2.5% higher. So even if the battery pack looks healthier for this system, there are greater losses related to it.

13.2.7 Performance Ratio

The performance ratio for the system with no backup generator amounts to 66.1%. Also for this system the month with the lowest performance ratio is April due to the massive spillage occurring this month because of fully charges batteries. The performance ratio for this system is in general lower than the performance ratio for the system with a backup system, however looking at the performance ratio only regarding the PV array in the report, one will discover that the system with no backup has a higher performance ratio of 66.1% vs 64.2%. However on a system basis, the system with a backup has a PR of 70.2%, a number that is higher than for the system solely consisting of a PV array. The fact that the array with no backup has a higher PR than the other system, implies that this system could me more productive regarding the design, however the frequent spillage is not taken into account in the performance ratio, and it seems like even if the system is more productive, it might not be a better one because of unused energy.

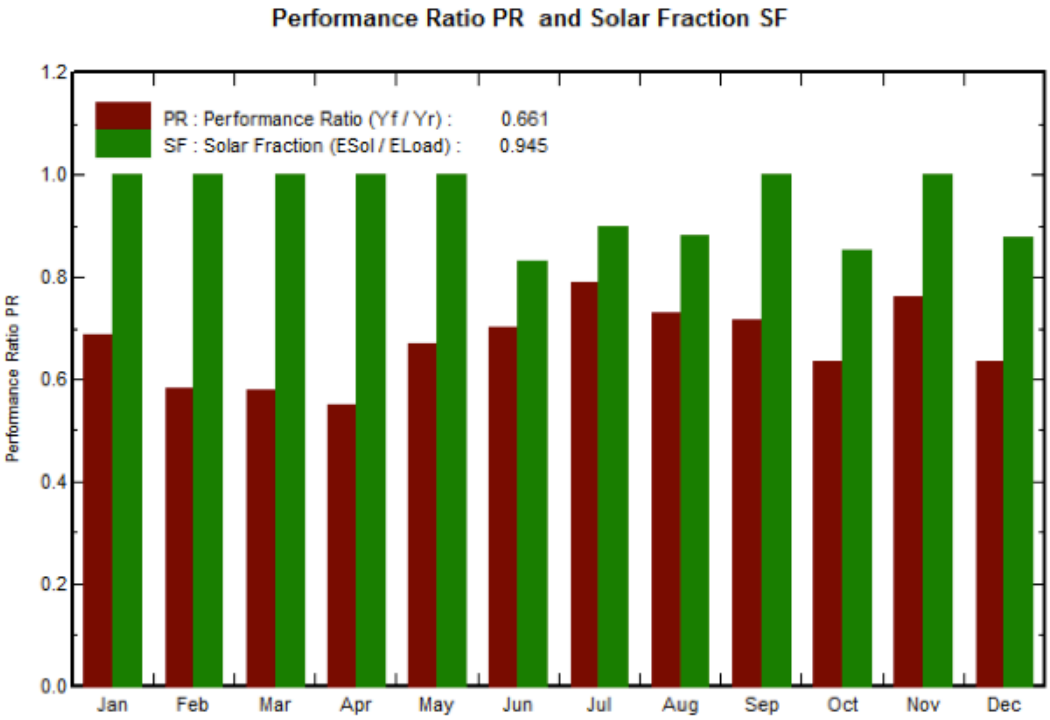


Figure 18 Performance ratio (PR) II

14 HOMER Simulation Settings

HOMER, Hybrid Optimization Modelling Software for electric renewable and fossil energy, is a energy-based system optimization tool developed by the US national Renewable Energy Laboratory, (NREL) which mainly makes economic analysis and ranks the systems according to their net present costs. The software is a hybrid system design software that facilitates the design of eclectic power systems, also for stand-alone applications. Just like in PVsyst, numerous input information posts need to be implemented and for being able to compare the two simulation tools and use their outputs jointly, as far as it was possible the same input data has been implemented. However as HOMER simulates an economical optimization, in addition to the parameters needed in PVsyst, also economical data had to be implemented. The simulations in HOMER were as mentioned before the reason for choosing the modules that were used, as they where the only deliverable modules of that size with a known cost. In HOMER it would have been possible to include some of the currently present modules in the complex for an optimization as they are for free, however the limitations of PVsyst exclude that possibility as a comparison and combined usage of the two software packages is the main goal. HOMER also allows performing sensitivity analysis where one can give variable inputs and see how the optimization of the simulation changes when the variables are changed. The fuel price, irradiation data and real interest rate, are parameters that were performed sensitivity analysis on, as they are the most unpredictable factors of the simulation. The simulations were performed both with a cycling battery pack and load following battery pack, these two terms are describing how the batteries and the generator are cooperating. Hence whether the generator is always running full load if it is operating and supplying excess energy to the batteries (circulating) or if the generator is always running a minimal load (load following). The simulations have been performed multiple times to narrow down to the optimal scaling of the system with as precise numbers as possible. In this chapter the inputs, which were implemented into PVsyst will be presented and briefly discussed, as well as the main results from the simulations will be presented.

14.1 Input Parameters

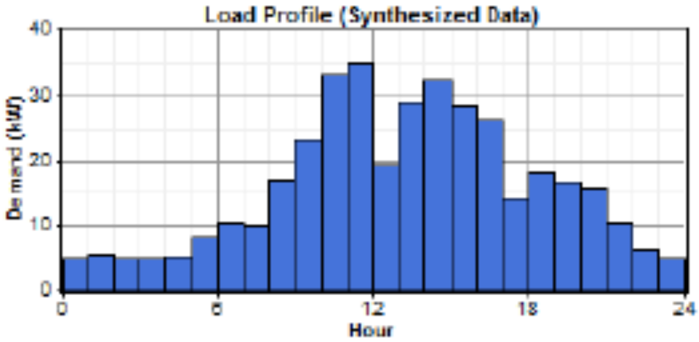
HOMER requires a much larger number of parameters being implemented into the software settings. As far at it has been possible, the same parameters as in PVsyst have been applied. In the overview below, one can see the parameters that were implemented in HOMER. As there is a large number of them, only the most relevant parameters that have not been commented in the chapter regarding the implemented parameters in PVsyst, will be commented. Where there are two or more data for the same parameter present, a sensitivity analysis between those numbers have been performed.

HOMER Input Summary

File name: HomersimXcykle.hmr
File version: 2.81
Author:

AC Load: Wawashang Load Profile

Data source:	Synthetic
Daily noise:	0%
Hourly noise:	0%
Scaled annual average:	397 kWh/d [34]
Scaled peak load:	49.0 kW [34]
Load factor:	0.338



PV

Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
0.215	520	520	0

[35]

Sizes to consider:	0, 121, 122, 123, 127 kW
Lifetime:	20 yr [35]
Derating factor:	95% [36]
Tracking system:	No Tracking
Slope:	13 deg
Azimuth:	0 deg
Ground reflectance:	25%

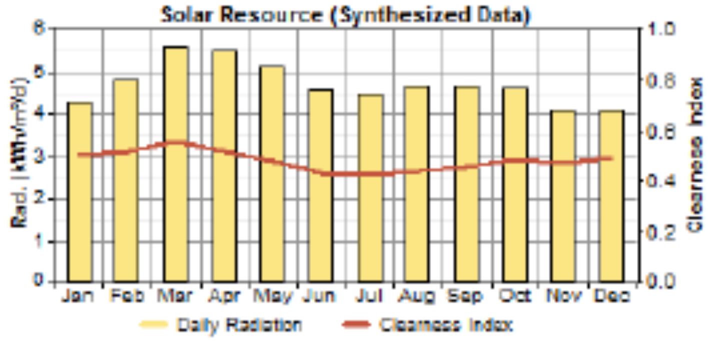
Solar Resource

Latitude:	12 degrees 59 minutes North
Longitude:	83 degrees 59 minutes West
Time zone:	GMT -6:00

Data source: Synthetic

Month	Clearness Index	Average Radiation ($kWh/m^2/day$)
Jan	0.502	4.259
Feb	0.518	4.798
Mar	0.555	5.600
Apr	0.521	5.493
May	0.483	5.123
Jun	0.432	4.541
Jul	0.426	4.480
Aug	0.445	4.671
Sep	0.457	4.661
Oct	0.485	4.596
Nov	0.473	4.082
Dec	0.497	4.082

Figure 19 Parameter overview HOMER

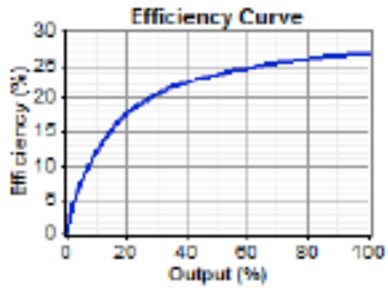


AC Generator

Size (kW)	Capital ($)	Replacement ($)	O&M ($/hr)
10.000	0	1,168	0.292

[37]

Sizes to consider: 0, 10 kW
Lifetime: 7,500 hrs [37]
Min. load ratio: 10%
Heat recovery ratio: 0%
Fuel used: Diesel
Fuel curve intercept: 0.05 L/hr/kW [37]
Fuel curve slope: 0.33 L/hr/kW [37]



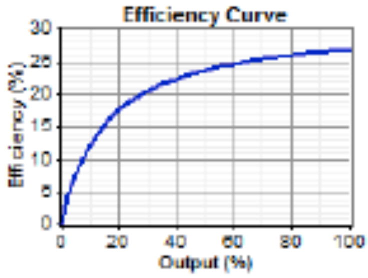
AC Generator: Generator 2

Size (kW)	Capital ($)	Replacement ($)	O&M ($/hr)
24.000	0	2,803	0.700

[37]

Sizes to consider: 0, 24 kW
Lifetime: 7,500 hrs [37]
Min. load ratio: 10%
Heat recovery ratio: 0%
Fuel used: Diesel
Fuel curve intercept: 0.05 L/hr/kW [37]
Fuel curve slope: 0.33 L/hr/kW [37]

Figure 20 Parameter overview HOMER



Fuel: Diesel

Price: $ 1.19, 1.50, 2.00, 2.50/L [38]
Lower heating value: 43.2 MJ/kg [39]
Density: 820 kg/m3 [39]
Carbon content: 88.0% [39]
Sulfur content: 0.330% [39]

Battery: Trojan L16P

Quantity	Capital ($)	Replacement ($)	O&M ($/yr)
1	284	284	0.00

[35]

Quantities to consider: 0, 58, 60, 68, 70, 72, 80
Voltage: 6 V
Nominal capacity: 360 Ah
Lifetime throughput: 1,075 kWh
Min battery life: 7 yr [40]

Converter

Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
1.000	711	711	25

[41][42]

Sizes to consider: 0, 10, 20, 30, 49, 50, 51, 70, 80 kW
Lifetime: 10 yr [42]
Inverter efficiency: 95% [42]
Inverter can parallel with AC generator: Yes
Rectifier relative capacity: 95% [37]
Rectifier efficiency: 85% [37]

Economics

Annual real interest rate: -1.6, 1.6% [43]
Project lifetime: 20 yr
Capacity shortage penalty: $ 0/kWh
System fixed capital cost: $ 0
System fixed O&M cost: $ 0/yr

Generator control

Check load following: No
Check cycle charging: Yes
Setpoint state of charge: 80%
Allow systems with multiple generators: Yes
Allow multiple generators to operate simultaneously: Yes
Allow systems with generator capacity less than peak load: Yes

Figure 21 Parameter overview HOMER

Emissions

Carbon dioxide penalty:	$ 0/t
Carbon monoxide penalty:	$ 0/t
Unburned hydrocarbons penalty:	$ 0/t
Particulate matter penalty:	$ 0/t
Sulfur dioxide penalty:	$ 0/t
Nitrogen oxides penalty:	$ 0/t

Constraints

Maximum annual capacity shortage:	5%
Minimum renewable fraction:	0%

Operating reserve as percentage of hourly load:	10% [39]
Operating reserve as percentage of peak load:	0% [39]
Operating reserve as percentage of solar power output:	25% [39]
Operating reserve as percentage of wind power output:	50% [39]

Figure 22 Parameter overview HOMER

14.1.1 Load Profile

The same load profile as for PVsyst has been implemented into HOMER. Unlike PVsyst, HOMER offers an option where one can implement a percentage of which the load can vary on a daily basis around the implemented profile. This was set to zero as PVsyst does not provide this choice and the settings should be as similar as possible for obtaining a proper base for comparison.

14.1.2 Costs of Components

In the table below, the costs regarding the different equipment that was implemented into HOMER, is stated. BlueEnergy provided the prices regarding batteries and modules through a distribution company in Managua. The converter costs were taken from SolarBuzz´s internet page, a company performing solar market research and analysis.

Equipment	Brand	Price in US$
Modules	Not Specified, 215 W	520
Batteries	Trojan 6V	284
Converter	Not specified	711per kW

Table 13 Module, battery and converter cost [16] [41]

14.1.3 PV Modules

As mentioned before, the prices on PV modules were provided from Ecami, a distributor in Managua through the organization BlueEnergy. The operation and maintenance costs were set to zero, as the person in the complex currently in charge of the electrical system could perform the cleaning of the modules as well as other maintenance. By providing a good ”how to” manual, the maintenance would be done in a proper way, and if sufficient security precautions would be taken, the oldest students could also be trained to do the maintenance and thereby obtaining valuable knowledge which they in the future could be paid for in other settings. Ecami claimed a lifetime of the modules of 20 years. HOMER does not offer to choose specific PV modules, however only the power of the modules is implemented, so for this parameter PVsyst offers a much more accurate simulation.

14.1.4 Solar Resource

When it comes to the solar resource data, the same monthly irradiation data as for PVsyst was implemented and hourly synthetic data as well as HOMER provided a clearness index was based on the information provided by PVsyst. The solar irradiation was one of the parameters which was performed a sensitivity analysis on and the results of that will be returned to. An average irradiation of 4,7 kWh/m2/day was stated after the implementation of the monthly irradiation in table 2 and it was this value that was changed for the sensitivity analysis.

14.1.5 The Generators

As there were poor information on the generators that are present in Wawashang except from their power magnitude. The other information regarding the parameters that needed to be implemented into HOMER had to be found elsewhere. Therefore the article ”Energy for Sustainable Development” by Alam Hossain Mondal and Manfred Denich from 2009 was mainly used to obtain proper economical and technical data. As the generators were already provided, there would be no investment costs connected to the generators. The two diesel generators that where investigated for system optimality, were modelled as two different units with a fixed amount of power potential as it would be interesting to know which one or if both of the generators would be the optimal for implementation into the system. Both generators were tested in HOMER even if the 10 kW generator had been set as a backup system in PVsyst and the 24 kW plant had not been taken into considerations because of PVsyst poor complexity regarding backup generators. The normal lifetime of such generators are according to the article where the data was retrieved 15 000 hours, however as the generators have already been used in the Wawashang complex for many years, this number was halved.

14.1.6 Fuel

The information related to the diesel consumed by the generators, are mainly emissions and price. The price was obtained by the world data bank, however as one knows, the fuel costs from fossil fuels are highly varying and increasing steadily. To be able to see how the feasibility of the scaled system changes along with changing the fuel costs, a sensitivity analysis was applied to this parameter. The current fuel price in Nicaragua is about 1.19 US$ [38].

