Addis Ababa Institute of Technology
School of Mechanical& Industrial Engineering

Design and Techno-economic Evaluation of Solar PV power Supply for Off-Grid Communities in Ethiopia: The Case of Indode Village.

A Thesis Submitted for Partial Fulfillment of the Requirements for a degree of Master of Science in Thermal Engineering.

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DECLARATION

I, Genanaw Embiale, declare that this thesis is the result of my own original work and that all source or materials used for this thesis have been duly acknowledged. This thesis is submitted in partial fulfillment of the requirements for Master's Degree in Thermal Engineering at Addis Ababa University and to be made available at the University's Library under the rule of the Library. I confidently declare that this thesis has not been submitted to any other institutions anywhere for the award of any academic degree, diploma, or certificate.

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SCHOOL OF MECHANICAL AND INDUSTRIAL INGINEERING

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By

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Acknowledgement

First I would like to give thanks to the Almighty God who gives me patient, courage and wisdom.

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Symbols and Abbreviations

PV	Photovoltaic
W/m^2	Watt per meter square
cm	Centimeter
V	Voltage
W	Watt
A	Current
C^o	Degree Celsius
kWh	Kilo-watt-hour
kWh/m^2	Kilo-watt-hour per meter square
kWh/d	Kilo-watt-hour per day
Ah	Ampere-hour
AC	Alternating Current
Co2	Carbon Dioxide
DC	Direct Current
Gh	Global Horizontal solar radiation
GIS	Geographic Information System
PR	Performance Ratio
GPS	Geographical Positioning System
STC	Standard Test & Conditions

Abstract

Now a day, alternative energy supply has become compulsory to improve the life standard and increase the development of rural areas which are living without modern electricity and still dependent on traditional fuels. Usage of these traditional fuels is hazardous to human health and the environment. Solar energy is one of the alternative energy sources to overcome this problem. This thesis study has presented off-grid solar PV system to power Indode village which has 322 households and 1,171 people. Based on the village's load demand and metrological data, the system components are sized and simulation was done using PVsyst software to optimize the system technically and assure its economic viability.

The total numbers of common kitchens to serve Indode's community are 10 which consume the major part of the solar power produced. In addition to powering the kitchens, the system is designed to power the health center, the schools, the administration offices and other business shops. The total installation cost of the project is 21,328,100.00 Birr with total number of 1028 batteries, 1812 solar modules, and 63 inverters are required for the system.

The Net Present Value, the Return on Investment and the Payback period of the project are determined to be 84,730,997.18 Birr, 397.3%, 9.3 years, respectively. Considering a 25-year project life span, the economic indicators show that the solar PV system is a viable source of electricity in Indode's village and can be considered as applicable to other off-grid communities in the country.

Keywords: Stand-alone PV system, Off-grid, Storage batteries, Inverters, Performance ratio, Net Present Value, Payback period, Return on Investment.

Chapter 1: Introduction

1.1. Background of the Study

Wood, biomass and other traditional fuels are the main causes for environmental pollution and depletion of forest resources; and Ethiopia is the third largest user of traditional fuels for household energy use in the world with 96 % of its population is dependent on traditional biomass to meet household energy demand; more than 50% of this energy goes entirely on baking Injera[1]. Injera is Ethiopian cultural food prepared from teff, sorghum, maize, wheat, rice etc., which needs 180-220 ^{o}C for cooking using the traditional Mitad[2].

Presently, there is insufficient electrical power supply in Ethiopia, since most of the power produced from different power plants is distributed to urban areas and industrial centers. Because of this reason, remote rural areas are still using traditional fuel to cook foods as grid extension is not affordable for rural consumers due to the effect of constraints such as high cost of electricity and geographical barriers[3].

The high cost and their great environmental impact of fossil fuels while generating electricity have been forcing the world to search and develop a sustainable and affordable energy resources that are not harmful to the environment [2]. Thus, all communities or facilities which have no access to a main electricity grid, as they are placed in remote locations or rural areas, can be powered at a reasonable cost level by developing Off-grid systems[4].

Currently, Solar PV has grown to have considerable alternative in powering remote rural areas and it becomes popular in rural electrification programs[5]. Solar energy can be used to generate electricity by using solar panels to convert sunlight into electricity via the photovoltaic principle and if well designed, PV rural electrification projects can contribute to the reduction of greenhouse gas emissions by replacing fossil fuel based electricity and to the development of rural areas[6].

This thesis paper presents a study conducted on the design and techno-economic analysis of an off-grid multi-purpose PV system to provide electricity access for Injera baking for a selected remote rural community in Ethiopia.

If an off-grid rural community much far away from Addis Ababa is selected for the study, it will unnecessarily increase the amount of budget needed and the period for the study. Therefore, the Indode village is selected, as the site for the study, which is an off-grid community close to Addis Ababa city located in Oromia Special Zone, Akaki Woreda Administration, Hechu Kebele.

1.2. Problem Statement

The economic development and health and life standards improvement of a community has become dependent on the availability of electric power access. However, most rural areas of Ethiopia are not yet electrified as electrifying these remote areas by extending the national grid system is difficult and costly and the difficulty of geographical situations. Because of these difficulties of grid electrification, Indode's communities, the selected site, are using traditional fuels to bake Injera which consumes major share of the traditional energy collected by individual households. The use of biomass for cooking activities can worsen greenhouse gas emissions as well as bringing lifelong health problems to the community, wastes their time collecting biomass far away home, decreases children and women's contribution in the economic development of the country.

Therefore, off-grid PV system will be proposed as a sustainable solution to be implemented at Indode village that can produce electricity for Injera baking; there by electrifying home appliances &equipment of the households, business centers, health and education centers in the community. This approach can be applied in such a way that it will serve as an economical and reliable solution for electricity access for Injera baking for off-grid communities which do not have access to national electric grid line in Ethiopia.

1.3. Objective

1.3.1. General Objective

The general objective of this study is to design and carry out a techno-economic feasibility analysis of solar PV power supply for off-grid communities in Ethiopia, thereby improving people's livelihoods by creating energy access such that it should provide maximum efficiency, reliability and flexibility with an affordable price for the individual households of the community.

1.3.2. Specific Objectives

The following objectives should be accomplished to achieve the desired goal:

a. To collect significant data and identify the energy requirement;
b. To size solar PV system;
c. To model and simulate solar PV system using software;
d. To conduct techno-economic feasibility of the project.

1.4. Scope of the Study

The study will focus on the design and optimization of the solar PV system which includes site selection, data collection, sizing and performance simulations using PVsyst software. In addition, the techno-economic feasibility analysis will be done to determine the initial costs of the solar PV system by foreseeing all the costs that will be incurred during the lifespan of the system.

1.5. Significance of the Study

As communities of Indode village are away from the main grid line and there is no access to electricity; in addition to Injera Baking for individual households, other facilities of the community such as the school, administration offices, health center and individual homes will be powered by the Solar PV System; thereby imposing a positive impact on decreasing greenhouse gas emissions and destruction of forests. The final report of the thesis will also help as a reference for further study on the same area in the future.

Chapter 2: Literature Review

2.1. Injera Baking Practices in Rural Communities

In the rural area, as there is no family planning, each family have a lot of children with a need of more Injera daily which is eaten almost every meal which causes more than 50% of the wood consumption goes on baking Injera[1]. People in rural areas have low income which is not sufficient to buy fuel. Every day, rural women's main activity is collecting fuel for cooking.

2.1.1. Injera

Injera is traditionally eaten in Ethiopia, Somalia and Eritrea, which is prepared from teff, sorghum, maize, wheat, rice etc[1]. The flour is mixed with water and allowed to ferment for a few days. It is then ready to bake into large thin pancakes which can be prepared either on electric stove or fire based stove.

Figure 2. 1: Injera[16]

2.1.2. Injera Baking Methods

In Ethiopia, there are three methods of injera baking practices; baking on open fire method (three stone method), baking on Mirt-injera stove and baking on Electric baking pan. The temperature of the baking plate shall be220 ^{0}c for all methods of baking[2].

a) The Three Stone Method

Traditionally injera is baked on a clay plater using three stones, in between is a wood or biomass fire to make the platter hot to the required temperature. The disadvantage of this method is that it consumes more wood or biomass there by making women to waste much of their time to search for wood. This activity aggravates the degradation of the environment and; as it produces much smoke, pollution will also be the major hazard.

Figure 2. 2: Three stone method[12]

b) Mirt Injera Stove

This stove is used to save wood, which has covers round sides so that the heat will not escape to make the stove hot for a longer amount of time with

less wood consumption and has a specific fuel consumption reduction of 35% compared to the open-fire (three stone) Injera baking stove. The disadvantage of this method is that it still uses wood or biomass and produces smoke.

Figure 2. 3: Wood saving stove[16]

c) Electric Injera Baking Pan

Electric baking pan is used by urban area people only who have electric access to the national grid. The injera is baked on clay through which an electric wire runs to generate electric resistance heat. The advantage of this method is that it does not use wood or biomass which produces smoke to the environment; its disadvantage is that it still uses non-renewable energy which is also very expensive and a lot of rural people do not have access to the national grid.