14.1.7 The Batteries

BlueEnergy and Ecami provided the prices regarding the batteries, just like for the modules. The maintenance costs were set to zero for the same reason as for the PV array, as it is expected that the maintenance will be done by the person who is responsible for the electrical system in the complex. The battery life time of 7 years [40] means that the batteries will have to be replaced twice during the project lifetime as the modules are claimed to have a lifetime of 20 years. When it comes to the batteries, HOMER offers to choose between actual battery brands and types. The batteries with the closest characteristics to the 6V Trojan 420Ah were chosen and almost identical 6V

Trojan 360 Ah batteries proved to be the closest match. The battery pack voltage had to be decided, and by determining a string length of 8 batteries, a battery-pack with a voltage of 48 was chosen. HOMER was to decide the amount of strings and thereby amount of batteries.

14.1.8 The Converter

In HOMER, a converter is defined as a component that converts alternating current, AC, to direct current, DC, (rectifier), DC to AC (inverter) or both. For this system the converter has been set to function both as a rectifier and an inverter with maximum power point tracking characteristics (MPPT) just as in PVsyst. As there only are AC loads it would not be strictly necessary to have the rectifier function, however this setting does not influence the simulations, it just provides rectifier data being 0. Close to all of the parameters regarding the converter function in HOMER, were provided by the article "Energy for Sustainable Development" by Alam Hossain Mondal and Manfred Denich, as no other data was obtainable in a set and these numbers seemed fair when studying other sources. The cost of the converter per kW, was provided by Solar Buzz, a solar market researcher and analyst.

14.1.9 Economics

HOMER requires an input of the real interest rate, which is the rate of interest an investor expects to receive after inflation is taken into account. According to Trading Economics, the real interest in Nicaragua is -1.6% [43]. This means that the inflation rate is greater than the nominal interest rate. The fact that the real interest rate in Nicaragua is so low, is a great base for an investment and HOMER is therefore expected to favour PV as a source of energy, as it is connected to the largest investment costs and no operational cost. The real interest rate was one of the parameters that it was performed a sensitivity analysis on, as it is very interesting to look at when the optimality of the system changes, regarding the magnitude of the real interest rate.

The lifetime of the PV modules were the decisive factor for determining the lifetime of the entire project. This resulted in a lifetime of 20 years.

14.1.10 Emissions

The emission calculations were based on the default settings in HOMER. Even if the emissions of the scaled project is outside the scope of this thesis, it could be interesting to see what the default settings will provide of information regarding the emissions related to the generators in the system.

14.1.12 Controllers

Just like in PVsyst, no data around the controllers are specified and the cost related to controllers securing safe operation for the battery pack, are not included in the parameter list like the other equipment. Therefore (if wanted) they could be implemented in the costs for either the converter, PV-modules or batteries. However as there in the Wawashang complex, is a large amount of controllers available (see table 5 in chapter 6.3) and as inaccuracy and disorganization would be connected to the implementation of the controller cost into other parameters, it is assumed that the controllers that are already in Wawashang can be implemented into the new system. Even if it would turn out that this would be unfeasible, there are no large costs related to the purchase of controllers and the optimal solution would not be changed regarding that the PV-array is equally large for both the optimal and suboptimal system design.

14.1.11 Constraints

The default settings were applied as the constraints that had to be set in HOMER, as it is not common procedure to interfere with these settings according to the HOMER help menu. It is possible to modify these values, however not many have the expertise to find better suited values than the ones provided by HOMER. The maximal annual capacity shortage that can be set in the constraint menu, is basically the same as the loss of load which had to be set in PVsyst and a 5% limit was chosen.

15 HOMER Simulation Results

In this subchapter the most important results of the simulations in HOMER will be presented and briefly commented, full reports can be found in appendix 4 and 5. It was intended to show 3 different sets of results, hence the optimal and second optimal system for the type of diesel generator configuration which seemed to be the best, as well as the optimal solution for the other type of generator-battery relationship. However with both cycling and load following charging of the batteries by the generators, the same optimal solution appeared since a system solely consisting of a large PV-array proved to be the economically optimal solution. Therefore only two sets of results will be presented and compared, the optimal result for both types of generator controlling as well as the second optimal solution of the configuration with the best sub optimal numbers. The sensitivity analysis was performed separately and will be presented with a focus on when the optimality of the system changes and the likelihood of that change. When it is referred to optimal and suboptimal system designs, it is important to keep in mind that this is only regarding an economical aspect. All figures and graphs presented in this chapter are taken from the reports produced by HOMER.

15.1 Optimally Scaled System Configuration, No Backup System

In the coming sub chapters the simulation results of the optimally scaled system according to HOMER, will be presented as well as briefly commented. As already mentioned the load following and cycling configuration of the generator/battery-pack proved to have an identical optimal scaling and that turned out to be a system solely consisting of a large PV array.

15.1.1 Main Result

Below the two main charts of the HOMER report is represented, stating the architecture and costs related to the system.

System architecture

PV Array	121 kW
Battery	560 Trojan L16P
Inverter	50 kW
Rectifier	47.5 kW

Cost summary

Total net present cost	$ 770,101
Levelized cost of energy	$ 0.232/kWh
Operating cost	$ 11,888/yr

Table 14 Main results HOMER

The only source of energy in the system is solar power and according to HOMER, using a backup generator creates a suboptimal solution regarding lowest net present cost. This may seem odd, as the generators had no investment cost attached, however operating cost connected to the operation of the diesel generator are high and the fact that a 5% delivery deficit is allowed, are contributing factors. This matter will be further studied in the chapter of discussion. The economically optimal system is consisting of a 121 kW PV array, which implies the number of modules being 563 (121kW/0.215kW per module) as well as 560 Trojan batteries and a 50 kW Inverter. Rectifier power is not being used as there are only AC loads and can therefore be disregarded. The costs related to this system is a net present cost of 770 101 US$, which represents a levelized cost of energy of 0.232 US$/kWh. Operating costs amounts to 11 888 per year.

15.1.2 Power Production

According to the overview below provided by HOMER, the system is able to produce an amount of 182 209 kWh/year with a mean power output of 20.8 kW. The consumption of electricity based on the load profile implemented in HOMER is 139 599 kWh/year. This leaves a gap of 42 610 kWh/year in deficit, which mainly makes up for losses.

Quantity	Value	Units
Rated capacity	121	kW
Mean output	20.8	kW
Mean output	499	kWh/d
Capacity factor	17.2	%
Total production	182,209	kWh/yr

Table 15 Power production from PV

In the table below, some of those unused kWh are being accounted for as well as shortages are identified. The system produces an amount of 25 210 kWh/yr of excess electricity, this represents spilled energy due to fully charged batteries or other losses. The amount of unmet load is 5 308 kWh/year which implies a LOL of 3.8%, a number which is well within the limit of 5% which was set. Capacity shortage is almost the same as 'unmet load', meaning electrical demand that remains un-served because electrical production falls short of demand. The difference is that capacity shortage comprises both unmet load and unmet operating reserve. A capacity of 7 339 kWh/yr is stated, meaning 2031 kWh/yr. are not satisfying the operating reserves minimum state.

Quantity	Value	Units
Excess electricity	25,210	kWh/yr
Unmet load	5,308	kWh/yr
Capacity shortage	7,339	kWh/yr
Renewable fraction	1.000	

Table 16 Electricity production balance

Below an overview over the monthly average electric production is displayed. One can see that February, March and April are the moths with the highest power production. In April it is close to 25 kW in average.

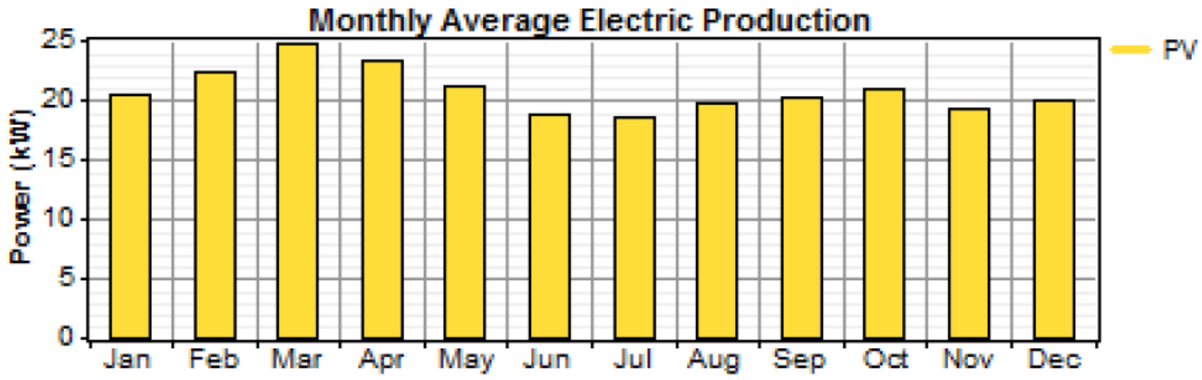


Figure 23 Monthly average electricity production

The same overview, only with data for an average year is displayed below. The hours of the day is represented vertically. The red dots are presenting hours with the highest power production and black gaps represents hours with no power production at all. January, February, March and November are the moths where the highest momentarily power production is reached. Months like June, July, August, September, November and December are months that are characterized by many outages and underproduction of energy. This is exactly the same that was stated by PVsyst, this is natural as the irradiation data that was implemented was the same.

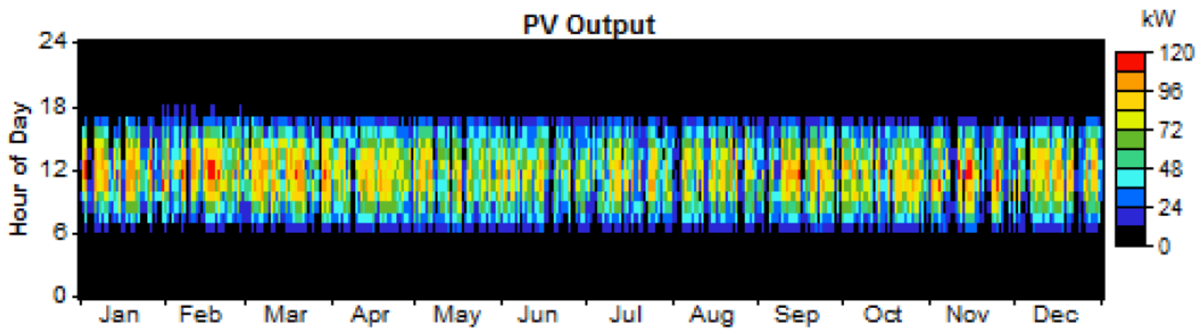


Figure 24 PV output curve

15.1.3 The Battery Pack

A battery pack of a total of 560 batteries with a string size of 8 was, chosen to be able to have a battery pack operating with a voltage of 48. 70 parallel strings each containing 8 batteries were demanded to cover the storage capacity needed to satisfy the system settings.

On the next page the state of charge for an average year is displayed regarding the hours of the day. As one can see it happens quite frequently that the battery bank is reaching a 90-100% state of charge. This suggests that unlike PVsyst HOMER does not have a upper value when it comes to charging the batteries and they will charge to 100% before being disconnected. This practically means that the operation of the batteries as they are now, could cause damaged batteries and shorten the battery-packs lifetime. Full batteries (marked by red) are characterizing the system, this implies that spillage is a quite frequent problem for the scaled system. On the other hand at some periods the batteries are reaching the critical level of 30% which automatically decouples the batteries from the loads to avoid battery damage, something which is causing shortages and loads not being served. As there is both problems with spillage and un-served loads because of empty battery banks, one can conclude with that both a large and a smaller battery bank would lead to suboptimal systems as solving one problem only worsens the other issue.

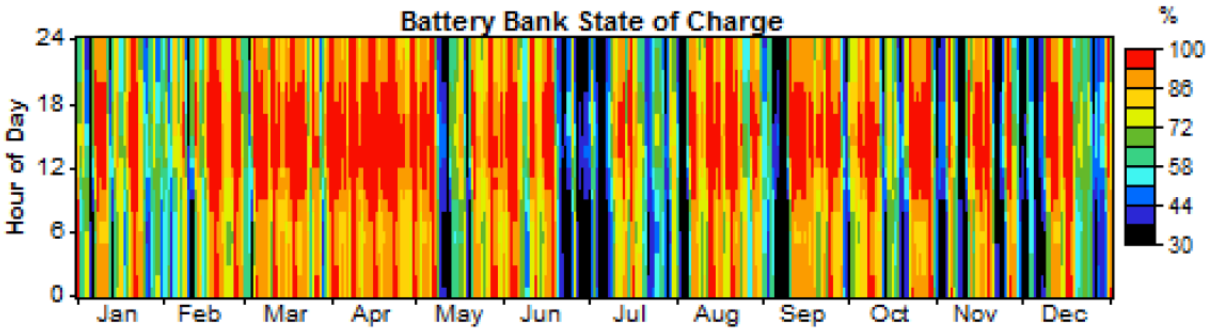


Figure 25 State of charge

The frequency histogram is an other interesting overview provided by HOMER. It basically displays the same as figure 25, however it shows clearly the occurrences of the different state of charge. The frequency diagram gives important information regarding the healthiness of the battery pack, and can be used to detect spillage and how frequent the batteries are reaching unhealthy low or high levels. Close to 8% of the time the batteries are 30% full and 14% of the time they are 90% full, this is a rather high percentage of when the batteries are at critical levels. Spillage seems to be a more frequent problem that unmet loads, however one must keep in mind that the 5% loss of load has to be satisfied, meaning that no more than 5% of the loads can be unmet.

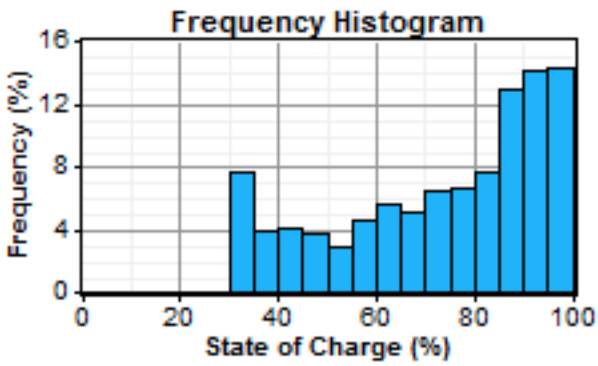


Figure 26 State of charge frequency

15.1.4 Converter Data

In the table below the converter data is displayed. A 50kW inverter is needed to satisfy the system and transform DC power produced by the PV modules to AC power, which can supply the loads. The mean output of the inverter is 15.9 kW, however even if this seems to be a low number, one have to keep in mind all the hours in the night where the demand is very poor and this lowers the average. The converter is not in this system working as a rectifier, hence converting AC to DC as no DC loads have to be served.

Quantity	Inverter	Rectifier	Units
Capacity	50.0	47.5	kW
Mean output	15.9	0.0	kW
Minimum output	0.0	0.0	kW
Maximum output	49.0	0.0	kW
Capacity factor	31.9	0.0	%

Quantity	Inverter	Rectifier	Units
Hours of operation	8,471	0	hrs/yr
Energy in	146,948	0	kWh/yr
Energy out	139,599	0	kWh/yr
Losses	7,348	0	kWh/yr

Table 17 Converter data

On the below in figure 27, the inverter output power over an averaged year is displayed, showing how the output is changing over each hour of the day. As the vertical changes are very varied one can tell that the load-changes during a 24 h period are severe, something that fits with the load profiles that were implemented. The peak occurs at 11 am and serving this load demands an inverter capacity of between 45 and 50 kW. In figure 27 one can also see that the same pattern is mainly repeated over and over again, implying the same load profile no matter which season it is. This is exactly as it should be, as it in the settings was specified that there were to be no load changes during the year. However one can detect some dark spaces in between the pattern, these are representing the undelivered energy from the PV array that has been mentioned. One can see that June, July, August, September, as well as December are the months with the highest delivery deficits. The rectifier shows the same pattern as in the graph displaying array power production in figure 24, since all power has to go through the rectifier before being distributed to the loads.