Figure 2. 4: Electric Injera Baking Pan[7]

2.2. Development of Solar Energy for Off-grid Application

There are lots of resources available for understanding solar power system design methods and to know how solar power is generated; but there are limited resources such as books and research papers which are intentionally prepared to understand the application of solar energy for Injera baking. As illustrated in the Figure 2.5below, solar energy can be converted in to heat and electricity depending on the purpose of the application of the energy; for cooking using heat and electricity[8].

Hassen et al. [2] conducted a study to design and manufacture a prototype for an oil based Injera baking glass stove system and analyzed its performance in an experimental approach. For experimental purpose, the oil was heated using a 2 kW electrical heater instead of an equivalent solar energy collected through parabolic collector; and then heat is transferred to the glass baking pan by convection and to Injera by conduction. The oil gallery had an insulation of thickness 3.5cm to decrease heat loss in the system. The baking of Injera starts after the baking pan surface temperature reached 191 °C. During the experiment, the temperature of the pan surface is allowed to reach 191^{o}c and dropped to 92^{o}c immediately the batter was poured on the pan and the time to bake a single injera was recorded 2 minutes. To start baking the second injera by recovering the temperature of the pan needed 2 minutes, with a total of 4 minutes for a single baking cycle. After the power source was off, the oil could maintain the temperature for an estimated 3 to 4 hours to be used for times of fluctuations in sunshine periods. This research was done to determine possibility of using solar thermal energy for Injera baking.

Tesfaye et al. [1]discussed the integration of solar thermal with heat storage for Injera baking there by developing Phase change material(PCM) based heat storage prototype and tested it at Norwegian university of science and technology. In his experiment, the PCM (salt mixture) was allowed to melt by charging it with an average power of 650W for about 4.5 hours; and heat was stored for more than one day. A similar result was found after conducting a simulation by using COMSOL software. He tried to charge the thermal storage using electric power source and real sun energy sources to see the effect by setting the electric heating element at a temperature of 350^{O}c, took longer time to fully charge the storage; while parabolic dish concentrator with concentration ratio of 144 was mounted and fully charged the storage which was faster by an hour than heating using the electric source. He fried an egg during the night and it took 32 minutes to fry completely; according to his investigation, the frying time is longer because of gripped aluminum surface due to thermocouples. Generally, based on his experimental results, Tesfaye argued that heat was transported, stored and utilized by indoor cooking; and it is feasible in the sense of developing countries.

Negera[9] tried to study factors affecting adoption of electric injera mitad in Ethiopia, making the study area to be Woliso town and primary data collected by selecting households using a random sampling technique. In his analysis of the data collected, he found that only 33% of the households are using electric injera mitad and some of them are still using fuelwood side by side of electricity, showing that it is not easy to adapt modern energy sources in the community. The income of individual household, education level of the family members, the affordability of the price of electricity and price of fuel wood are the major factors that usually affect adoption of electric injera mitad in Woliso. He also concluded that energy adoption policy and governmental subsidizing of electricity costs are very mandatory to easily switch people to modern energy sources.

Feron[10]reviewed off-grid Photovoltaic(PV) systems by identifying different indicators so as to study sustainability on their application for rural electrification in developing countries. According to his investigations, economic, environmental, institutional and socio-cultural aspects are the most important factors to be studied and considered while a rural electrification program is needed to run so that its sustainability will be assured by setting certain rules, regulations and standards during the program life span. He also ascertained that rural electrification programs shall be not only socio-culturally accepted but also government subsidy schemed for considering the poor households. Off-grid PV systems demands cost-effectiveness, reliability and durability. Therefore, the study shows that different aspects have to be assessed and set standards for the implementation of rural electrification program to make the program sustainable at every aspect.

Hailu et al.[11]studied the energy consumption performance of electrical Mitad taking selected samples in different setup and making a serious of baking activities with a baking temperature range of 130-140 ^{0}c. The research results show that the specific average energy consumption of locally available Mitad types is 0.82, 0.73 and 0.54 kWh/kg of injera for double clay, single clay and rotating type, respectively; and their average energy consumption is found to be from 3.5 KW to 3.9 KW; thereby experiencing losses from 50-60% of the input energy.

Adem and Ambie[12] reviewed different Injera baking technologies focusing on the current challenges and gaps that are the main reasons for energy wastage and creating difficulties for Injera baking, especially in rural areas. The review covered the existing methods and various attempts& researches done to improve and support the Injera baking system with modern technologies and alternative energy sources by using as a reference the widely used open-fire method of Injera baking which is more available in rural parts of Ethiopia. It is clear that Adem and Ambie’s review results are much helpful as an input for future studies to improve Injera baking methods pertaining to associating technologies and other energy sources for efficient, easy and environmentally friendly Injera baking activities.

The above literature reviews show different application of solar PV and thermal energy applications; and we can understand that attempts have been done to use and improve the efficiency of solar thermal energy for Injera baking. However, it needs to conduct further research for other ways of energy sources for Injera baking; and this is why it is important to design, study the feasibility and carry out techno-economic evaluation of Solar PV based Injera baking system for off-grid communities.

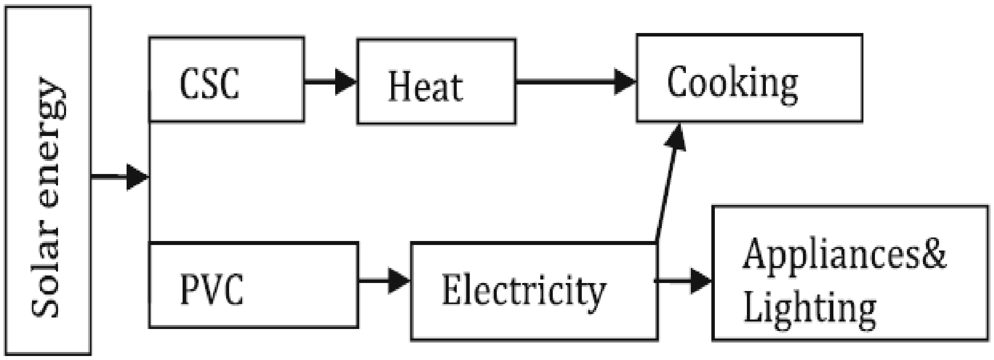

Figure 2. 5: Solar energy conversion in to heat & electricity[8]

2.1.3. Solar Oven

Solar oven is used for cooking through the application of greenhouse effect so that reflection and black areas sun-beams are “trapped” in the solar oven to reach its temperature up to 150^0C

Figure 2. 6: Solar Oven[www.wikipidia.com]

2.1.4. Parabolic cooker

A parabolic cooker is used to direct the sun-beams into one point to generate heat to get a temperature of up to 200°C[13].

Figure 2. 7 :Parabolic cooker[www.wikipidia.com]

2.3. Benefits of Solar PV Based Rural Electrification

When solar energy is used instead of wood or biomass as energy source for Injera baking, women will be able to participate in society; children can get an education instead of searching for wood, or walking to the place where it can be bought, and life standard of off-grid villages will be improved. With solar energy, cow dung will not be used as fuel; it will be used for fertilizer. The other benefit of using solar energy is that deforestation will decrease and more plants continue to grow there by decreasing soil erosion so that the soil fertility increases. Solar energy is smokeless, there will not be indoor pollution at home; hence eye and lung diseases will not occur. If batteries are properly handled and used system components disposed wisely; it has less harm to the environment[10].

2.4. Solar PV Systems

2.1.5. Types of Solar PV Systems

Based on their application PV systems are classified into the following distinct types:

a) Stand-alone systems

These types of PV systems are systems where the energy is generated and applicable in the same place where it generated and it is not connected with the national grid[14].

b) Grid-connected systems

This solar PV system is connected to the national grid and which can feed any surplus power into the grid. Some grid-connected PV systems with energy storage can also provide power locally. These systems have the advantage of reducing reliance on the national grids and ensure that more of the electricity is produced in an environmentally efficient way[15].

c) Solar PV hybrid system:

In this system, as wind, biomass or diesel, can be hybridized with the solar PV system to deliver the required energy demand and used to attain more reliability into the system at an inexpensive way by adding one or more energy source(s) together[16].

2.1.6. Solar PV System Components

2.1.6.1. Solar Panels

The basic information that applies to every type of solar cell is that all photovoltaic cells consist of two or more thin layers of semi-conducting material, which is usually made from silicon. When exposed to light or solar radiation, the semi-conductor generates electrical charges that can be conducted as DC using metal contacts with little energy. Cells are usually connected to form strings. Strings are again connected to one another to form a module or panel which again forms an array. Using several panels, it is usually enough for systems intended to power a single house-hold or a small building. However, for the Indode solar PV project, it is very likely that many solar arrays will be necessary, given the dimension of the project.

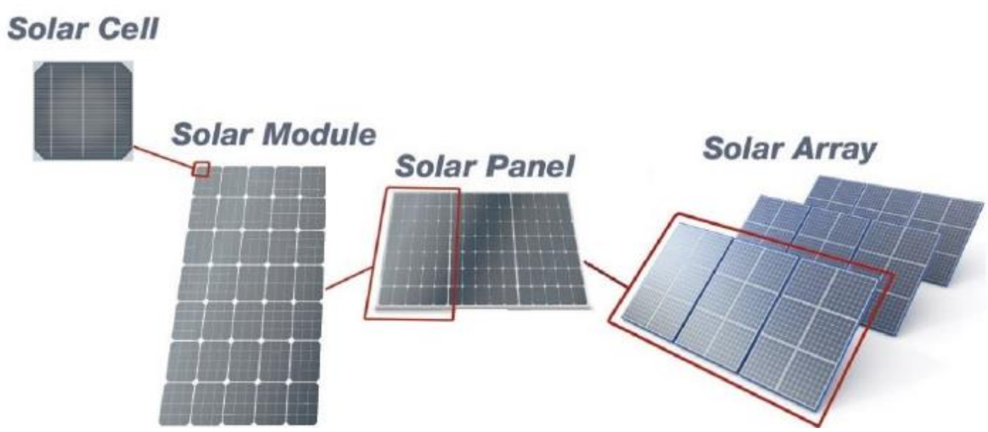

Figure 2. 8: Solar cell, Module, Panel and Array [18]

2.1.6.1.1. Types of PV Panels

To choose the type of solar PV for this project, PV types must be discussed as follows:

a) **Mono-crystalline silicon PV panels:** These panels are made from cylindrical crystal of silicon cells. As its efficiency rates range between 14%-19%[17], these panels are the most efficient panels. Their complicated manufacturing process results in slightly higher prices than other panel technologies.

b) **Polycrystalline Silicon PV panels:** These are made from an ingot of melted and recrystallized silicon. These ingots are then cut into thin slices and assembled into cells. Even if their manufacturing process is simpler and is slightly cheaper compared to mono-crystalline panels, their efficiency also tends to be slightly lower ranging 12%-15%[18].

Although we discussed the most typically commercialized technologies for producing PV panels, mono-crystalline PVs and polycrystalline PVs. are two technologies that stand out from the rest when it comes to micro solar project design and dimensioning.

Property	**Monocrystalline**	**Polycrystalline**
Efficiency	14%-19%	12%-15%
Aesthetics	Black hue, uniform	Blue heterogeneous color
Cost	More expensive	Cheaper
Longevity	+25 years	+25 years

Table 2. 1: PV technology comparison[18][17]

The table above shows that both PV technologies have advantages and disadvantages. For projects with lower installation space, efficiency will be considered; while for projects where space is not a constraint, cheaper technologies will be considered. For this study, mono-crystalline PV technologies are selected based on their efficiency because of space constraint since the surrounding is reserved for farming area.

2.1.6.1.2. PV Performance Factors

There are some factors which can affect PV performance as reviewed below:

a) Temperature: PV module operating voltage is reduced on average for crystalline modules approximately 0.5% for every degree Celsius above STC[19]. PV cells will usually generate less energy in summer than in winter, but this is due to the shorter days, lower sun angles, greater cloud cover.

b) **Partial Shading:** A small shading on a portion of the PV array can cause a large reduction in the output power. But, since there are no considerable shadings in Indode’s solar PV station; shading effect is not considered in the design of this PV system.

c) **Soiling:** Dust, snow and other deposited materials on the PV module glass which interferes with the incoming radiation will harmfully affect the power generating capacity of the module.

d) **System Voltage:** Since PV cells operate at a relatively stable voltage, the current and power output of photovoltaic modules is approximately proportional to the solar insolation.

e) **Aging:** The performance of any PV module will drop gradually over the course of its life span due to aging.

2.1.6.2. Charge Controller

Solar charge controllers are used to managing the power that goes into the battery bank from the solar panels by insuring that the batteries do not overcharge during high irradiance periods, or that the power does not run backwards from the batteries to the solar panels during night time. Charge controllers include a DC-DC converter to ensure batteries are charged at their optimal voltage and current for every instant and it will convert the current from the solar PV arrays to match the voltage of the battery bank. When the battery is full, the PV array should be disconnected; and, when the battery is empty, the user should be disconnected. The MPPT automatically adjusts system voltage such that the PV array operates at its maximum power point.

2.1.6.3. DC Combiner

In most PV systems, several modules are wired together in series to form a string with a cumulative voltage throughout the string; and a DC combiner is important for the strings to be combined in parallel. A DC combiner box contains overcurrent protection devices and the necessary bus bars and terminals for the input combination.

2.1.6.4. Battery Bank

While sizing the PV system of Indode village, a reliable battery bank will be the most important component of the system. In recent times, lithium ion batteries are popular for PV system installations because of their characteristics that they are weight efficient and can operate under work cycles than lead acid batteries[15]. But, lithium ion batteries have the disadvantages of high purchasing cost as compared to lead acid batteries which are a time-tested technology with lower price. Moreover, lead batteries are more widespread and can be more easily found.

Based on the above selection indicators, it is considered that even though Li-ion batteries are better chosen from a technical perspective, its low purchasing cost and ease of availability in the market makes Lead Acid batteries a better choice for the installation in the PV system for Indode Village.

In lead acid batters, a battery cell consists of two leaded plates which are separated by an insulated material: a positive plate that is covered with a lead dioxide paste, and a negative plate, with these plates enclosed in a battery case and then submersed in an electrolyte, which consists of distilled water and sulfuric acid.

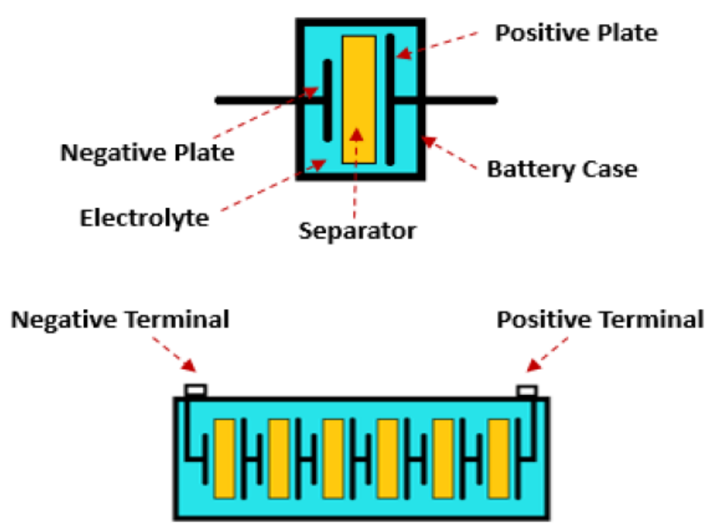

Figure 2. 9: Lead acid battery terminal diagram[20]

2.1.6.5. Inverter

Solar inverters are one of the components of a PV system which are used to convert the variable direct current(DC) output of the PV solar panels into AC current, that can be distributed for Indode villagers for usage. Some of the major factors to be considered while sizing the inverter are; the energy and power output of the solar array, the total PV panel installed, and whether a central inverter or a multiple inverter system is desired; and inverters over 2000 W are actually 24 V DC and inverters over 5000 W are often 48 V or above[14].

2.1.6.6. Wiring and connection

Well sized cables are required from the PV panels to the DC combiners and batteries, from the DC combiners to the Inverter going through the MMPT and charge controllers. To decide the type of wiring, the current going through the connection is a mandatory characteristic in the connection. These wire connections in the PV system are the wires that will be used to connect every panel in one string; the wires used to deliver the power from the charge controller to the main DC Bus, from the charge controllers meet to deliver the power to the battery bank and the inverter.

Chapter 3: Materials and Methods

3.1. Indode's Community Study

3.1.1. Site Location

Off-grid communities which have close proximity to Addis Ababa city in Oromia Special Zone, Akaki Woreda Administration, located in Hechu Kebele, Indode Village are selected for the study.

The village of Indode is found south of Addis Ababa city, 4km away from Indode railway station. The community can be accessed by car, Bajaj and animal transport or on foot. Figure 3.1 below shows the community's location on the Google satellite map. Since the PVsyst software requires exact GPS location, it is noted in the satellite data that the exact coordinates of the site are 8°50'49.2"N and 38°46'04.9"E.