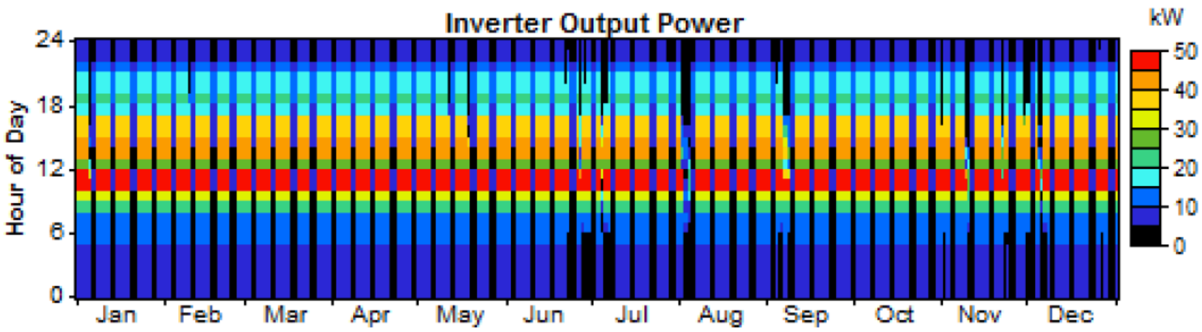


Figure 27 Inverter Output Power

15.2 Suboptimal Scaled System Configuration with Backup Generator

When it comes to the second best option of scaling the system, HOMER found that a large PV-array accompanied with the 10kW diesel generator as a backup with load following configuration of the generators, was the cheapest and thereby optimal alternative. For repetition; that the configuration and relationship between the generator and the batteries is load following, means that in stead of always running the generators at full capacity at all times of operation to use the extra energy to charge the batteries, the generator only provides energy to serve the load of which a small amount of excess energy is used for charging the batteries. It is not very surprising that the load following configuration is the optimal one as HOMER advices one to choose this setting if the system is expected to have a high degree of renewable energy. In this chapter the second best solution for the design of the system will be displayed in a similar manner to the optimal solution.

15.2.1 Main Result

On the following page an overview over the main results regarding the system with a backup generator is displayed. The charts with the main result for the second best design of the electricity supply sates that a system with a 121 kW PV array with 560 PV-modules and 576 batteries as well as a backup generator of 10 kW and an inverter capacity of 50kW is the second best system configuration. This system requires the same amount of modules as the optimal system and the same size of inverter, however, 16 further batteries are required. The suboptimal system is quite similar to the optimal one, however the biggest difference is that this system requires the 10 kW generator as a part of a hybrid system.

System architecture

PV Array	121 kW
Generator	10 kW
Battery	576 Trojan L16P
Inverter	50 kW
Rectifier	47.5 kW
Dispatch strategy	Load Following

Cost summary

Total net present cost	$ 818,298
Levelized cost of energy	$ 0.240/kWh
Operating cost	$ 13,723/yr

Table 18 Main results HOMER II

This system has a net present cost of 818 298 US$, which is 48 197 US$ and 5.9% more than the net present cost of the optimal system. This amounts to a levelized cost of energy of 0.240 $/kWh and an operating cost of 13 723 US$, values which has increased by respectively 3.3% and 13.4%. The reason for the higher costs related to this system is likely to be fuel costs, maintenance of the generators as well as the increased number of batteries.

5.2.2 Power production

Below the division between power production from the PV array and the generator is displayed.

Component	Production	Fraction
	(kWh/yr)	
PV array	182,209	98%
Generator	3,318	2%
Total	185,527	100%

Table 19 Fraction of production

The generator only produces 2% of the total 185 527 kWh/yr. that is being produced by the system. This production is 1.8 % higher than for the optimal system. It is also stated that the consumption is 143 020 kWh/year against 139,599 kWh/year for the optimal system. It may seem odd that the two systems states different consumption even if the same load profile has been implemented, however this system will have a lower amount of unmet loads as we can see in the table 20.

For the suboptimal system the amount of unmet loads is 1888 kWh/year giving a LOL of only 1.3 % compared to 3. 8 % for the optimal system configuration. The amount of unmet loads are 3421 kWh/yr. lower than for the optimal system, something that exactly is the amount of kWh more being consumed regarding the suboptimal system. The excess electricity is approximately the same, only 0.6 % less, so the spillage problem is not very different for the two systems. The power production from the PV array is exactly the same as for the optimal system, so table 15 for the optimal configuration yields also for the suboptimal system.

Quantity	Value	Units
Excess electricity	25,050	kWh/yr
Unmet load	1,888	kWh/yr
Capacity shortage	2,615	kWh/yr
Renewable fraction	0.977	

Table 20 Electricity production balance II

Below the monthly average electricity production is displayed and one can in addition to the power production from the PV-array, see which months the generator is used and how much power it produces. The months between June and December are the months where the generator is being used most frequently. November is the month where the need for the use of the generator is the highest. As the electricity production from the PV production is exactly the same as for the optimal system, the power from the generator is only helping to lift the power curve to a higher level and minimizing the unmet loads.

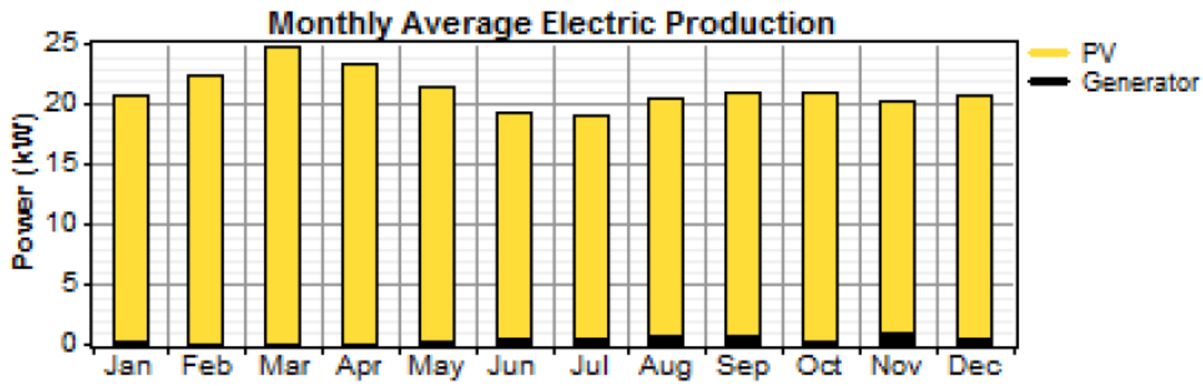


Figure 28 Monthly Average Electric Production II

Below the PV output curve is displayed, and as the PV array is identical in the optimal and suboptimal system, the PV output curve is identical to the one presented in figure 24. However the interesting factor here is to look at figure 28 and 29 jointly and discover that the ”black holes” in the graph below, are getting filled by the generator production displayed in figure 28. November is clearly the month that is characterized with the most frequent black areas in the graph below and coherently in figure 28 it has been stated that this is the month that requires the most power from the diesel generator.

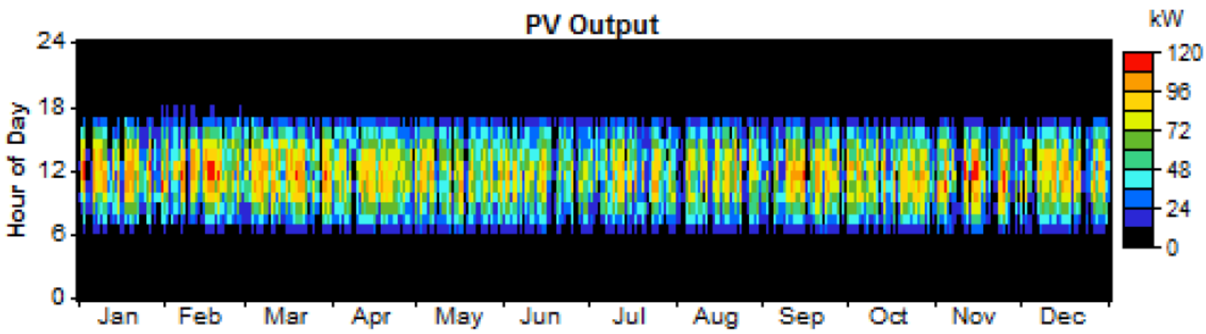


Figure 29 PV Output curve II

15.2.3 The Diesel Generator

As one could see from the overview in table 20, the generator is producing 3 318 kWh of energy per year. The details around the operation of the generator is displayed in the following tables.

Quantity	Value	Units
Hours of operation	679	hr/yr
Number of starts	273	starts/yr
Operational life	11.0	yr
Capacity factor	3.79	%
Fixed generation cost	1.04	$/hr
Marginal generation cost	0.393	$/kWhyr

Table 21 Generator operation

The hours of operation per year amounts to 679, and given a lifetime of 7500 hours, this implies that the generator will have a lifetime of 11 years. The diesel generator is started 273 times and the marginal generation cost is 0.393 US$/kWh*yr, a cost which is 63.7% higher than the levelized cost of energy for the system in general which is 0.240 US$/kWh.

In the table below one can see the details around the fuel usage. The total yearly consumption is 1434 litres . 0.432 litres are being used per kWh of produced energy from the generator.

Quantity	Value	Units
Fuel consumption	1,434	L/yr
Specific fuel consumption	0.432	L/kWh
Fuel energy input	14,114	kWh/yr
Mean electrical efficiency	23.5	%

Table 22 Fuel data

In the overview below one can get an impression of the usage of the diesel generator during 24 hours continuously for a whole year. If one compares this graph with the output curve in figure 29, one can see that these two graphs are like two perfectly fitting puzzle pieces. The generator is operating to fill in the missing power at times when the weather is cloudy and there is not enough energy from the PV array to cover the demand. As one can see the generator is most frequently being used in the early morning or late evening when the sun is not present. The use of the generator is most frequent in June, July, August, September, November and December.

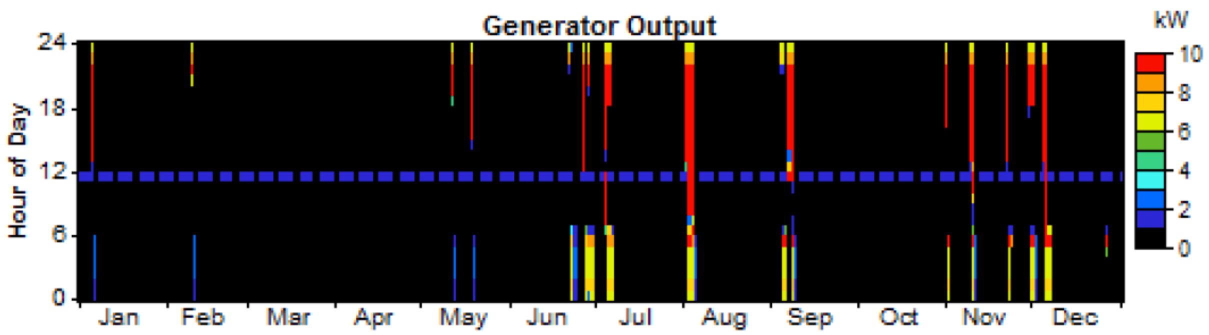


Figure 30 Generator usage II

15.2.4 The Battery Pack

The battery pack is configured in close to the same way as for the optimal system. However instead of 70 strings consisting of 8 batteries each, there are now 72 strings, hence 576 batteries resulting to 16 further batteries needed. The reason for the larger battery-pack needed for this system compared to the optimal system, is likely to be that the excess energy from the diesel generator demands extended storage capacity.

Below the state of charge of the battery bank is displayed, it looks very similar to the state of charge overview for the optimal system and this shows one that the power from the generator is mostly being lead straight to the loads and that the battery bank is not being charged. The reason for this is the load following configuration between the generator and batteries, which does not make the generator overproduce power just to charge the batteries. However it should be noted that trying to differentiate graphs like these, is very hard and even if it does look like the state of charge is identical for the two systems it might not be the reality.

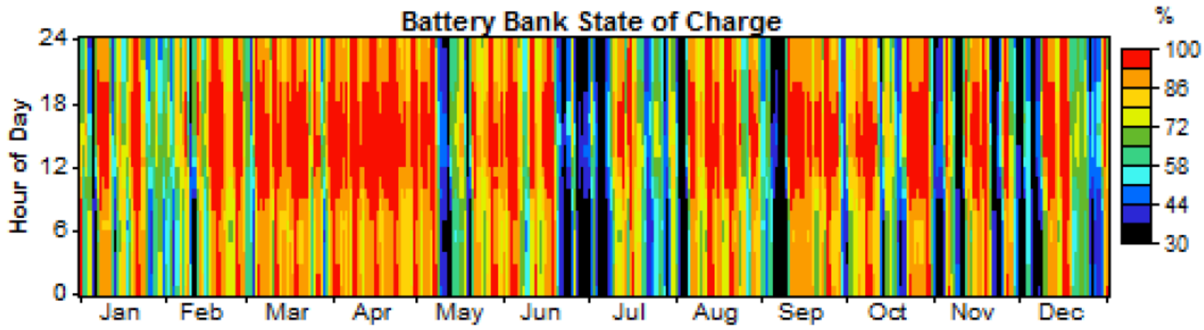


Figure 31 State of charge II

A frequency diagram showing how frequent and to what degree the battery bank is charged, is displayed on the following page. In this diagram it is easier to try to differentiate the battery bank of the optimal and suboptimal system. The biggest difference is that the very low charge of the batteries is being avoided. For this system the batteries are only 2% of the time down to a 30% state of charge, while in the optimal system this number is almost 8%. It seems like the suboptimal system is a more healthy one regarding the battery pack.

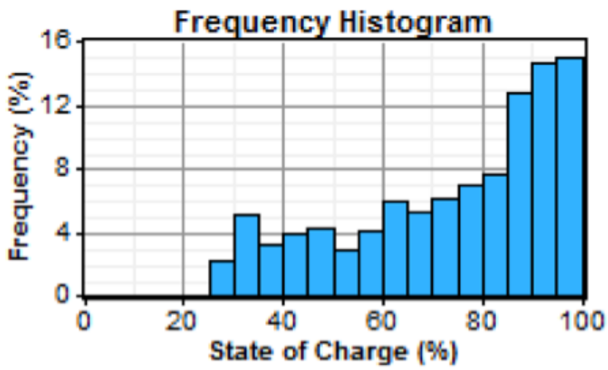


Figure 32 State of charge frequency II

15.2.5 Converter Data

Below the operation and details around the converter/inverter is clarified. The biggest differences for the inverter-use between the optimal and suboptimal configuration of the system, is that the maximum output is slightly lower (2%) for the sub-optimal system design, as well as the hours of operation and thereby energy in/out is higher. This is because of the generator activity causing increased energy production which is partially stored in the batteries and have to pass through the inverter for delivery to the loads. The losses are also slightly higher, as the operation of the inverter has increased. However all in all, the inverter output is very similar for the two systems. The converter is also not in this system working as a rectifier, as no DC loads have to be served.