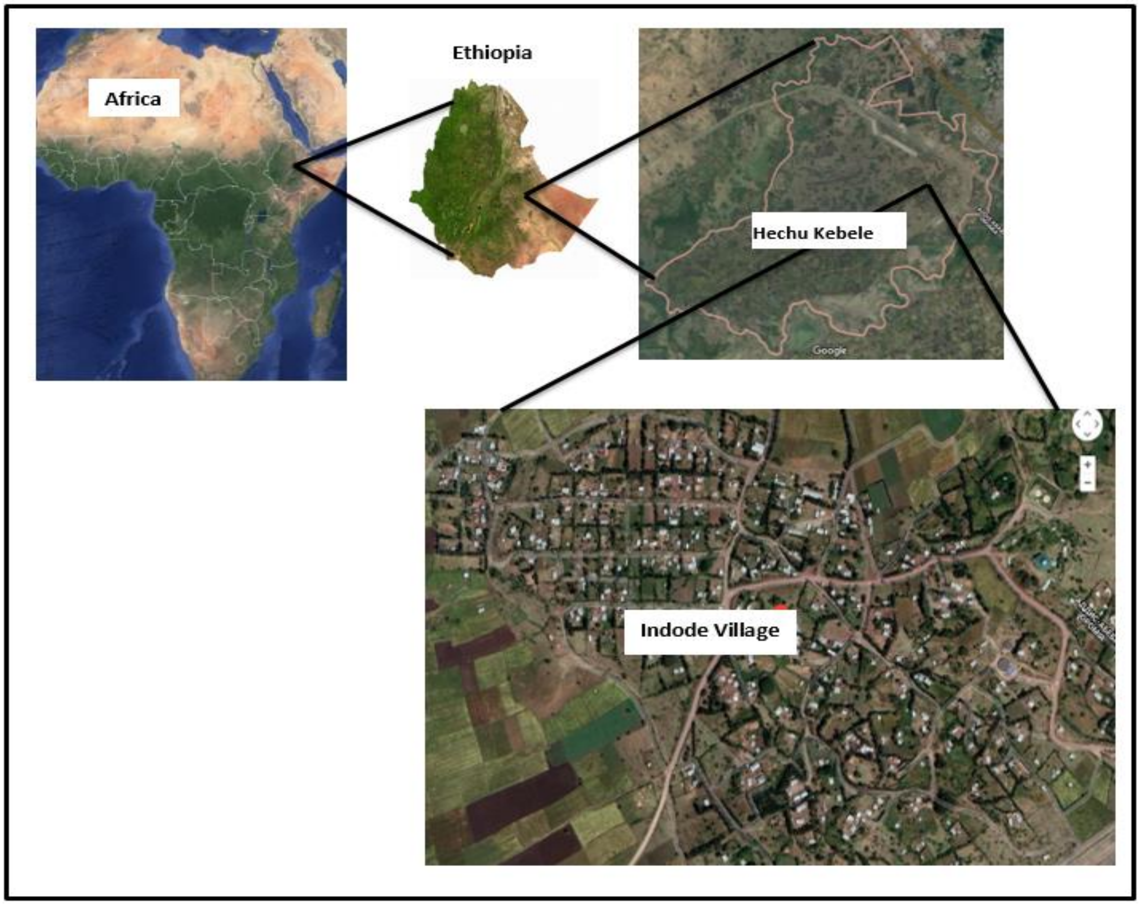

Figure 3. 1:Location Map of Indode Village

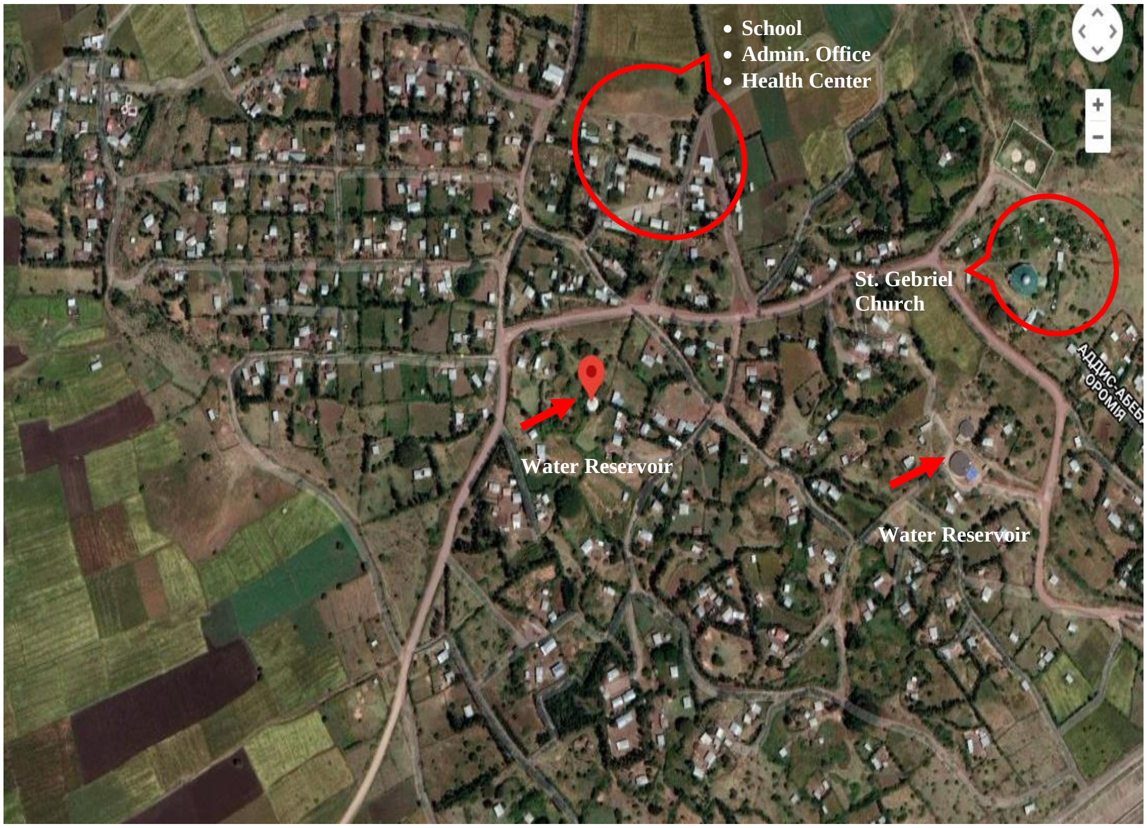

Figure 3. 2: Satellite Google Map of Indode Village.

3.1.2. Indode's inhabitants

As the Ethiopian census was conducted in 2007 E.C, the population size is not a recent and updated data. Thus, the current data found from the government office of Hechu kebele Indode Administrative zone Office shows that Indode is a home to 1,171 people and there are 322 households, which is divided in to 6 sections for administrative purpose. Agriculture is the most important economic activity in the village.

3.1.3. Indode's Facilities and Infrastructure

3.1.3.1.Road Access

The way to access the village of Indode is by car, Bajaj and Animal transport or on foot. From Indode railway station, it can take from 5 to 25 minutes, depending on means of transportation. The village has no proper roads. The following image shows the way to the village.

Figure 3. 3: The road to Indode village

3.1.3.2.Indode Village Facilities

The following table provides more information on the village's facilities, which are to be considered as electrical load points.

Service	Description
Services at Home	• Cooking such as Injera & bread baking, boiling and other home appliances. • Phone charging, TV and lighting purposes.
Education	There are two public schools; the first school (1-4 grades) which currently hosts 140 students and the second school (1-8 grades) which currently hosts 532 students. Power is required for lighting classrooms and staff area; and mobile phone charging.
Health care	The village's health center has no electricity facility. It serves the surrounding communities and power is needed for medical refrigerator for vaccinations and lighting to conduct emergency procedures in the evening if necessary.
Marketing	If there is an electric supply, beauty salons and barber shops are expected to emerge.
Church	The village's church(St. Gabriel) needs electricity access.

Table 3. 1: Load points of Indode's village

Figure 3. 4: Indode Community's Health center

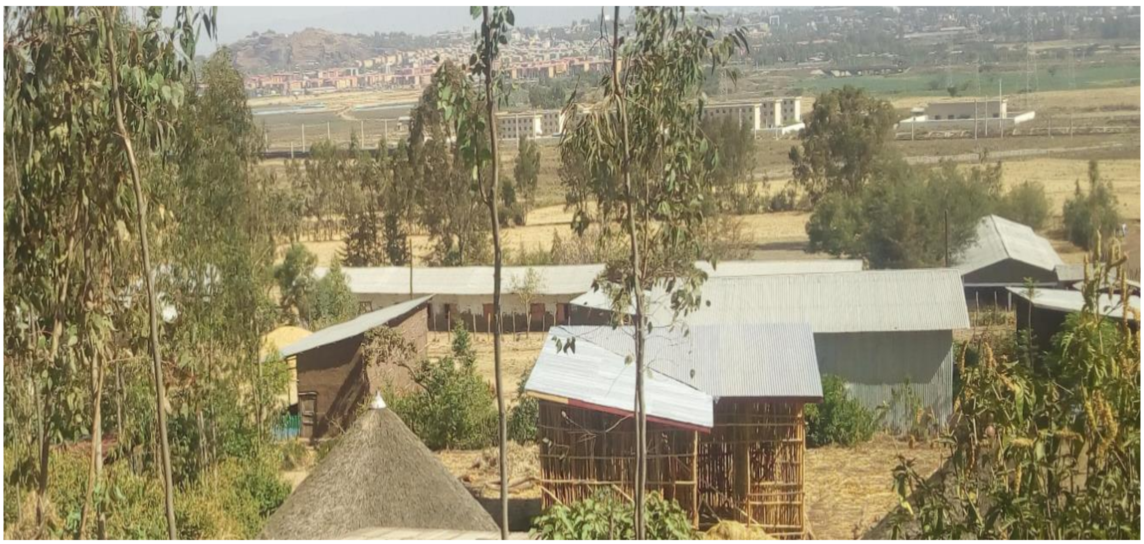

Figure 3. 5: Indode Community's School(1-8 grades)

3.1.4. Energy Situation of Indode Village

3.1.4.1.Current situation

Even though there is a national grid line passing nearby, Indode village has no energy access. The train station and water wells found at certain distance from the village are getting energy access from the national grid. For this reason, the construction of stand - alone solar energy source would strongly help the community to improve their life standards.

3.1.4.2.Energy Usage

The energy consumption in Indode village will basically be used for Injera baking, for energizing house hold appliances and lighting. Currently, cooking in Indode village is done in a traditional way; using firewood and cow dung which is dangerous to the environment and community's health.

Figure 3. 6: Fire wood[21]

3.1.5. Climatological Data

Climatological data are essentially important site-specific information unique to every solar project. Meteonorm [22][23] is one of the reliable databases providing global climate information through its 8,350 weather stations scattered around the globe (Meteonorm, 2019). Metereonorm database contains all the necessary information which includes global, direct and diffuse irradiation, temperature, peak sun hours, sun-paths and wind velocities for design and analysis of solar PV projects. Therefore, the climatological information of Indode's village provided by Meteonorm will be used as the basis of the simulation of this solar PV system.

3.2. Design of Solar Powered Community Kitchen

3.2.1. Requirements of the Solar Kitchen

The solar powered community kitchen will be used mainly for Injera baking. However, it must be a multi-purpose kitchen so that it can be used for bread baking and other boiling activities.

- It should be of acceptable size compared to the number of users.
- Even if its main purpose is for Injera baking, it should also serve as a multi-purpose kitchen for bread king and other boiling activities.
- From community interview result, we find that each individual household usually

bake averagely 15 Injera per 3 days, but previous research show that Ethiopian single household bake 25 Injera averagely per baking session[24]. Let's take 25 Injera per session (per 3 days) for this analysis.

- From Indode's community trends, baking a single Injera takes 5 minutes but literature reviews show that electric mitad takes about 3 minutes[24]. Thus, taking the 3 minute baking time, the Mitad should be at 220 ^{O}C[2] for at least 75 minutes (25*3min =75min).
- It is assumed that a single Mitad will work for 8 hours (480 min.) averagely per day and each kitchen will have 8 Mitads arranged in two parallel rows (4 by 4) with equal number of Mitads side by side to manage the kitchen room space.
- Averagely, a total of about 10.7 households that means =322/ (3*10) can be served in a single kitchen per day.
- The total number of kitchens to be constructed for Indode Village will be 10; which is located at appropriate distance to serve 32 nearby households.
  No of kitchens needed= Total no of households/32=322/32~10.
- Therefore, the total number of Mitads which will serve for Indode community will be 80. That means no. of Mitads in a single kitchen * no. of kitchens= 8*10=80
- The kitchen should only change the energy source; the community's method of baking Injera should not be any different.

Total no. of households	**No. of Injera/ 3 days/household**	**Total No of Kitchens**	**No. of households / kitchen/day**	**No. of Injera/ kitchen/day**	**No. of Injera in all kitchens/ day**
322	25	10	10.7	267.5	2675

Figure 3. 7: Summary of kitchen requirements

3.2.2. Design and Sizing Procedures

The study is carried out applying several steps and procedures combined with the data collection process at Indode village. These include the determination of daily load profile, a clear understanding of photovoltaic system configurations, component behavior as well as cost analysis, modeling and simulation of the solar system as well as selection of an optimum system referring to the simulation results using PVsyst software.

Generally, the following procedures were followed to design and carrying out a detailed techno-economic analysis of the solar PV system[25].

- Planning and site visit & survey;
- Assessment of energy requirement;
- Assessment of solar resource availability for Indode village;
- System concept development;
- Sizing and selection of main components;
- Techno-economic analysis of the solar PV system;
- Modeling and simulation using PVsyst software;

3.2.3. Modeling the Solar PV System

A stand-alone PV system is selected for the community because it is cost effective and affordable than other types of systems as they have additional components which will increase the cost of the project. The system modeling activity is conducted to determine the exact characteristics of the power to be generated, based on Indode village's solar resource data. The PV panel is dimensioned in cooperation with the batteries, charge controller and inverter to supply enough power to run the system operation throughout the year[8].

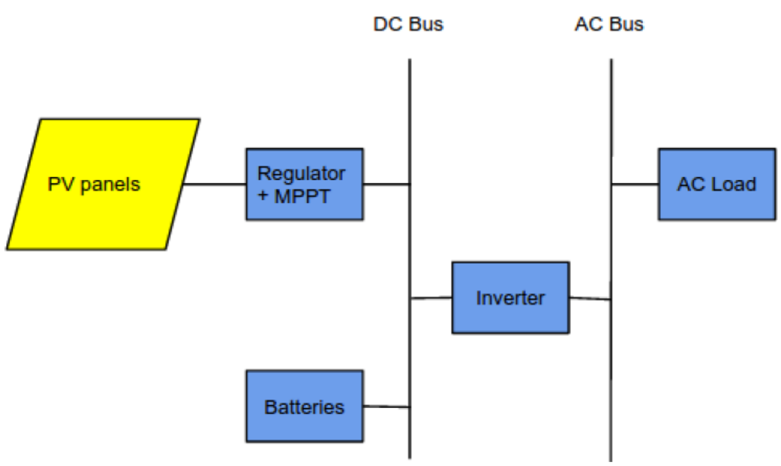

Figure 3. 8: Block Diagram of Stand-alone PV System [5]

The actual sizing of the PV system including its different components is done to decide the system configuration and specify the inverter ratings, the battery & PV capacities, and system wiring sizes. Basically, a stand-alone solar PV system for off-grid applications mainly consists of solar PV modules, solar charge controller, inverter, storage batteries, load and other accessories such as cables & connectors[26].

3.2.4. Simulating Software

3.2.4.1.Meteonorm

Meteonorm is one of the reliable databases providing global climate information through its 8,350 weather stations scattered around the globe (Meteonorm, 2019). Climatological data are essentially important site-specific information unique to every solar project[22][23]. Metereonorm database contains all the necessary information which include global, direct and diffuse irradiation, temperature, peak sun hours, sun-paths and wind velocities for design and analysis of solar PV projects.

3.2.4.2.The PVsyst Software

PVsyst is widely used simulation software for the study, sizing and data analysis of complete PV systems for solar energy systems such as grid-connected, stand-alone, pumping or DC-grid systems[27]. The software can evaluate hourly, monthly as well as yearly energy production and performance; performs economic evaluation of the PV system at the design stage, and also performs a detailed simulation and shading analysis according to many variables[28]. It is also used for evaluating the economics and the environmental performance of the solar systems.

The basic requirements for the study are[14]:

- Geographical data.
- Meteorological data (imported from Meteonorm).
- Technical data (tilt and azimuth).
- 3D model of near shadings.
- PV modules design based on available area.
- PV system components chosen from the PVsyst database: module, inverter and strings.

PVsyst is used for this study to select the optimal and cost effective configuration so that it will be designed and tested before spending any money on the actual components[29].

3.2.5. Solar Energy Resources of Indode Village

Most parts of Ethiopia have a daily solar radiation which varies from 5 and 7 kWh/m^2.day [8]. The results found from Meteonorm shows that the daily solar global irradiation of Indode village is 5.33 KWh/m^2.day. To determine the amount of energy for Indode Village that can be attained by means of solar PVs, the radiation data for the coordinates indicated below is considered.

Latitude	Longitude	Altitude(m)
8°50'49.2"N	38°46'04.9"E	2115

Table 3. 2: Indode Village's coordinates(from Meteonorm)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Hor. global	5.63	5.66	5.93	5.59	5.40	4.94	4.09	4.09	4.91	5.80	6.17	5.75	5.33	kWh/m².day
Hor. diffuse	1.84	2.42	2.41	2.55	2.58	2.52	2.50	2.40	2.49	1.87	1.75	1.60	2.24	kWh/m².day
Extraterrestrial	9.05	9.75	10.30	10.50	10.35	10.17	10.21	10.37	10.33	9.90	9.22	8.80	9.91	kWh/m².day
Clearness Index	0.622	0.581	0.575	0.532	0.521	0.486	0.400	0.395	0.476	0.586	0.669	0.653	0.537	
Amb. temper.	16.3	17.4	18.1	17.8	18.6	17.2	15.9	16.4	16.1	17.0	15.7	15.9	16.9	°C
Wind velocity	2.4	2.4	2.5	2.4	2.3	2.3	2.3	2.2	2.0	2.0	2.1	2.3	2.3	m/s

Table 3. 3: Indode's metrological data from Meteonorm

3.2.6. Load Assessment

The modeling of the solar PV system characteristics to estimate the generation of the power desires crucial inputs, namely load demand, solar irradiance and weather data needed for conducting the analysis based on the number of villagers, social activities and daily lifestyle[25][4].

Even though the Solar kitchens (10 kitchens which contains 8 Mitads each) are designed mainly for Injera baking, water heating, and lighting the room will be served

Generally, in designing this Multi-purpose PV system, it is known that most of the power produced goes to power the Injera baking kitchens; and the remaining power for powering the village's facilities which are important in improving the life standard of the community such as schools, health centers, administration offices, and homes as their power access status is assessed in table below.