Quantity	Inverter	Rectifier	Units
Capacity	50.0	47.5	kW
Mean output	15.9	0.0	kW
Minimum output	0.0	0.0	kW
Maximum output	48.0	0.0	kW
Capacity factor	31.9	0.0	%

Quantity	Inverter	Rectifier	Units
Hours of operation	8,530	0	hrs/yr
Energy in	147,055	0	kWh/yr
Energy out	139,702	0	kWh/yr
Losses	7,353	0	kWh/yr

Table 23 Converter data II

As one can see from the overview below, the inverter output power looks very similar to for the optimal system without a diesel generator. It is however hard to detect minimal differences in such a chart, and as it is stated in table 23 that the inverter activity has increased, there has to be slight differences regarding figure 33.

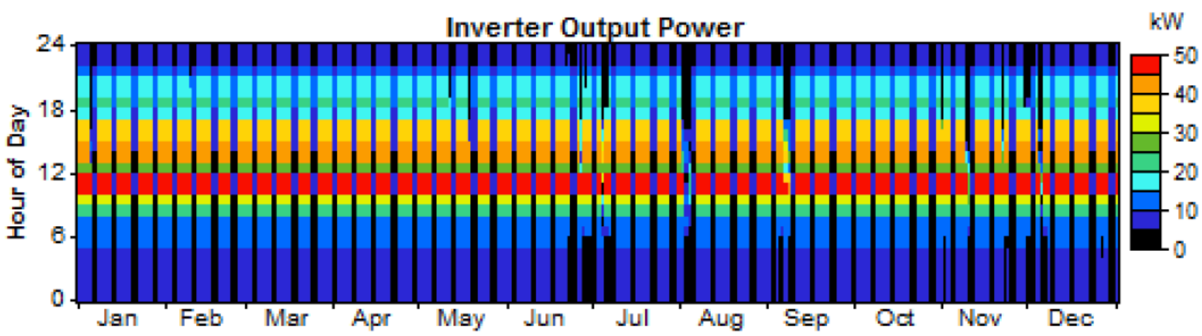


Figure 33 Inverter Output Power II

15.2.6 Emissions

For the system with a backup generator, an other factor to consider is the emissions connected to the operation of the system. For the optimal system one will have zero direct emissions, in contrast with the suboptimal system with the diesel generator that have direct emissions from the burning of diesel which also have to be taken into account. Below one can get a rough overview over the emissions connected to the suboptimal system.

Pollutant	Emissions (kg/yr)
Carbon dioxide	3,777
Carbon monoxide	9.32
Unburned hydocarbons	1.03
Particulate matter	0.703
Sulfur dioxide	7.59
Nitrogen oxides	83.2

Table 24 Emission data

According to HOMER, among others 3 777 kg of carbon dioxide per year will be emitted as well as 83.2 kg of nitrogen oxides due to the operation of the diesel generator. These are significant magnitudes and they have to be taken into account when determining the optimal system, as not only technical and economical aspects are taken into account.

15.3 Sensitivity analysis

Fuel Price, irradiation and real interest rate were the parameters that were performed a sensitivity analysis on regarding the simulations in HOMER. It has been studied for which values, these parameters makes HOMER suggest the system with a backup system with one or two diesel generators as the optimal system. In the coming sub-chapters, the sensitivity analysis that was applied to the simulations will be presented and commented.

15.3.1 Fuel Price

After performing multiple simulations in HOMER trying to narrow down to the exact number for which the system with backup is the optimal one, it was detected that a diesel price as low as 0.4 US$/litre, suggests that the system should consist of a PV array and both the 24kW and 10 kW backup generator. This would add up to a net present cost 0f 767 996 US$ and a levelized cost of 0.223 US$/kWh. Is not surprising that these costs are lower than the optimal design that has been found, as the diesel price has been severely decreased. The fact that the probability that the diesel prices will sink from 1.6 to 0.4 US$/l is equal to zero due to the scarcity of fossil fuels, excludes further discussions around this sensitivity variable. Quite oppositely, a raise in diesel prices is expected, something which only strengthens the statement that the system solely supplied by solar power is the economically optimal one.

15.3.2 Irradiation

An other interesting parameter to study when it comes to the sensitivity of the system, is the irradiation. HOMER states that with an average irradiation of 3.8 kWh/m^2/day and below, the optimal system consists of a 127kW PV-array and the 10 kW backup generator. This system would have a net present cost of 870,301 US$ and a levelized cost of 0.260 US$/kWh. The average irradiation for Wawashang is currently 4.7 kWh/m^2/day and it is not very likely that the average irradiation would sink with almost 20% to 3.8 kWh/m^2/day. However even if it is very unlikely, it is not impossible that the average radiation will sink. Atsumu Ohmura, professor at ETH Zurich, discovered that the solar irradiation globally decreased by 2% [44] per decade between the 1950s and 1990 and there is no reason to believe that the numbers should be lower now. However 20% within a period of 20 years, which is the lifetime of the project, seems very unlikely and the irradiation will therefore most likely not be a factor influencing the economical optimality of the system.

15.3.3 Real Interest Rate

Nicaragua at the time has a very high inflation rate, which causes a very low and even negative real interest rate, meaning that the inflation rate is even higher than the nominal interest rate. The low real interest rate which currently is -1.6%, makes investments lucrative. Through sensitivity a sensitivity analysis in HOMER, it is stated that a real interest rate of 13 % or more, makes the system with a 10 kW backup generator optimal. The system will then have a price tag of 560,793 US$ and a levelized cost of 0.562 US$/kWh. One might realize that the net present cost of the system is lower here than for the optimal system that has been presented in the previous chapter, however it is important to remember that this is only caused by the real interest rate being very high, making inflation very low, which again makes the money more valuable in the future. So the two net present costs cannot be discussed nor compared when they are based on two different real interest rates. What can be discussed, is whether a real interest rate of 13% or higher is a realistic variable and a potential threat for changing the optimality of the system. Looking at other countries real interest rates, one realize that it is very not very common that these go over 13%, even if some countries have abnormally high real interest rates. According to the World Databank, the United States had a real interest rate of 1% in 2011, Norway had in 2009 a real interest rate of 11.4 and Costa Rica, Nicaragua's neighbour country, in 2011 had a real interest rate of 11.5%. The economy in those countries are more stabile than the economy of Nicaragua, so one cannot really compare whether it is likely that Nicaragua's real interest rate rises to 13%. However, based on the fact that Nicaragua has a history of inflation problematic and the fact that at this point the real interest rate is even negative, it is not very likely that the real interest rate raises that severely within the next 20-year period.

16 Discussion

In this chapter the results from both the PVsyst and HOMER simulations will be discussed. As there are two sets of results for each of the software's, with and without backup diesel generators, the simulations within each software will be compared, as well as the results will be compared across the software that were used. The feasibility of the system in general will also be discussed.

16.1 PVsyst Simulations

Regarding the simulations performed in PVsyst, the system with a backup required 2 less PV modules than the one with no backup system. This is an expected outcome, as the supply system with a backup generator has a greater flexibility and is not completely relying on the power produced by the PV-array, as there is an alternative supply option. However as mentioned before, there is a factor of randomness applied to every simulation, and it may also have been this factor that designed this system different. Regarding the discussions around the system with and without backup systems that were simulated in PVsyst, it is important to differentiate between how the system functions when solely looking at the PV configuration and as a whole system including backup. Because even if the system with a backup has a 100% delivery rate because the diesel generator can make up for the energy that the PV system cannot deliver, the solar fraction of only the PV-array is 3.28% lower than for the system without a backup system. This could be caused by the 2 extra modules, however it might also imply that the PV system itself is more well functioning for the system with no backup even if regarding the total system, the system with a diesel generator backup is more reliable. Because while the system with no backup has a delivery deficit of 5.5% on a yearly basis, the same factor is 0 for the system with a backup system, implying that the system with a backup is a very reliable one. However, whether the use of the generators in PVsyst is simulated in a realistic way, can be discussed as totally different usage of the diesel generator has been identified in PVsyst and HOMER. This issue will be returned to.

The same trend yields for the performance ratio of the two systems, only regarding the solar power production, the system with no backup has a 1.9% higher performance ratio with 66.1% versus 64.2%. This confirms that it is not only the two extra modules that makes the system with no backup perform better, because the PR tells one about the array quality as a percentage and is regardless of amount of modules in the system. However for the system seen as a total package also taking the generator performance into account, the system with a backup has a 70.2% PR which is larger than the 66.1% PR ratio of the system with no backup. The spillage due to unused energy is however larger for the latter, this is most likely caused by the fact that the system has a larger PV-array, however the same battery pack.

It is not very surprising that the system with a backup is a much more reliable one, as there are two sources of power that are available. And even if the PV array itself has a higher performance for the system with no backup and the battery pack seems to be healthier, the system with a backup is as a whole from a technical perspective, stated to be the optimal design according to the results in PVsyst. This because the system with no backup has large expected supply deficits in months like June, July, August, October and December, the largest deficit being 16.7% in June. These significant deficits are expected to cause severe delivery problems and could potentially affect the activities in the Wawashang complex. There are however other aspects to take into account and the fact that PVsyst has a very simple modelling of the generator is questioning the reliability of the optimal system stated by PVsyst.

16.2 HOMER Simulations

When it comes to the results produced by HOMER, it is easier to determine the optimal system as HOMER serves it on a silver plate and it is not necessary to perform multiple simulations to find the suboptimal configurations of the system. As it has been stated, regarding the accepted loss of load and autonomy days, the optimal system configuration was a system solely consisting of PV modules and a battery bank. However, one must keep in mind that these are optimal result regarding an economical evaluation. A diesel generator configured in a hybrid system with a PV array was the second best solution with a 6.25% higher net present cost. Comparing the two systems, the PV array configuration of both of them are identical except that the hybrid system requires 16 further batteries. The reason why these extra batteries are needed in the hybrid system, is likely to be because if they would not be included, the diesel generator could not properly charge the batteries with the excess energy it produces, as the capacity would be too small or the batteries would filled up too soon and damage due to overcharging could be risked. The optimal system is significantly cheaper than the suboptimal one and 48 197 US$ less will be needed. As the diesel generator is already paid for, this sum of money is connected to fuel costs and the extra batteries that are needed. However even if the system is economically optimal, is should be registered that the hybrid system with a diesel generator is a more reliable system, as there are two options of electricity production and the LOL is lower.

Both systems had a PV array that was producing 182 209 kWh per year, however the system with a diesel generator implemented produced a further 3318 kWh per year something that made the amount of unmet load sink from 5308 kWh/year to 1888 kWh/year and this is strongly increasing the reliability of the system. The reason why the system with the highest reliability is suboptimal, is that both systems satisfy the boundary of a LOL under 5% (1.3 % compared to 3. 8 %) and the cheapest one is determined to be the optimal system because an economical analysis is being applied. Excess energy is slightly higher for the system with no backup, suggesting that the spillage problem is higher for this system. The reason for the spillage problem being higher is likely to be the smaller battery pack for this system. It seems as the battery pack in general is healthier for the suboptimal system, as a too high and too low battery state of charge is to a higher degree avoided according to the frequency bar diagram of the state of charge.

It has been stated that even if the hybrid system has the highest reliability and lowest amount of spilled energy, it is the suboptimal design of the system as it is more expensive and as the other system solely relying on solar power fulfils the requirements that has been set in a cheaper way. An other advantage concerning this system is the fact that there are no emissions connected to this system design whereas the hybrid system among others emits 3777 kg CO_2 per year. The conclusion produced by the simulation tool HOMER is the opposite of what simulations in PVsyst suggests, this because we are looking at an economical optimization as opposed to technical optimization. However looking at the details of the reports, almost the exact same outcome as for the simulations in PVsyst are provided regarding healthiness of the system and system design.

16.3 PVsyst versus HOMER

The perhaps most interesting factor in this thesis, is to study is the resemblance between the outcome of the two simulation tools PVsyst and HOMER. A good start is to look at the suggestions of system design that were produced. The key data for the design of all systems are displayed in the table below.

	HOMER		PVsyst	
Parameters	PV	PV + diesel gen	PV	PV + diesel gen
Peak power [kWp]	121	121	124	123
Number of Modules	563	563	576	574
Number of Batteries	560	576	480	480
Yearly production PV [kWh/year]	182 209	182 209	158 800	150 060
Yearly production 10kW Gen. [kWh/year]		3 318		12 400
Spillage [kWh/year]	25 210	25 050	15 100	11 500
Unmet Load [kWh/year]	5 308	1 888	8 000	0
Yearly consumption [kWh/year]	139 599	143 020	136 600	144 600
LOL [%]	3.8	1.3	5.5	0

Table 26 Summary of results in HOMER and PVsyst

The first factor that needs to be commented is the deviation in yearly consumption. Because as PVsyst states 136 600 kWh for the system with no backup and 144 600 for the hybrid system, HOMER states 139 599 kWh for the system with only a PV-array and 143 020 kWh for the hybrid system. In HOMER the consumption is apparently higher than in PVsyst for the system with no backup and lower regarding the hybrid system. It seems like the reason for this is that the amount of unmet load is not zero for the hybrid system as it is in PVsyst. This tells one that while PVsyst uses the backup system as a supplier for the entire amount of unmet load by the PV-array to design a 100% reliable system, HOMER still regards the LOL limit of 5% and simulates the generator in an economically optimal way still leaving an amount of unmet load. It is when it comes to the operation of the generator that the biggest differences between the software can be found. Because as the generator is producing 3 318 kWh in the hybrid system in HOMER, the same parameter amounts to 12 400 kWh in PVsyst, stating a 274% higher usage of the generator. While PVsyst has a focus on technical optimization, HOMER makes an economical optimization and the priority of keeping operation costs low are put up against minimizing the amount of unmet load. An indirect result of the priorities regarding the use of the generator, are the emissions. As the diesel generator is running 2.7 times more for the system scaled in PVsyst, the emissions are increasing proportionally to that number and the system suggested by PVsyst will emit 2.7 times more CO_2 and other unwanted combustion products.

The array peak power that is suggested is only deviating with 2-3kWp between PVsyst and HOMER, HOMER operates with the same peak power for both systems while PVsyst suggest a 1 kWp lager array for the system with a diesel generator. This results in a slight difference in the suggested amount of modules, and HOMER suggests a smaller array for both the hybrid system and the system solely consisting of solar power. The fact that the array is smaller implies a lower power production, however it is stated that the yearly production is significantly higher for the simulations performed in HOMER. The production is for the hybrid and the solar powered system respectively 21.4% and 14.7% higher than in PVsyst and this might be caused by different reasons. It is a possibility that there are more losses included in the stated production in PVsyst and therefore the production appears to be lower. An other possible reason for the deviation is that the two systems are processing the irradiation data in different ways, as HOMER only was implemented monthly values and PVsyst produces hourly synthetic data.

An interesting parameter to study regarding the healthiness of the supply system is the unused energy or spillage due to small battery capacity. HOMER states a much larger amount of kWh spilled because of full batteries. For the system solely supplied by solar power, the spillage stated in HOMER is 66.9% higher than in PVsyst, and for the hybrid system it was 117.8%. This is a significant deviation, and one would think that the reason for this could be that the battery pack scaled in HOMER would be smaller. However this is not the case and for both systems the battery pack is larger in PVsyst. The reason for the higher spillage could however have its source in the significantly much higher production, which is operated with in HOMER that leads to the energy production simply being to high to fit in the battery pack at various points during the year. The extreme production by the PV-array stated by HOMER is possibly also the reason for the much larger battery pack.

For both software tools approximately the same months are stated to struggle with supply regarding the system with no backup system. June, July, August, October and December are according to both software the critical months, however in HOMER it also seems like November is a month where the delivery rate is poor. It is rather surprising that the systems are deviating when it comes to the critical months as the same irradiation data has been implemented. However, the higher production and spillage that is stated for HOMER could be the reason for this. As PVsyst is a software solely made for the scaling of PV systems and the fact that PVsyst has a more accurate handling of the irradiation data, indicates that critical months that are most realistic are the ones stated by PVsyst.