By identifying the loads with their power ratings and time of operation during hours per day for each facility, we can obtain the total energy demand for the community[4]. A list of the devices, their power consumption and maximum operating quantity is provided in the table below:

Services	Load	Quantity	Rated power (W)	Total Power (W)	Usage Time (hrs.)	Total energy/day (Wh)
Solar kitchens (10 kitchens which contains 8 Mitads each)	Mitad (for Injera Baking)	80	3,500	280,000	8	2,240,000
	Water heater, Kettle	10	1,500	15,000	4	60,000
	Fluorescents	12	40	480	4	1,920
School	Computers	8	150	1,200	7	8,400
	Fluorescents	60	40	2,400	4	9,600
	Printer	2	100	200	4	800
Village Administration office	Radio	4	10	40	4	160
	Computers	3	150	450	7	3,150
	Fluorescents	10	40	400	4	1,600
	Printer	2	100	200	4	800
Health Center	Fluorescent	6	40	240	4	960
	Vaccine Refrigerator	1	2,200	2200	24	52,800
Home	TV	150	75	11,250	5	56,250
	Refrigerator	50	2,200	110,000	24	2,640,000
	Lamps	422	40	16,880	4	67,520
	Mobile charges	400	4	1,600	2	3,200
	Laptops	50	150	7,500	5	37,500
	Radio	322	10	3220	4	12,880
Church	Lamps	10	25	250	4	1,000

Services	Load	Quantity	Rated power (W)	Total Power (W)	Usage Time (hrs.)	Total energy/day (Wh)
Beauty salons and Barber shops(6 shops)	Lamps	12	40	480	4	1,920
	Hair cutting machines	12	20	240	5	1,200
	Sterile machines	6	500	3,000	8	24,000
	TV	6	75	450	5	2,250
	Water Heater Kettle	6	1,500	9000	2	18,000
				Total Daily Energy Demand		**5,245,910**

Table 3. 4: List of Loads and their power consumption for the village

After the list of loads and their power consumption has been determined, it is necessary to know their operating hours so that a minimum energy production (kwh) can be approximated.

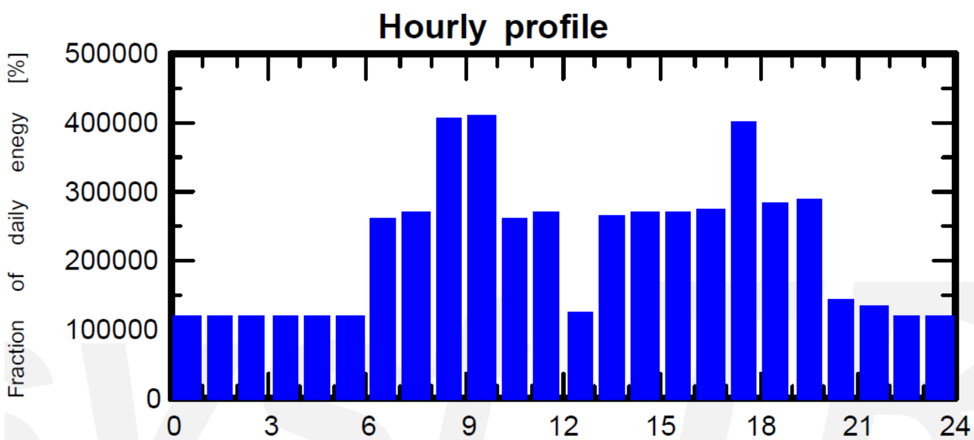

Figure 3. 9: Indode's Load Demand Profile

Figure 3.7 above shows the daily and hourly primary load demand of Indode community that the electricity load profile varies during the day. The load is very low from middle of night till morning, between 21:00–6:00 hours. On the other hand, the demand rises during times from 6:00–12:00 hours and 13:00-20:00, especially 8:00-10:00 and 17:00-18:00 hour intervals show the maximum power demand than other hours of the day. From PVsyst analysis, Indode's daily total energy demand is found to be 5,245.9kWh/day.

Indode's consumption shows two clear peak times. This is due to the fact that at this times of the day villagers are active in baking Injera, resulting in a high demand of power for the kitchens. And also, it is an office hour with additional power need to power the schools, health centers and administration offices. The other aspect that will extensively increase the capacity of the PV system is the constant consumption of the Mitads for baking and refrigerators. The refrigerators will consume power 24 hours in a day, including non-solar-active hours. Assuming that temperature decreases during night and refrigerator doors will not be opened during night hours, it is expected that power during night-hours may be to some extent lower than during day hour.

3.2.7. Tilt and azimuth

In sizing and modeling the PV system, it is an azimuth of 0° towards the south and with a tilt angle of 18°. The tilt angles impact on produced power is assessed by making the azimuth constant and varying the tilt angle with different values of the angle. And also, the same is done by fixing the tilt angle constant and varying the azimuthal angle. The PVsyst result shows that the average daily solar incidence over the year (Gav) is about 5.44kWh/m^2/day. The graph below illustrates that the incidence energy at Indode is relatively lower during the months from June-September and higher from October – May. The result is shown in the figures below.

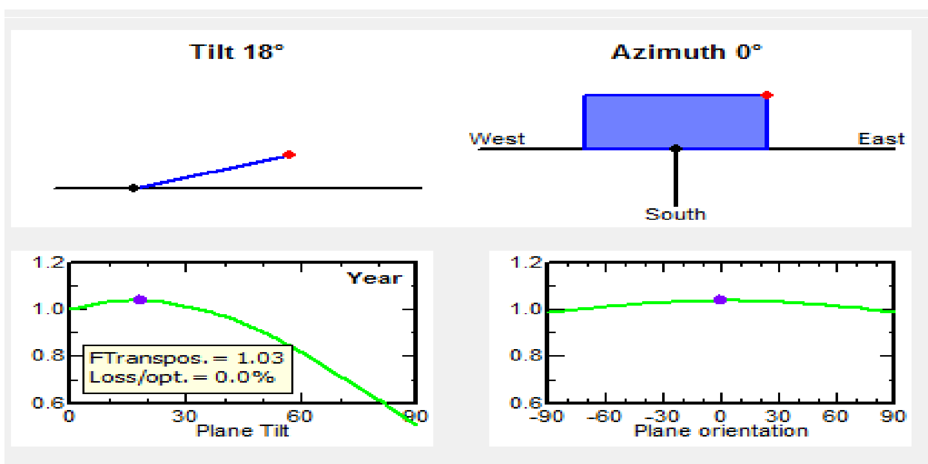

Figure 3. 10: Plane Tilt and Azimuth

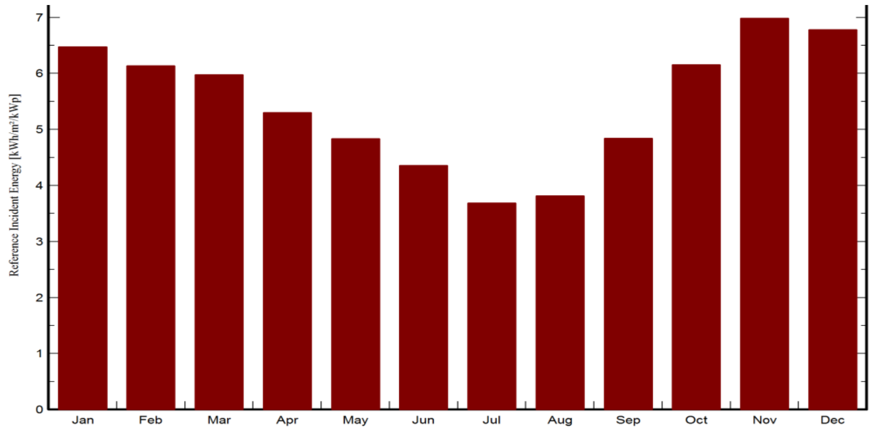

Figure 3. 11: Incidence energy on collector plane

3.2.8. Near shading

Indode solar PV project is not affected by any shading types such as buildings, trees or mountains which can form shadow/shade onto the panels at certain time periods of the day. Therefore, no shading analysis is conduct for the project.

3.2.9. Solar PV Powered Single Kitchen

3.2.9.1. Assumptions

The following assumptions are taken in to consideration while conducting the study:

- Most manufacturers give a warranty of 25 years for PV panels. Thus, Indode’s solar PV project is assumed to have a project life time of 25 years.
- The irradiance and the metrological data accessed from Meteonorm site are internationally acceptable to undertake the modeling and simulation of solar PV system.
- The Annual solar radiation at the village and the power requirement for all kitchens and other loads are assumed not to vary throughout the project lifetime.

3.2.9.2. Daily Consumption and Hourly Distribution

The PVsyst result shows the daily consumption and hourly distribution of a single community kitchen as indicated in the figures below.