All in all there are only small deviations regarding the scaled PV array, battery pack and yearly consumption for all systems, even if the production and spillage is significantly deviating between the two software tools. But regarding the hybrid PV-diesel generator systems, the results are deviating significantly. Small deviations are expected even if the parameters that were implemented into the two software tools were similar, because PVsyst and HOMER are processing the parameters differently and sometimes adding a factor of randomness or simply using different equations and settings within the systems. As mentioned the most significant deviation between the results of the two systems, is the way the diesel generator is implemented and used. As PVsyst only offers a very limited simple operation of the generator, only allowing it to supply all the missing energy making a LOL of 0%, HOMER operates the generator in a realistically and economically optimal way only decreasing the LOL slightly.

Shortly summed up it has been stated that regarding the simulations in PVsyst, a system with a backup diesel generator is the technically optimal system, however HOMER states that the economically optimal system is a system solely consisting of a large PV-array even if this system seems to be technically slightly worse regarding healthiness of batteries and spillage. Even if both software tools favours the system with the backup from a technical point of view, it should be noted that HOMER states a much smaller difference between the two systems and as PVsyst struggles with simulating hybrid systems, the seemingly great advantages that is stated by PVsyst are probably not very exact. So which software should dominate the decision? In addition to the economical and technical aspect, one also have to take into account factors like fuel accessibility, abundance of fossil fuels, unpredictable future operation costs, emissions and environmental aspects. One also have to take into account that a 5% LOL has been accepted as well as the Wawashang complex´ s has a goal of being a zero emitter and their attitude and perceptions around emissions. It also has to be considered that PVsyst has a poor accuracy when it comes to simulating hybrid systems and that the results from this simulation regarding that system cannot be considered with the same seriousness as for HOMER.

An other very important thing to enlighten, is the time aspect. Because as mentioned earlier it is not until 2023 that the load profiles that have been applied are valid. The fact that there is a relatively large time frame until the peak power is needed, as well as it is expected that other renewable sources of energy are to be implemented into the microgrid, is making it seem like the system with no backup could be the optimal solution for now. A supply deficit in June of over 16% and significant deficits for other months, will be acceptable for quite a while and if no other renewable and sustainable source of energy has been found until the deficit affects the complex, a diesel generator could be implemented at that point. However it is highly probable that an energy source such as biomass, would be implemented before that point of time, as students from NTNU will continue the work with studying the potential energy sources in the area.

Depending on whether economics, emissions, reliability, simplicity or efficiency is the most important factor when scaling a system, the optimality of the system changes. And ultimately, it is up to FADCANIC to decide which system suits the complex the best and which of systems that is the optimal solution for their needs, ideology and preferences.

16.4 Feasibility of System

It has been suggested that it is the system solely consisting of a large PV array and no backup, is the optimal one for the Wawashang complex regarding that the time perspective of the load profile could temporary eliminate the problematic around the significant deficit of supply in June, July, August, October and December. Even if the system has a poorer reliability, it still fulfils all criteria's that were defined and it is according to HOMER a significantly cheaper and simpler alternative with a saving potential of 48 197US$ as well as it is a zero emission system with predictable operating costs. The next question is whether the scaling parameters provided by HOMER or

PVsyst should be used for the scaling of the system. It seems as the main differences for the system design lies within the software and their handing and prioritizing regarding energy production, spillage and unmet loads. Because as HOMER operates with a higher amount of energy production, spillage and lower amount of unmet load, PVsyst optimizes the other way around with a minimized amount of spilled energy, low production and a higher allowance for unmet load. In other words, HOMER over scales the PV-array and PVsyst over scales the battery pack. The odd thing is that this is not what is occurring according to table 26. The reason why that it doesn't appear to be so, lies within the production numbers. Because as a smaller array in HOMER provides a much higher amount of produced energy, a larger array produces a much lower amount of kWh during the year according to PVsyst. The reason for this deviation is the way the irradiation data is treated in the two software tools and the key to understand is the term relativity. Because as HOMER operates with much higher irradiation numbers, PVsyst uses a much worse scenario and it appears that the system scaled by HOMER needs a smaller PV array. However it has a much higher production, which leads to a spillage problem of much higher magnitudes than for PVsyst. In the same way it looks like battery pack is slightly over scaled in HOMER instead of PVsyst, even if the reality is the opposite because the production magnitude is much higher in HOMER and the opportunity of storing the energy is much better for PVsyst. The same yields for the un-served energy; as the production appears to be much higher for the simulations in HOMER than in PVsyst, there would need to be a much, much bigger array to compensate for the unmet energy and even if the array appears to be larger, the amount of unmet energy is significantly higher than in HOMER.

So the choice between using the PVsyst scaling of the system that HOMER designed is a matter of prioritizing between oversized battery pack, low spillage and a larger amount of unmet loads for PVsyst or an oversized PV-array, lower amount of unmet load and high amount of spillage in HOMER. However the most important issue is which software has the most reliable and realistic processing of data. The author believes that as PVsyst is a simulation tool solely for solar powered supply systems and as the software offers a much greater amount of details and parameters that can be implemented as well as the irradiation data is handled by producing synthetic hourly values, PVsyst is the software that should be regarded when scaling the PV system. However HOMER offers a much more realistic simulation of backup systems and offers a unique possibility of the determination of the economically optimal system. It is important to emphasize that if the system with a backup generator was stated to be the optimal one, it would have been strongly recommended to consider the results from HOMER as the most correct ones.

An important thing to remember is that the net present value which was stated by HOMER is not perfectly coherent with the outcome of the PVsyst simulation as the systems designed in PVsyst and HOMER showed slight differences. The system of which the costs in HOMER are related to, consists of 13 further PV-modules and 80 less batteries. This will lead to slight cost differences, however as the modules are 520US$ each and the batteries are 280 US$ each, this will even lead to a decrease in net present cost and will only underline the economical optimality of the suggested system.

Even if it has been stated that a system with no backup is suggested for the Wawashang complex, it is important to emphasize that it is a matter of preference that determines which system is optimal when taking other aspects like reliability and emissions into account. Because if access to the full capacity of the system from day 1 is the most important factor, and the willingness to pay for that reliability is there, at the same time as emissions are considered with indifference, the system with a 10kW backup diesel generator could be the optimal configuration. However the author's recommendations are highly relying on other renewable energy sources being implemented into the microgrid before full capacity of the system is necessary.

There is one last factor that needs to be discussed regarding the feasibility of the system and that is the alternative cost versus the suggested system. As it was seen in chapter 10, the alternative of the suggested microgrid, was a grid-connected system, which demanded a grid extension of 65 km from the nearest connection point Kakabila. The grid connection had a net present cost of 1 949 928 US$, which is 153% more than the microgrid. And even if the net present cost according to HOMER does not include costs related to the microgrid distribution system or the fence around the cluster, the net present cost of the microgrid will stay far below the alternative of grid extension underlining the optimality of the microgrid. Even though it is stated that the construction of the suggested micro grid is much lower than the alternative cost, it should be noted that 770 101 US$ is a significant amount of money for the FADCANIC and sponsors, and whether the system could be affordable or not is up to the organization to deliberate.

17 Conclusion

Through 4 weeks of fieldwork, crucial data regarding the design of a feasible, economically optimal and technically optimal system, was retrieved for implementation into the software tools PVsyst and HOMER. In both simulation tools, two systems, a system with a 10 kW diesel backup generator and a system with no backup, were investigated regarding optimality. Whereas HOMER stated that the system with no backup was the economically optimal solution, both simulation tools concluded with that regarding technical optimality, the system with a backup diesel generator was the optimal system. This is based on a fact that even if a 5% LOL to a certain degree is followed on a yearly basis, according to PVsyst; June, July, August, October and December were critical months with large supply deficits. The largest deficit occurs in June where the solar fraction is clamed to be 0.833 implying an amount of un delivered energy to be 16.7%, 11.7% over the accepted amount of 5%. HOMER provided similar numbers, however states a much higher productivity of the array. Based on the fact that PVsyst is a software tool specialized on designing PV-systems and the fact that the irradiation data is being used in a much more accurate way because of synthetic hourly data being produced, it was decided to apply the results and design that was claimed by PVsyst.

HOMER stated that the economically optimal configuration of the system was a system without a backup generator and even if both software tools implied that this was a technically suboptimal design, the system design with no backup generator ended up being the suggested system for the Wawashang complex. The reason for this is the time perspective for the project and the fact that load profiles for 2023 have been applied for the scaling of the system. The plan is to implement the system with no backup generator that was scaled in PVsyst and the planned microgrid for distribution to supply the current demand, and in the future when the demand approaches the levels for year 2023, an other renewable energy sources like biomass could be integrated in the microgrid. In this way, the economically optimal system could be implemented with no backside of technical sub-optimality as well as a simple, zero emission system which is independent of fossil fuels is obtained.

The system that regarding the above mentioned factors is found to be the optimal system, is according to PVsyst an 124kWp array consisting of 576 Kyocera 215W PV-modules and a battery-pack containing 480 420 Ah Trojan 6V batteries and a 50 kW inverter. This systems has a yearly supply to the user of 136 600 kWh resulting in a yearly shortage of 8000 kWh amounting to 5.5%. The net present cost of the system is according to HOMER 770 101US$.

An alternative option of electricity supply, which is attaching to the national grid instead of creating an own microgrid, was also investigated. It was stated that the distance to the closest connection point grid, Kakabila, was 65 km and a demanded an investment with a net present value of 1 949 928 US$, which is 1 179 827 US$ more than the system PVsyst suggested. The investigation around the alternative cost is thereby not changing the optimality of the microgrid.

Sensitivity analyses that were performed by HOMER proved that none of the most unstable variables that were implemented, will by small variations of magnitude change the economical optimality of the system. A decrease of fuel costs of 75%, a decrease of average solar irradiation of 20% or an increase of real interest rate of 912%, all very unlikely magnitudes, would change the economical optimality.

It is important to emphasize that system that has been suggested, a large PV cluster distributed by a microgrid, only is a start of a long and rewarding relationship with the organization FADCANIC which hopefully will end up with a feasible, reliable, sustainable and environmental friendly electrical system for the complex. For the individual taking over this work, the author suggests a focus on biomasses and the opportunity of exploiting the local biomass potential as an energy source that could be implemented into the microgrid. This would be an important step on the way towards creating a hybrid system that could cover the Wawashang complex future energy demand, so that more youth can get the opportunity of an education in the Wawashang complex and thereby the hope of a brighter future.

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APPENDIX I: Detailed Inventory List

No	Description	PV panels/Generators	Batteries	Inverters	Controllers
1	**Carpentry**	Dieselgenerator 440 V: Perkins Renault, 26 kW Dieselgenerator 220V: Kubota ASK R3100 ER 1400, 10 kW Transformator for using the 440 generator for 110/120 loads.			
2	**Sports court**				
3	**Computer room**	SolarShell, polycrystalline, 28 W x 5	Trojan 6V x 20	Magnum Energy, 1500W	Xantrex C35 12/24 VDC x2
4	**Library and teachers offices**	Isofoton, monocrystalline, 55 W x 13 Trina Solar 225W x 4	4 in series, 5 parallells		
5	**Kitchen and Diningroom**	GE, 20W x 6 Isofoton, monocrystalline, 100W x 3 SolarShell, polycrystalline, 85 W x 4 SunWize, 85W x 3	Trojan, 6V x 8 4 in series, 2 parallells	XPower 1200 plus	Xantrex C35 12/24 VDC
6	**Classrooms**				
7	**Student dorms and house of professor** **USAID dorm**	SunSwifer, 35W x 1 China, 18 W x 4 ShellSolar, polycrystalline, 28W x 9 GE, 20W x 12 EGE monocrystalline, 100W x 8=800, 12 VDC	Trojan 6V x 20, 4 in series, 5 parallells Trojans 6V x 8, 4 in series, 2 parallells Trojans 6v x 8, 4 in series, 2 parallells Trojan 6V x 19, Crown Deep Cycle x 1, 4 in series, 5 parallells	Xantrex, 1500 W Magnum Energy, 1500W	Xantrex C35 12/24 VDC x 2 Xantrex C40 12/24 VDC x 2
8	**Building for water processing** **Pump house**	Unkjnown brand, 2 x 50W	Unknown brand, 12V x 1	Samlex power, 450 W	Steca Solar charge controller 6A
9	**Offices**	Solar Shell, polycrystalline, 28 W x 24	Trojan 6V x 20 4 in series, 5 parallells	Xantrex1500W, 24 VDC	Xantrex C40 12/24/48 VDC x 2
10	**Auditorium**	GeEnergy, 20W x 8 ShellSolar, 85 W x 14	Trojan, 6V x 18 Deka Pro Master 6V x 2 4 in seriess, 5 parallells Deka Pro Master 6V x 8 4 in series, 2parallells	Xantrex, 1500 W	Xantrex C40 12/24/48 VDC Xantrex C35 12/24 VDC
11	**House of technical team, guests and professors**	Kyocera, polycrystalline,85W x 8 Isofoton, monocrystalline,55W x 16	Crown Solar Deep Cycle 6V x 9 Deka Pro Master 6V x 1, 2 in series, 5 parallells,	IGTEC Flash Power, Model 1512FP, 1500W, 12 VDC VPS	Xantrex C35 12/24 VDC x2
12	**Irrigation system**				
13	**Food processing building (backup generators)**	Gasoline Generator: Briggs & Stratton Elite Series portable generator, 10000W Gasoline Generator: Suzuki, 7500W			
14	**Quality seed production facility**				
15	**Forestal and Livestock farm**				
16	**Street lights and wharf**				
17	**Kahka Creek**	Kyocera, 130W x 5 Kyocera, 135W x 1 Photo Watt, 75W x 2 Kyocera, 65W x 2 Kyocera, 54W x 2 BPSolar, 230W x 4	Trojan x 28, 220Ah 6V	Magnum, 4kW	Xantrex C 35 Xantrex C40
18	**Building for leisure activities**				
19	**House of carpenters**	Unknown brand , 85W x 4	Trojan, 6V x 4, 2 in series. 2parallels.	WAGAN TECH AC, 1500W	Xantrex C35 12/24 VDC
20	**Laboratory**	Kyocera, polycrystalline, 136 W x 6	Crown Deep Cycle 6V x 20	Inverter being repaired in Managua	Xantrex C40 12/24/48 VDC
	Unattached Inventory	Trina Solar, 225 W x 2	Willard 12 V x 2 Trojan 6V x 4 Crown Deep Cycle, 6V x 9	Xpower 1200 Plus	Controller: C 60 12/24 VDC

APPENDIX 2: Full report PVsyst: System with Backup

Stand Alone System: Simulation parameters

Project :	**LinnWawashangMaster2013nyny**			
Geographical Site		**Wawashang(ny)**	**Country**	**Nicaragua**
Situation	Latitude	12.6°N	Longitude	83.8°W
Time defined as	Legal Time	Time zone UT-6	Altitude	20 m
	Albedo	0.25		
Meteo data :	Wawashang(ny), Synthetic Hourly data			

Simulation variant :	**kyocera 3, 5, optemp, diesel finalversion13tiltnyprofil**			
	Simulation date	10/05/13 17h42		

Simulation parameters

Collector Plane Orientation	Tilt	13°	Azimuth	0°

PV Array Characteristics

PV module Si-poly	Model	**KD215GX-LPU**		
	Manufacturer	Kyocera		
Number of PV modules	In series	2 modules	In parallel	287 strings
Total number of PV modules	Nb. modules	574	Unit Nom. Power	215 Wp
Array global power	Nominal (STC)	**123 kWp**	At operating cond.	105 kWp (56°C)
Array operating characteristics (50°C)	U mpp	45 V	I mpp	2318 A
Total area	Module area	**852 m²**		