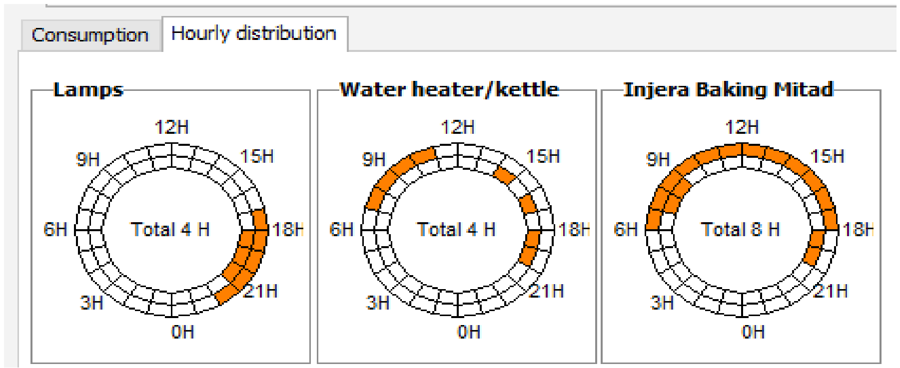

Figure 3. 12:Hourly Consumption Distribution

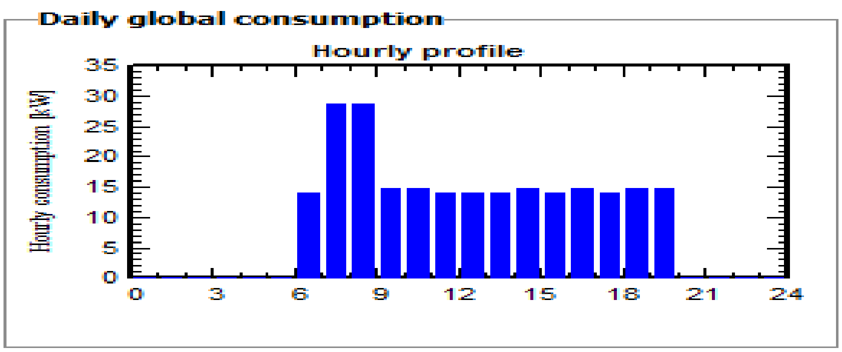

Figure 3. 13: Daily hourly consumption profile

3.2.9.3. Power demand and energy consumption for a Single Kitchen

Literatures show that the power rating of electric Injera baking stove is not still standardized in Ethiopia and the average power demand of a single electric Injera baking electric stove varies from 3-4 kW depending on the experience of the baking stove manufacturer[30][11][31]. For this study, the average power demand of an Electric Injera Mitad is estimated to be 3.5 kW/Mitad. The power demand for a single kitchen is estimated to be = 3.5 kW/Mitad X 8 Mitad = 28 kW and the energy consumption of Injera baking for a single kitchen will be =28 kW x 8 hours/day=224 KWh/day. Therefore, energy consumption of all Kitchens is estimated to be = 224 kWh/day. Kitchens x 10 Kitchens = 2,240 kWh/day or 817.6 MWh/year.

Services	Load	Quan tity	Rated power (W)	Total Power (W)	Usage Time (hrs.)	Total energy/day (Wh)
Solar kitchens (10 kitchens which contains 8 Mitads each)	Mitad (for Injera Baking)	80	3,500	280,000	8	2,240,000
	Water heater, Kettle	10	1,500	15,000	4	60,000
	Fluorescents	12	40	480	4	1,920
				Total daily energy demand		**2,301,920**

Table 3. 5: Energy demand for a single kitchen

3.2.9.4. Kitchen layout and Wiring

All Mitads will be connected in a parallel electrical arrangement, because each of them can be put on and off independently. If one Mitad is turned on or off or damaged, it should not affect the remaining Mitads as each of them can have a unique switch and they will have the same potential difference across, which is 220V. This will not be possible if all the Mitads are connected in a series electrical arrangement as there will be one switch that either switches all of them on or off at a time. To manage the kitchen room space, the Mitads will be arranged physically in two parallel row (4 by 4 Mitads) as shown figure 3.12 below. As the Mitads are arranged in parallel electrical connection, each Mitad will get a 220V voltage electricity from the inverter.

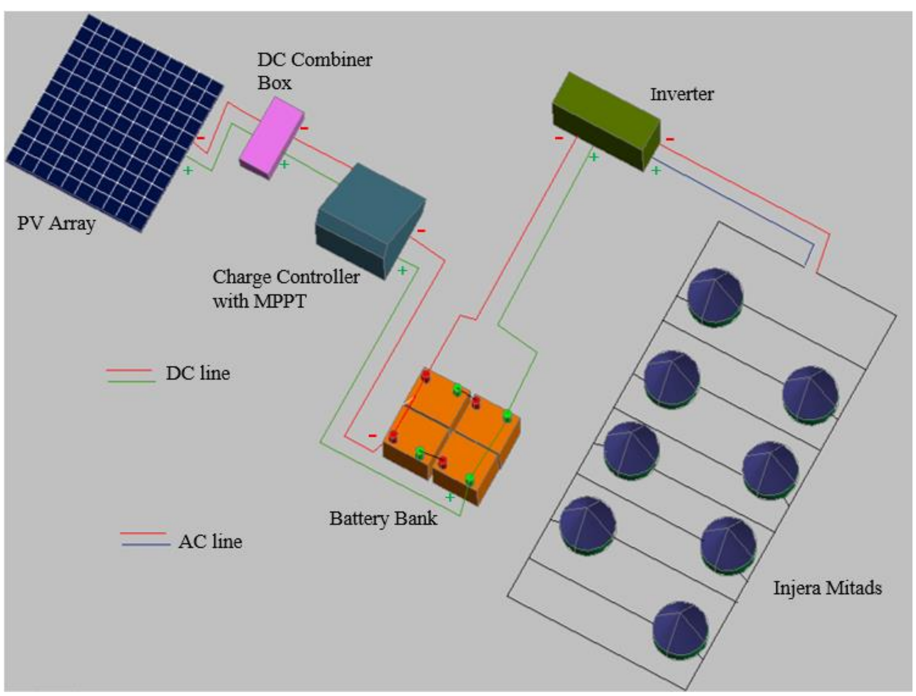

Figure 3. 14: Electrical Layout of a Single Kitchen

3.2.10. Multi-Purpose Solar PV Injera baking System Project

Literature reviews show the promotion of longer injera baking sessions like in community kitchens may lead to additional fuel wood savings, thereby increasing the number of injeras baked per session[11].

Indode's solar PV system project will be modeled financially to determine the proposed project cost there by considering item procurement, installation and various fixed & operational costs incurred under regular operating conditions in the project life.

Since sunlight is free, the costs related to the power generation are almost zero; only the initial investment is put in to consideration. The total solar PV system costs are sum of component costs such as purchase of PV modules, MPPT, Inverter, battery, DC combiner, wiring and supports with the addition of other direct costs such as installation, labor and transportation costs. Moreover, increasing solar energy utilization capacity involves reducing fossil fuel generation and consequently reduces operating costs and greenhouse gases emissions [32].

Because of requirement of high project cost, off-grid PV systems for rural population require policy intervention; in other words, allocating public funds for covering both the initial investment and the operation & maintenance cost of the systems or a subsidizing mechanism for rural electrification which can promote local economic development. Due to lack of experienced local expertise, other prior technological experiences in remote areas have shown that productive uses of off-grid PV systems require government programs, offering co-operation and training to enhance the reliability of the systems for their sustainability[10].

3.2.10.1. The Kitchen System Layout and Concept Analysis

The designed solar based Injera baking system must be technically and economically feasible and can meet the social requirements of Indode community. As the people are settled crowdedly on the hill of Indode, a centralized stand-alone solar energy source can comply with the energy and social requirements of the community. Then, this power source is divided the serviced area into groups of nearby houses or facilities.

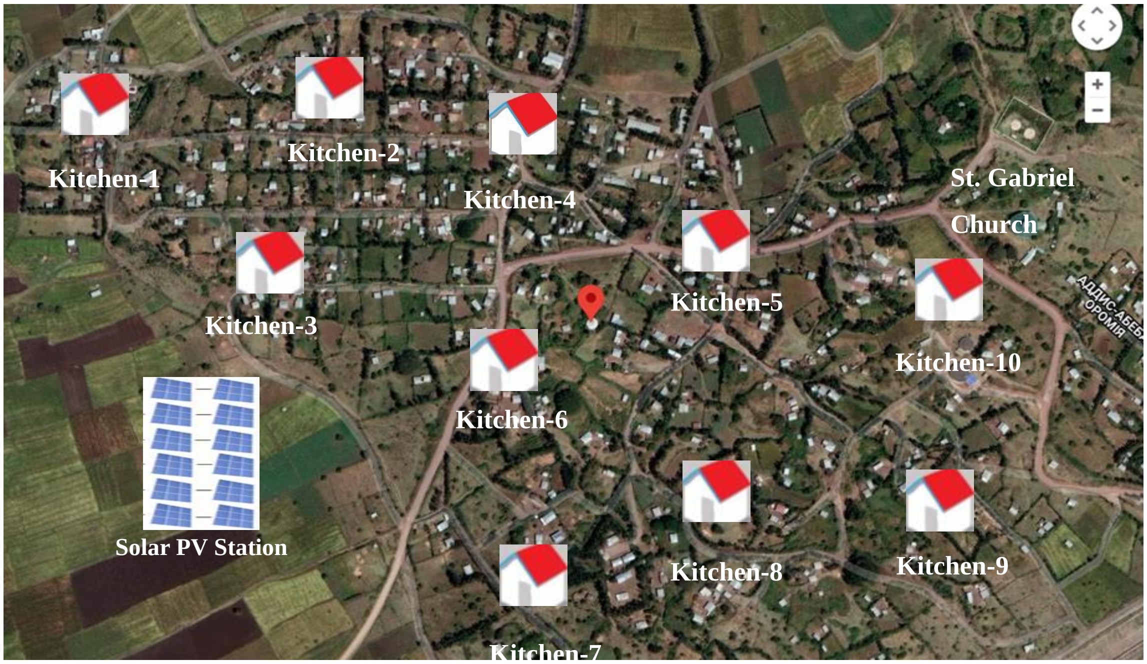

Figure 3. 15: Location & Layout of the solar PV station and the kitchens

Viewing technically, the centralized system will operate with an AC distribution system with voltage of 220V; with possibility of distributing the electricity within each nearby household is technically possible, although voltage drop analysis for some of the distant households might be still the problem.