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)			NOCT	56 °C
Wiring Ohmic Loss	Global array res.	0.35 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	0.1 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

System Parameter	System type	**Stand alone with back-up generator System**		
Battery	Model	**6-CS-17PS**		
	Manufacturer	Rolls		
Battery Pack Characteristics	Voltage	48 V	Nominal Capacity	27180 Ah
	Nb. of units	8 in series x 60 in parallel		
	Temperature	Fixed (20°C)		
Regulator	Model	Generic Default with MPPT converter		
	Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter	Maxi and EURO efficiencies	99.0/97.4 %		
Battery Management Thresholds	Charging	54.0/52.3 V	Discharging	47.0/50.4 V
	Back-Up Genset Command	47.3/51.6 V		
Back-up generator (genset)	Model	10 kW		
	Manufacturer	Back-up generator		
	Power	10 kW		

User's needs :	daily profile	weekly modulation
	average	397 kWh/Day

Stand Alone System: Detailed User's needs

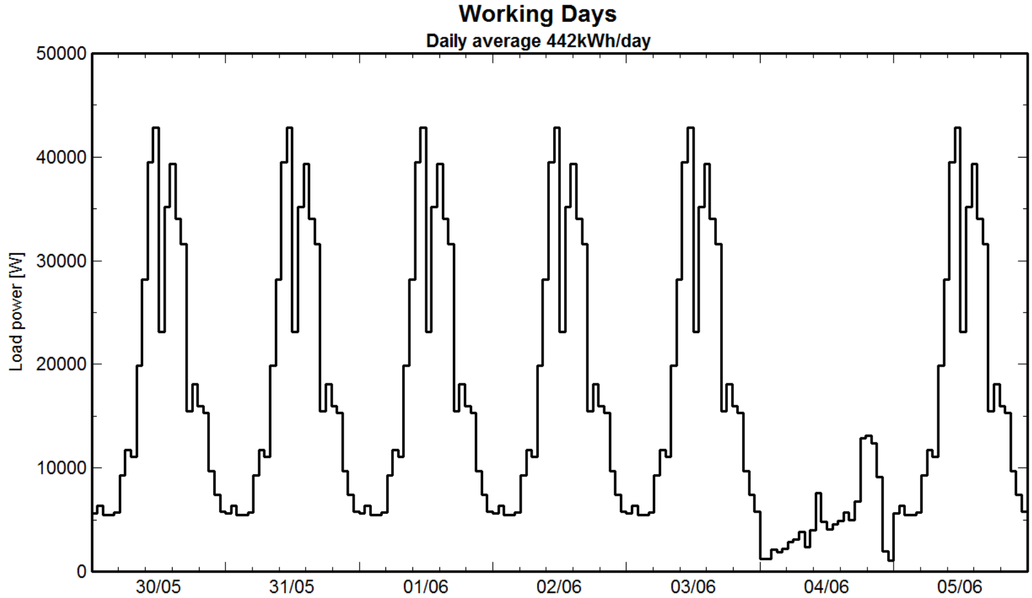
Project : **LinnWawashangMaster2013nyny**

Simulation variant : **kyocera 3, 5, optemp, diesel finalversion13tiltnyprofil**

Main system parameters	System type	**Stand alone with back-up generator**			
PV Field Orientation	tilt	13°	azimuth	0°
PV Array	Nb. of modules	574	Pnom total	**123 kWp**
Battery	Model	6-CS-17PS	Technology	sealed, plates
battery Pack	Nb. of units	480	Voltage / Capacity	**48 V / 27180 Ah**
User's needs	daily profile	weekly modulation	global	145 MWh/year

daily profile, weekly modulation, average = 397 kWh/day

	0 h / 12 h	1 h / 13 h	2 h / 14 h	3 h / 15 h	4 h / 16 h	5 h / 17 h	6 h / 18 h	7 h / 19 h	8 h / 20 h	9 h / 21 h	10 h / 22 h	11 h / 23 h	
Working days	5.60	6.40	5.50	5.50	5.70	9.30	11.70	11.10	19.90	28.20	39.50	42.80	kW
	23.10	35.20	39.30	34.00	31.60	15.50	18.10	16.00	15.30	9.70	7.40	5.80	kW
Week-end	1.20	1.20	2.10	1.90	2.20	2.90	3.10	3.80	2.40	4.00	7.60	4.80	kW
	4.10	4.60	4.90	5.70	5.00	6.80	12.90	13.10	12.40	9.10	2.00	1.10	kW



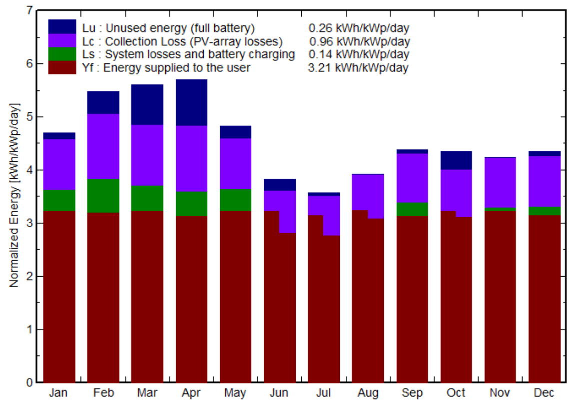
Stand Alone System: Main results

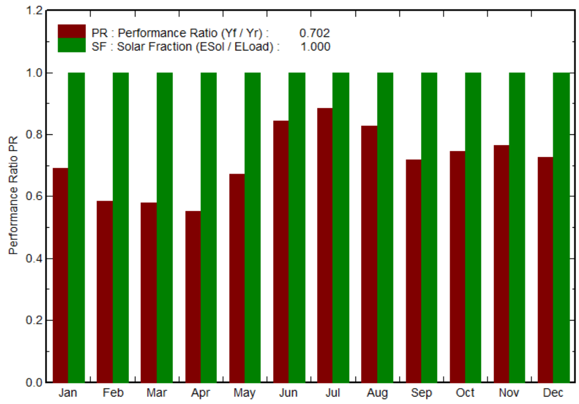
Project : **LinnWawashangMaster2013nyny**

Simulation variant : **kyocera 3, 5, optemp, diesel finalversion13tiltnyprofil**

Main system parameters	System type	**Stand alone with back-up generator**		
PV Field Orientation	tilt	13°	azimuth	0°
PV Array	Nb. of modules	574	Pnom total	**123 kWp**
Battery	Model	6-CS-17PS	Technology	sealed, plates
battery Pack	Nb. of units	480	Voltage / Capacity	**48 V / 27180 Ah**
User's needs	daily profile	weekly modulation	global	145 MWh/year

Main simulation results				
System Production	**Available Energy**	**150.6 MWh/year**	Specific prod.	1220 kWh/kWp/year
	Used Energy	144.5 MWh/year	Excess (unused)	11.5 MWh/year
	Performance Ratio PR	64.2 %	Solar Fraction SF	91.4 %
Back-Up energy from generator	Back-Up energy	12.4 MWh/year	Fuel Consumption	3467/year





kyocera 3, 5, optemp, diesel finalversion13tiltnyprofil

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E Avail MWh	EUnused MWh	E User MWh	E Load MWh	SolFrac
January	133.0	141.1	13.25	0.415	12.41	12.42	1.000
February	143.8	148.9	13.71	1.455	11.08	11.09	0.999
March	169.6	168.4	15.97	2.836	12.40	12.42	0.999
April	174.3	165.3	15.53	3.158	11.64	11.65	0.999
May	156.9	144.2	13.69	0.838	12.41	12.42	1.000
June	121.2	110.6	10.24	0.760	11.97	11.97	0.746
July	115.0	106.4	9.97	0.223	12.09	12.09	0.827
August	124.6	116.9	10.89	0.010	12.42	12.42	0.882
September	131.4	127.0	11.84	0.234	11.65	11.65	0.890
October	128.7	130.4	12.31	1.287	12.41	12.42	0.826
November	118.5	122.7	11.24	0.005	11.97	11.97	0.977
December	121.8	130.5	11.98	0.328	12.09	12.09	0.827
Year	1638.8	1612.7	150.62	11.548	144.52	144.59	0.914

Legends:
- GlobHor: Horizontal global irradiation
- GlobEff: Effective Global, corr. for IAM and shadings
- E Avail: Available Solar Energy
- EUnused: Unused energy (full battery) loss
- E User: Energy supplied to the user
- E Load: Energy need of the user (Load)
- SolFrac: Solar fraction (EUsed / ELoad)

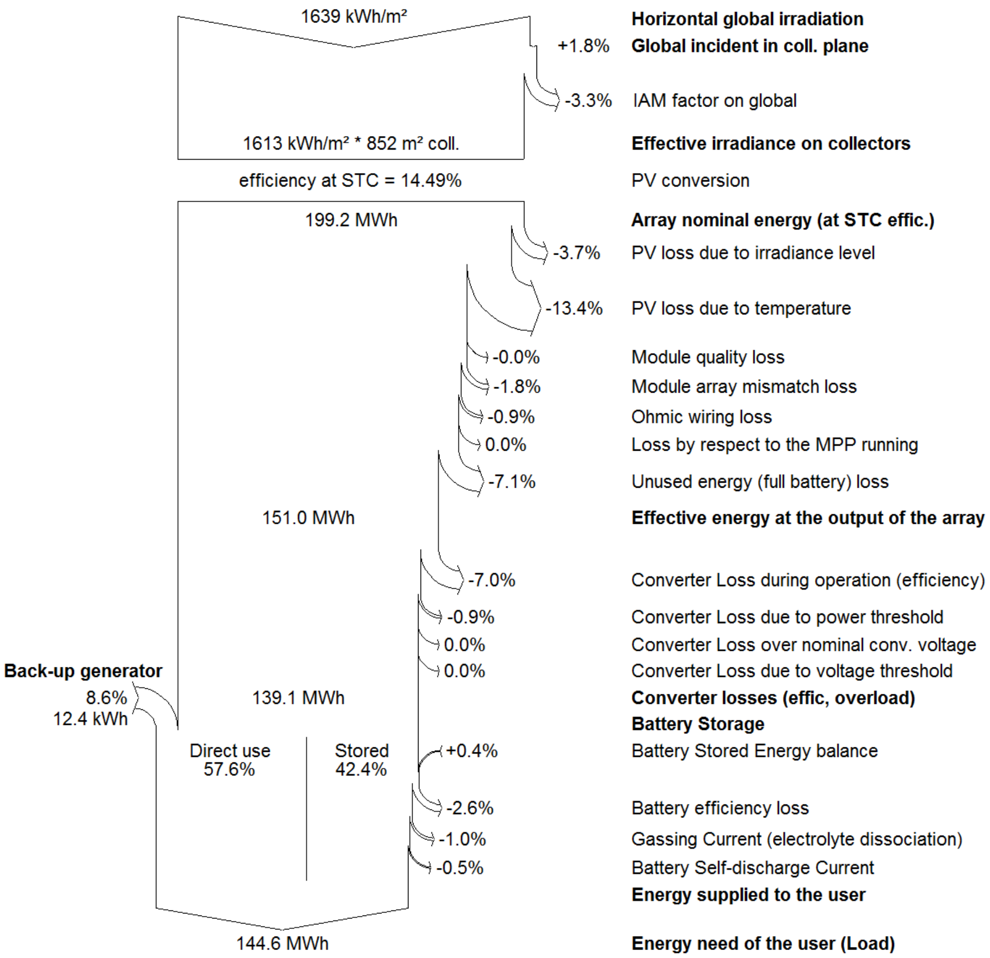
Stand Alone System: Loss diagram

Project : **LinnWawashangMaster2013nyny**

Simulation variant : **kyocera 3, 5, optemp, diesel finalversion13tiltnyprofil**

Main system parameters	System type	**Stand alone with back-up generator**		
PV Field Orientation	tilt	13°	azimuth	0°
PV Array	Nb. of modules	574	Pnom total	**123 kWp**
Battery	Model	6-CS-17PS	Technology	sealed, plates
battery Pack	Nb. of units	480	Voltage / Capacity	**48 V / 27180 Ah**
User's needs	daily profile	weekly modulation	global	145 MWh/year

Loss diagram over the whole year



APPENDIX 3: Full Report, PVsyst: System with no Backup

PVSYST V5.55		23/04/13	Page 1/4

Stand Alone System: Simulation parameters

Project :	**LinnWawashangMaster2013nyny**			
Geographical Site	**Wawashang(ny)**		**Country**	**Nicaragua**
Situation	Latitude	12.6°N	Longitude	83.8°W
Time defined as	Legal Time	Time zone UT-6	Altitude	20 m
	Albedo	0.25		
Meteo data :	Wawashang(ny), Synthetic Hourly data			

Simulation variant :	**kyocera 3, 5, optemp, diesel finalversion13tiltnyprofil**	
	Simulation date	23/04/13 18h55

Simulation parameters

Collector Plane Orientation	Tilt	13°	Azimuth	0°

PV Array Characteristics

PV module Si-poly	Model	**KD215GX-LPU**		
	Manufacturer	Kyocera		
Number of PV modules	In series	2 modules	In parallel	288 strings
Total number of PV modules	Nb. modules	576	Unit Nom. Power	215 Wp
Array global power	Nominal (STC)	**124 kWp**	At operating cond.	106 kWp (56°C)
Array operating characteristics (50°C)	U mpp	45 V	I mpp	2326 A
Total area	Module area	**855 m²**		

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)			NOCT	56 °C
Wiring Ohmic Loss	Global array res.	0.34 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	0.1 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

System Parameter	System type	**Stand Alone System**		
Battery	Model	**6-CS-17PS**		
	Manufacturer	Rolls		
Battery Pack Characteristics	Voltage	48 V	Nominal Capacity	27180 Ah
	Nb. of units	8 in series x 60 in parallel		
	Temperature	Fixed (20°C)		
Regulator	Model	Generic Default with MPPT converter		
	Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter	Maxi and EURO efficiencies	99.0/97.4 %		
Battery Management Thresholds	Charging	54.0/52.3 V	Discharging	47.0/50.4 V
	Back-Up Genset Command	47.3/51.6 V		

User's needs :	daily profile	weekly modulation
	average	397 kWh/Day

Stand Alone System: Detailed User's needs

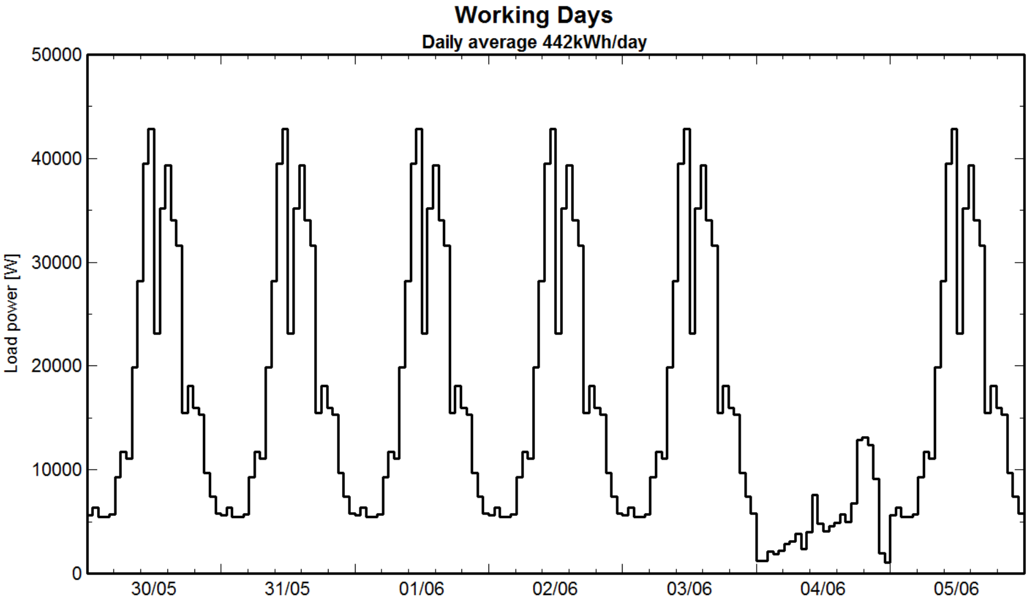
Project : **LinnWawashangMaster2013nyny**

Simulation variant : **kyocera 3, 5, optemp, diesel finalversion13tiltnyprofil**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	13°	azimuth	0°
PV Array	Nb. of modules	576	Pnom total	**124 kWp**
Battery	Model	6-CS-17PS	Technology	sealed, plates
battery Pack	Nb. of units	480	Voltage / Capacity	**48 V / 27180 Ah**
User's needs	daily profile	weekly modulation	global	145 MWh/year

daily profile, weekly modulation, average = 397 kWh/day

	0 h / 12 h	1 h / 13 h	2 h / 14 h	3 h / 15 h	4 h / 16 h	5 h / 17 h	6 h / 18 h	7 h / 19 h	8 h / 20 h	9 h / 21 h	10 h / 22 h	11 h / 23 h	
Working days	5.60	6.40	5.50	5.50	5.70	9.30	11.70	11.10	19.90	28.20	39.50	42.80	kW
	23.10	35.20	39.30	34.00	31.60	15.50	18.10	16.00	15.30	9.70	7.40	5.80	kW
Week-end	1.20	1.20	2.10	1.90	2.20	2.90	3.10	3.80	2.40	4.00	7.60	4.80	kW
	4.10	4.60	4.90	5.70	5.00	6.80	12.90	13.10	12.40	9.10	2.00	1.10	kW



Stand Alone System: Main results

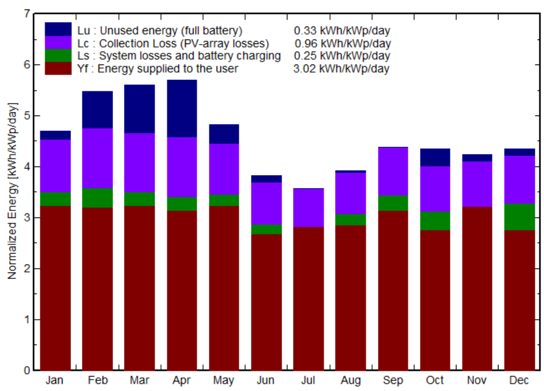
Project : **LinnWawashangMaster2013nyny**

Simulation variant : **kyocera 3, 5, optemp, diesel finalversion13tiltnyprofil**

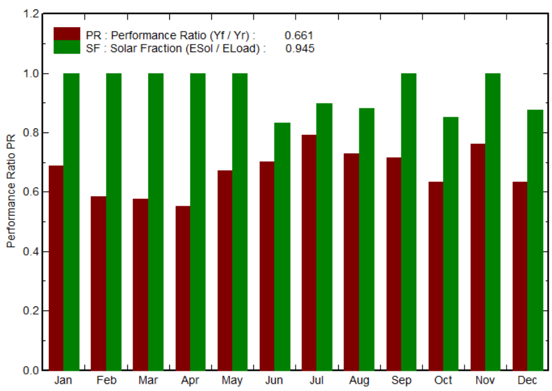
Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	13°	azimuth	0°
PV Array	Nb. of modules	576	Pnom total	**124 kWp**
Battery	Model	6-CS-17PS	Technology	sealed, plates
battery Pack	Nb. of units	480	Voltage / Capacity	**48 V / 27180 Ah**
User's needs	daily profile	weekly modulation	global	145 MWh/year

Main simulation results				
System Production	**Available Energy**	**158.8 MWh/year**	Specific prod.	1282 kWh/kWp/year
	Used Energy	136.6 MWh/year	Excess (unused)	15.1 MWh/year
	Performance Ratio PR	66.1 %	Solar Fraction SF	94.5 %
Loss of Load	Time Fraction	5.8 %	Missing Energy	8.0 MWh/year

Normalized productions (per installed kWp): Nominal power 124 kWp



Performance Ratio PR and Solar Fraction SF



kyocera 3, 5, optemp, diesel finalversion13tiltnyprofil

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E Avail MWh	EUnused MWh	E Miss MWh	E User MWh	E Load MWh	SolFrac
January	133.0	141.1	13.79	0.653	0.000	12.42	12.42	1.000
February	143.8	148.9	14.65	2.511	0.000	11.09	11.09	1.000
March	169.6	168.4	16.76	3.594	0.000	12.42	12.42	1.000
April	174.3	165.3	16.49	4.084	0.000	11.65	11.65	1.000
May	156.9	144.2	14.35	1.411	0.000	12.42	12.42	1.000
June	121.2	110.6	10.65	0.492	1.999	9.97	11.97	0.833
July	115.0	106.4	10.47	0.025	1.242	10.85	12.09	0.897
August	124.6	116.9	11.53	0.119	1.454	10.96	12.42	0.883
September	131.4	127.0	12.48	0.007	0.000	11.65	11.65	1.000
October	128.7	130.4	12.81	1.263	1.839	10.58	12.42	0.852
November	118.5	122.7	12.02	0.440	0.000	11.97	11.97	1.000
December	121.8	130.5	12.79	0.539	1.485	10.61	12.09	0.877
Year	1638.8	1612.7	158.79	15.139	8.019	136.57	144.59	0.945

Legends:

GlobHor	Horizontal global irradiation	E Miss	Missing energy
GlobEff	Effective Global, corr. for IAM and shadings	E User	Energy supplied to the user
E Avail	Available Solar Energy	E Load	Energy need of the user (Load)
EUnused	Unused energy (full battery) loss	SolFrac	Solar fraction (EUsed / ELoad)

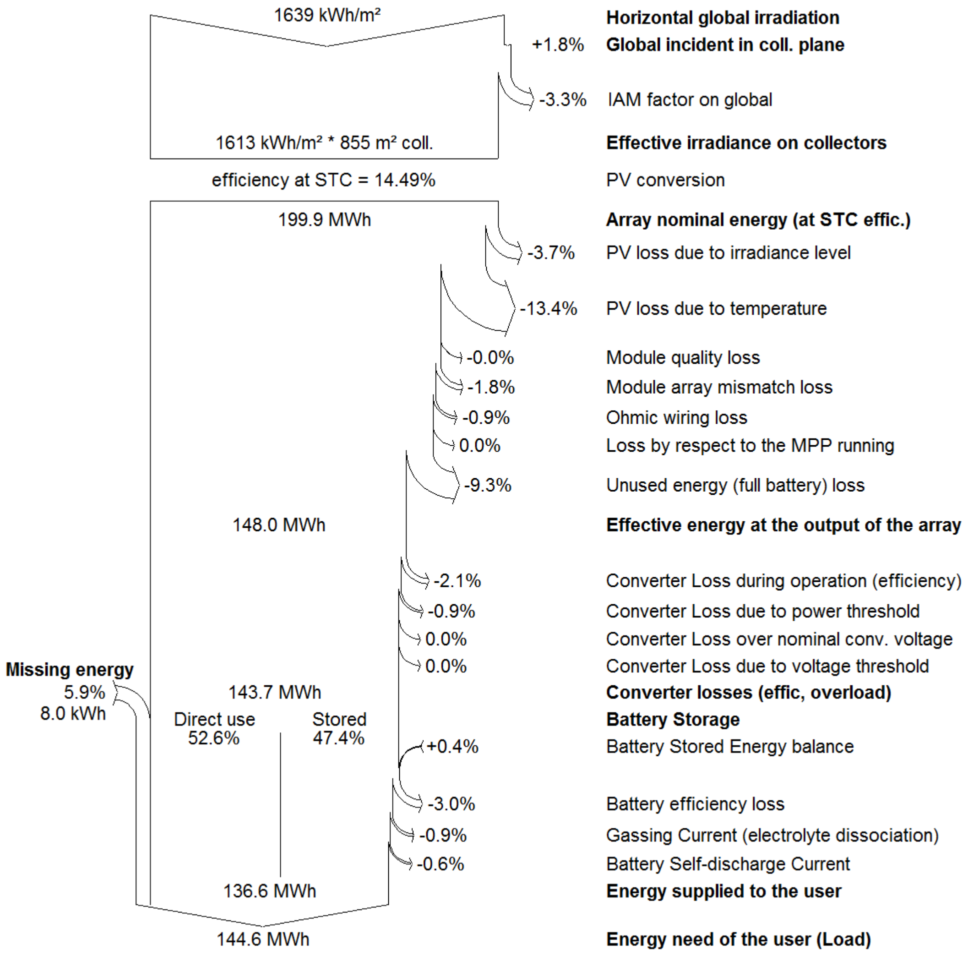
Stand Alone System: Loss diagram

Project : **LinnWawashangMaster2013nyny**

Simulation variant : **kyocera 3, 5, optemp, diesel finalversion13tiltnyprofil**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	13°	azimuth	0°
PV Array	Nb. of modules	576	Pnom total	**124 kWp**
Battery	Model	6-CS-17PS	Technology	sealed, plates
battery Pack	Nb. of units	480	Voltage / Capacity	**48 V / 27180 Ah**
User's needs	daily profile	weekly modulation	global	145 MWh/year

Loss diagram over the whole year



APPENDIX 4: Full Report, HOMER: System with NO Backup

System Report - HomersimXLoadFollowing

Sensitivity case

Solar Data Scaled Average: 4.7 kWh/m²/d

Diesel Price: 1.19 $/L

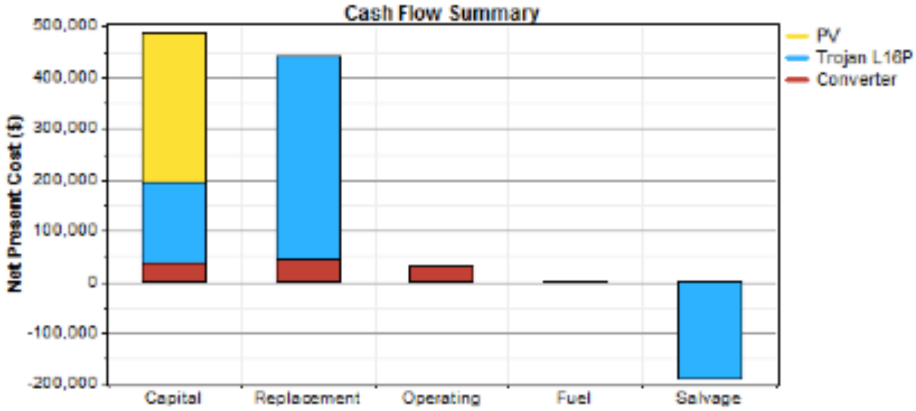
Annual Real Interest Rate: -1.6 %

System architecture

PV Array	121 kW
Battery	560 Trojan L16P
Inverter	50 kW
Rectifier	47.5 kW

Cost summary

Total net present cost	$ 770,101
Levelized cost of energy	$ 0.232/kWh
Operating cost	$ 11,888/yr

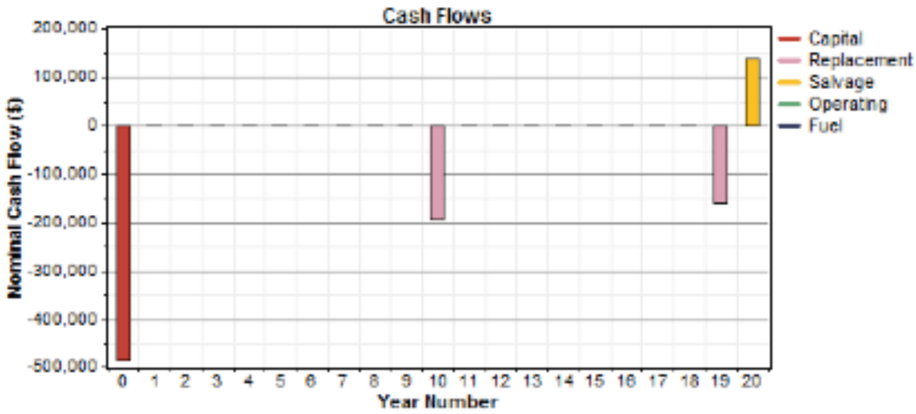


Net Present Costs

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	292,651	0	0	0	0	292,651
Trojan L16P	159,040	399,848	0	0	-188,503	370,385
Converter	35,550	41,772	29,742	0	0	107,064
System	487,241	441,621	29,742	0	-188,503	770,101

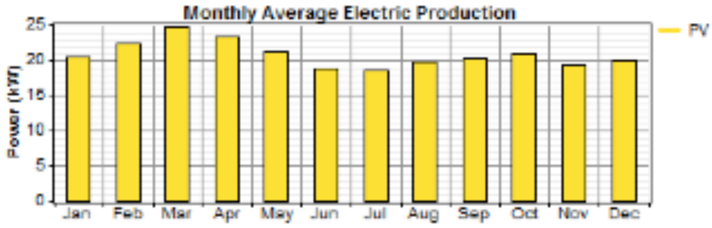
Annualized Costs

Component	Capital ($/yr)	Replacement ($/yr)	O&M ($/yr)	Fuel ($/yr)	Salvage ($/yr)	Total ($/yr)
PV	12,300	0	0	0	0	12,300
Trojan L16P	6,684	16,805	0	0	-7,922	15,567
Converter	1,494	1,756	1,250	0	0	4,500
System	20,478	18,561	1,250	0	-7,922	32,366



Electrical

Component	Production	Fraction
	(kWh/yr)	
PV array	182,209	100%
Total	182,209	100%



Load	Consumption	Fraction
	(kWh/yr)	
AC primary load	139,599	100%
Total	139,599	100%

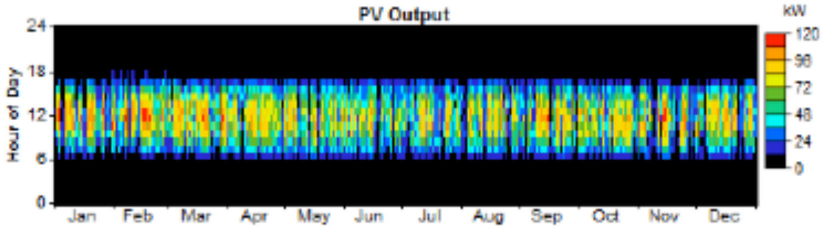
Quantity	Value	Units
Excess electricity	25,210	kWh/yr
Unmet load	5,308	kWh/yr
Capacity shortage	7,339	kWh/yr
Renewable fraction	1.000	

PV

Quantity	Value	Units
Rated capacity	121	kW
Mean output	20.8	kW
Mean output	499	kWh/d
Capacity factor	17.2	%
Total production	182,209	kWh/yr

Quantity	Value	Units
Minimum output	0.00	kW

Maximum output	115	kW
PV penetration	126	%
Hours of operation	4,435	hr/yr
Levelized cost	0.0675	$/kWh

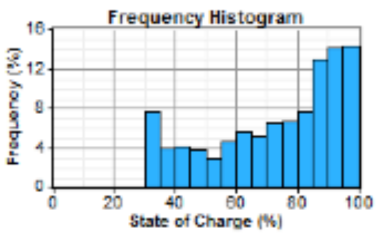


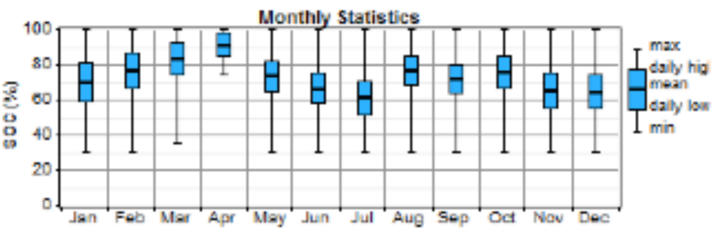
Battery

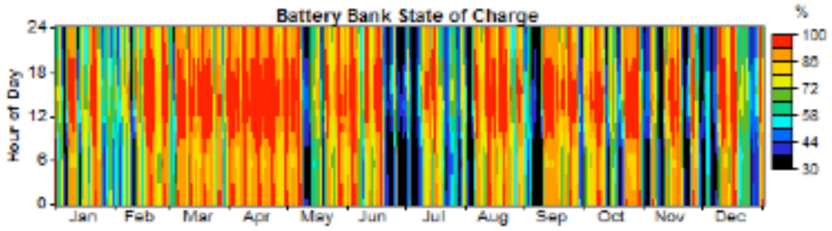
Quantity	Value
String size	8
Strings in parallel	70
Batteries	560
Bus voltage (V)	48

Quantity	Value	Units
Nominal capacity	1,210	kWh
Usable nominal capacity	847	kWh
Autonomy	51.2	hr
Lifetime throughput	602,000	kWh
Battery wear cost	0.287	$/kWh
Average energy cost	0.000	$/kWh

Quantity	Value	Units
Energy in	69,482	kWh/yr
Energy out	59,429	kWh/yr
Storage depletion	301	kWh/yr
Losses	9,752	kWh/yr
Annual throughput	64,461	kWh/yr
Expected life	9.34	yr



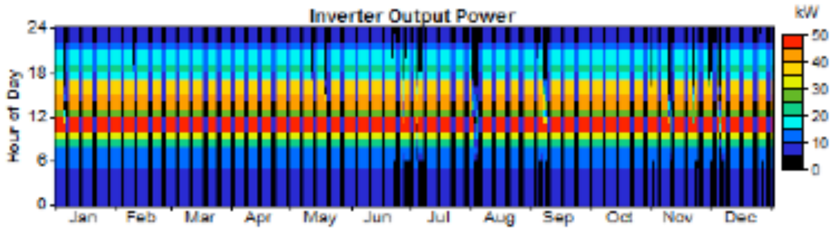


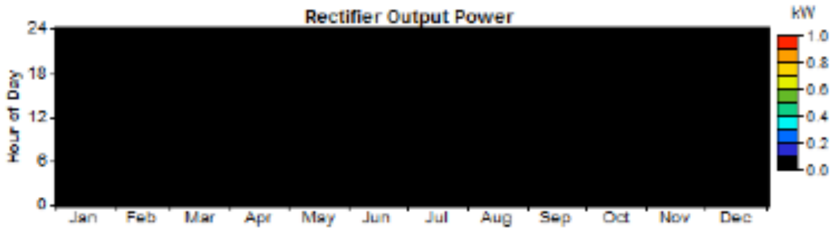


Converter

Quantity	Inverter	Rectifier	Units
Capacity	50.0	47.5	kW
Mean output	15.9	0.0	kW
Minimum output	0.0	0.0	kW
Maximum output	49.0	0.0	kW
Capacity factor	31.9	0.0	%

Quantity	Inverter	Rectifier	Units
Hours of operation	8,471	0	hrs/yr
Energy in	146,948	0	kWh/yr
Energy out	139,599	0	kWh/yr
Losses	7,348	0	kWh/yr





Emissions

Pollutant	Emissions (kg/yr)
Carbon dioxide	0
Carbon monoxide	0
Unburned hydocarbons	0
Particulate matter	0
Sulfur dioxide	0
Nitrogen oxides	0

APPENDIX 5: Full Report, HOMER: System with Backup Generator

System Report - HomersimXLoadFollowing

Sensitivity case

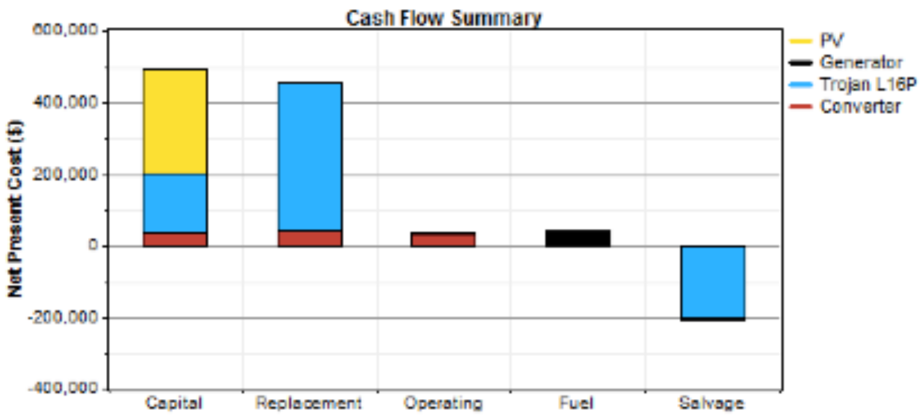
Solar Data Scaled Average: 4.7 kWh/m²/d
Diesel Price: 1.19 $/L
Annual Real Interest Rate: -1.6 %

System architecture

PV Array	121 kW
Generator	10 kW
Battery	576 Trojan L16P
Inverter	50 kW
Rectifier	47.5 kW
Dispatch strategy	Load Following

Cost summary

Total net present cost	$ 818,298
Levelized cost of energy	$ 0.240/kWh
Operating cost	$ 13,723/yr



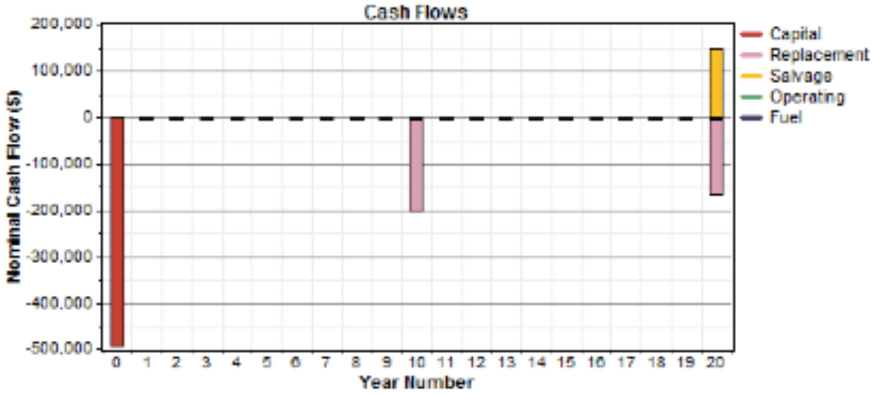
Net Present Costs

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	292,651	0	0	0	0	292,651
Generator	0	1,396	4,717	40,612	-305	46,420
Trojan L16P	163,584	413,503	0	0	-204,924	372,163
Converter	35,550	41,772	29,742	0	0	107,064
System	491,785	456,671	34,459	40,612	-205,230	818,298

Annualized Costs

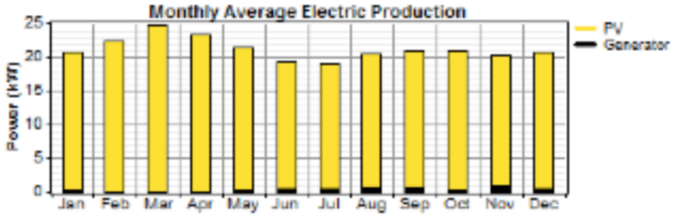
Component	Capital ($/yr)	Replacement ($/yr)	O&M ($/yr)	Fuel ($/yr)	Salvage ($/yr)	Total ($/yr)
PV	12,300	0	0	0	0	12,300
Generator	0	59	198	1,707	-13	1,951

Trojan L16P	6,875	17,379	0	0	-8,613	15,641
Converter	1,494	1,756	1,250	0	0	4,500
System	20,669	19,193	1,448	1,707	-8,625	34,392



Electrical

Component	Production	Fraction
	(kWh/yr)	
PV array	182,209	98%
Generator	3,318	2%
Total	185,527	100%



Load	Consumption	Fraction
	(kWh/yr)	
AC primary load	143,020	100%
Total	143,020	100%

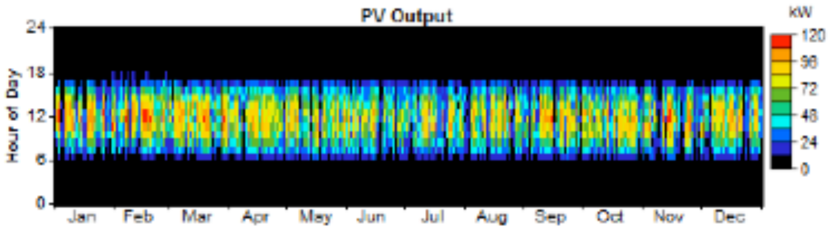
Quantity	Value	Units
Excess electricity	25,050	kWh/yr
Unmet load	1,888	kWh/yr
Capacity shortage	2,615	kWh/yr
Renewable fraction	0.977	

PV

Quantity	Value	Units
Rated capacity	121	kW
Mean output	20.8	kW
Mean output	499	kWh/d

Capacity factor	17.2	%
Total production	182,209	kWh/yr

Quantity	Value	Units
Minimum output	0.00	kW
Maximum output	115	kW
PV penetration	126	%
Hours of operation	4,435	hr/yr
Levelized cost	0.0675	$/kWh

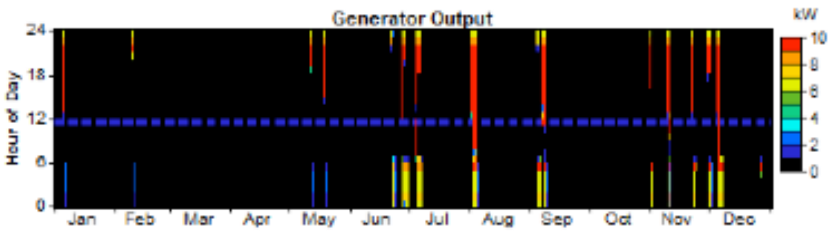


Generator

Quantity	Value	Units
Hours of operation	679	hr/yr
Number of starts	273	starts/yr
Operational life	11.0	yr
Capacity factor	3.79	%
Fixed generation cost	1.04	$/hr
Marginal generation cost	0.393	$/kWhyr

Quantity	Value	Units
Electrical production	3,318	kWh/yr
Mean electrical output	4.89	kW
Min. electrical output	1.00	kW
Max. electrical output	10.0	kW

Quantity	Value	Units
Fuel consumption	1,434	L/yr
Specific fuel consumption	0.432	L/kWh
Fuel energy input	14,114	kWh/yr
Mean electrical efficiency	23.5	%

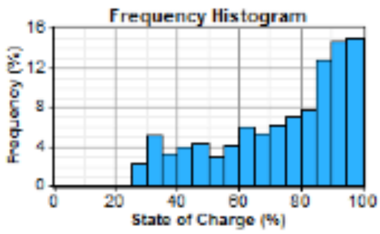


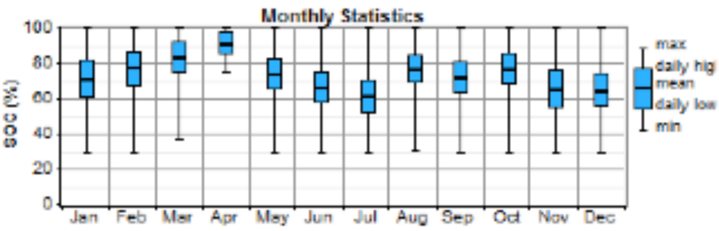
Battery

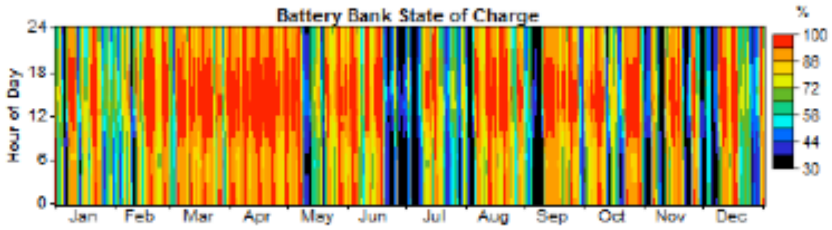
Quantity	Value
String size	8
Strings in parallel	72
Batteries	576
Bus voltage (V)	48

Quantity	Value	Units
Nominal capacity	1,244	kWh
Usable nominal capacity	871	kWh
Autonomy	52.6	hr
Lifetime throughput	619,200	kWh
Battery wear cost	0.287	$/kWh
Average energy cost	0.000	$/kWh

Quantity	Value	Units
Energy in	69,838	kWh/yr
Energy out	59,733	kWh/yr
Storage depletion	299	kWh/yr
Losses	9,806	kWh/yr
Annual throughput	64,790	kWh/yr
Expected life	9.56	yr





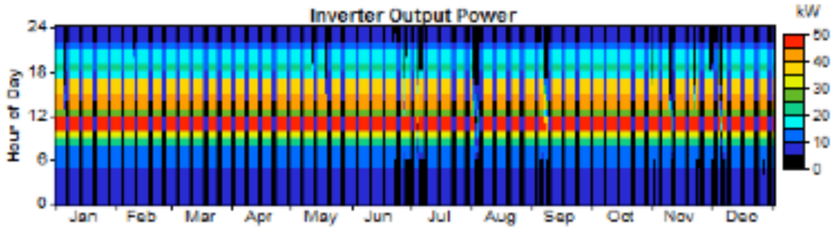


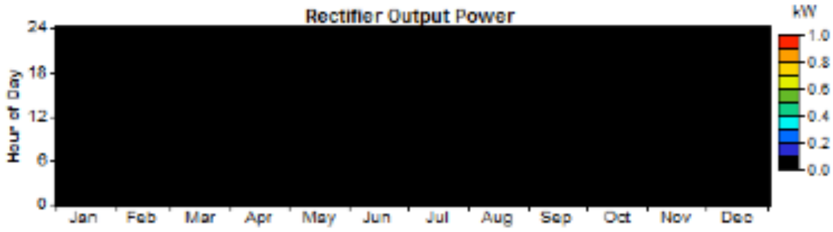
Converter

Quantity	Inverter	Rectifier	Units
Capacity	50.0	47.5	kW
Mean output	15.9	0.0	kW
Minimum output	0.0	0.0	kW
Maximum output	48.0	0.0	kW
Capacity factor	31.9	0.0	%

Quantity	Inverter	Rectifier	Units
Hours of operation	8,530	0	hrs/yr

Energy in	147,055	0	kWh/yr
Energy out	139,702	0	kWh/yr
Losses	7,353	0	kWh/yr





Emissions

Pollutant	Emissions (kg/yr)
Carbon dioxide	3,777
Carbon monoxide	9.32
Unburned hydocarbons	1.03
Particulate matter	0.703
Sulfur dioxide	7.59
Nitrogen oxides	83.2