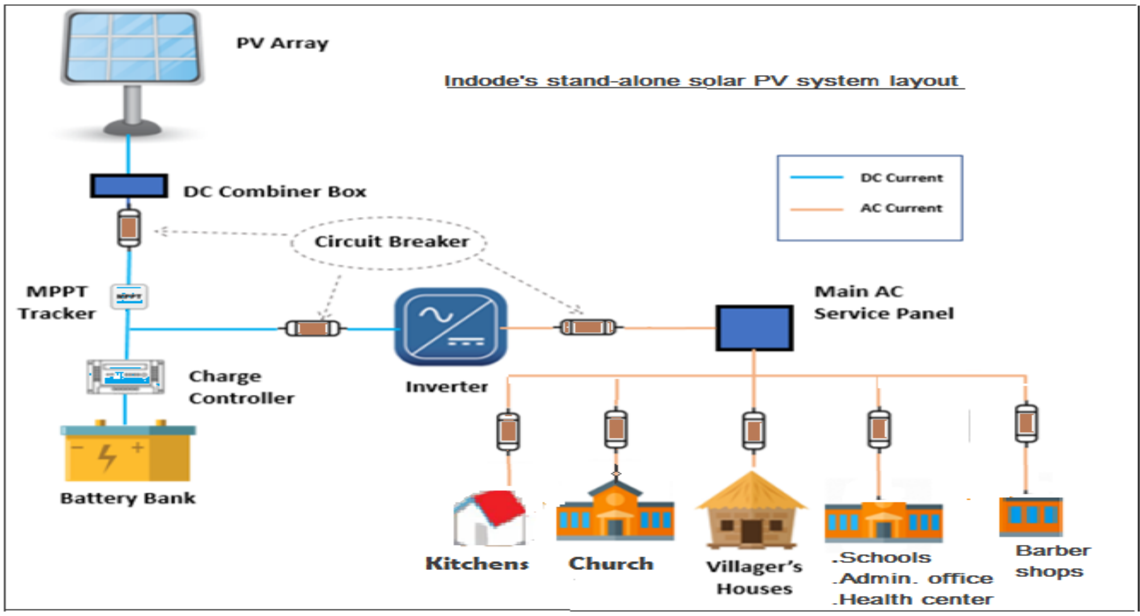

Figure 3. 16: Indode's Off-grid stand-alone solar PV system layout

Chapter 4: Results and Discussions

4.1. Solar PV Powered Single Kitchen

4.1.1. Solar Panels

The total amount of installed power to operate a single community kitchen is 52kW. The total number of solar panels is 130 and a single solar panel will cost 3,800 Birr, with an initial investment cost of 494,000 Birr for the total solar panels needed to power a single kitchen. The PVsyst analysis shows that each solar array will consist of 13 panel strings, each string has 10 panels arranged in series with the arrays passing through a DC combiner Box and then monitored by the MPPT.

Technology	Unit PV nominal power	No of PV modules			Global array power, nominal(STC)	Power at operating condition (50°c)	Total Module area	Initial cost (Birr)
		Total	In series	In parallel				
Si-mono, 72 cells	400Wp	130	10	13 Strings	52kW	47.1kW	291m^2	570,000

Table 4. 1: PV panel details

4.1.2. Battery Bank

From the PVsyst analysis result, the total number of batteries required to fully secure and maintain the performance of a single kitchen is 44, of which 4 batteries are connected in series and while 11 batteries are in parallel. The total storage capacity of the battery bank is 5,500Ah. Since it is assumed that the site shall not be cloudy more than a day, the autonomy of the battery is assumed to be 24 hours.

Technology	**Unit battery capacity**	**Battery bank capacity**	**No of batteries**			**Autonomy**	**Daily storage**	**Initial cost** (Birr**)**
			Total	**In series**	**In parallel**			
Lead-acid, sealed	12V/ 500Ah	48V/ 5,500Ah	44	4	11	24h	211.2KWh	550,000

Table 4. 2: Battery bank details

4.1.3. Inverters

According to the manufacturer's data, the selected invertor has the following technical information:

Model	Sunny 15000TL inverter
Manufacturer	SMA Solar Technology
Maximum dc power	15000W
Maximum power point voltage range	360V-800V
Rated input voltage	600V
Minimum input voltage	150V
Maximum input current	40A/16A
Maximum efficiency	98.2%
Rated power	15000W at 230V 50Hz
Nominal AC voltage	220/380V

Table 4. 3: Selected Inverter data

The size of the selected inverter shall be 25%-30% bigger than the system power to satisfy the system requirements[14].

$$Inverter\ size = \frac{130\%\ of\ the\ system\ power}{100} = \frac{130 * 52Kw}{100} = 67.6KW$$

$$No\ of\ Inverters = \frac{inverter\ size}{Rated\ power\ of\ the\ inverter} = \frac{67600}{15000} = 5\ inverters$$

4.1.4. Summary of Sizing Results

s/no	System components	Description	Simulation Results
1	Estimated load		230KWh/day
2	PV array	Type	Si-mono, 400Wp
		PV array capacity	52kW
		No of modules (in series)	10
		No of modules (in parallel)	13 strings
		Total no of modules	130
3	Battery bank	Type	Lead-acid, sealed
		Battery bank capacity	48V/ 5,500Ah
		No of batteries (in series)	4
		No of batteries (in parallel)	11
		Total no of batteries	44
4	MPP Charge controller	Type	Universal controller with MPPT convertor
		Capacity	MPPT 1000W,48V
		No of charge controllers	1
5	Inverter	Capacity	15KW
		No of inverters	5

Table 4. 4: Summary of sizing results

4.1.5. Analysis of Energy Production

The energy analysis of PVsyst software indicates that 68.1% of the energy produced from the system is supplied to the user while the contribution of the system and battery charging losses are 31.9%. Since the incidence energy at Indode site is relatively higher during the months from October-May, the graph shows that there is 0.5kWh/KWp/day unused energy (battery full case). There is a high collection loss (PV-array loss) during from June-September months as there are cloudy and rainy days with low irradiance which have an effect on PV array performance.

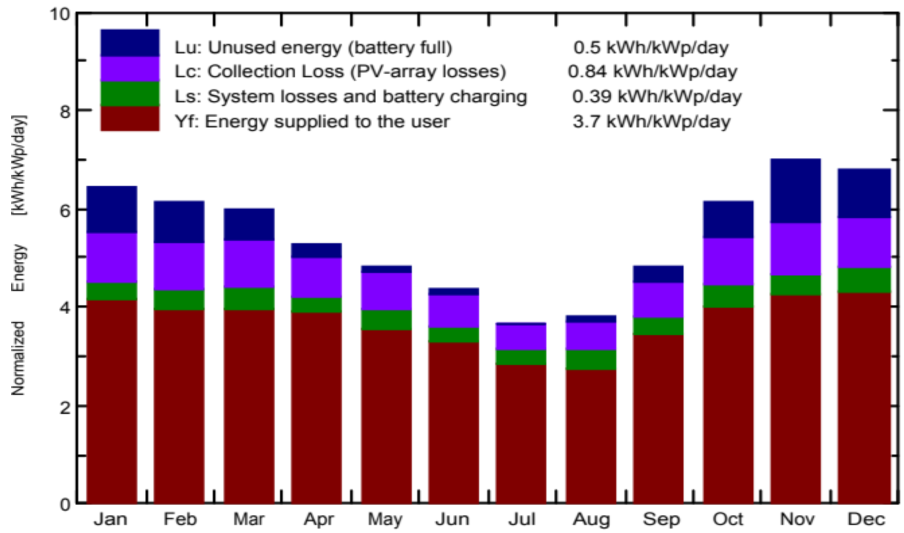

Figure 4. 1: Normalized Productions(per installed KWp)

4.1.5.1. The PV System Losses

The analysis result in the figure below shows that the collector plane received an effective irradiance of cells about 1938 kWh/m^2 of global incident radiation while the effectiveness plane receives the irradiances only at 1874 kWh/m^2. Even though the array nominal energy (at STC) of the system is 97,414kWh, the loss due to ambient temperature, solar incidence, manufactures mismatch, wiring and others; the effective energy at the output of the array is 77,686kWh. The energy missed (battery full cases) is 13,767.1 kWh, while 70,300kWh energy is supplied to the end users.

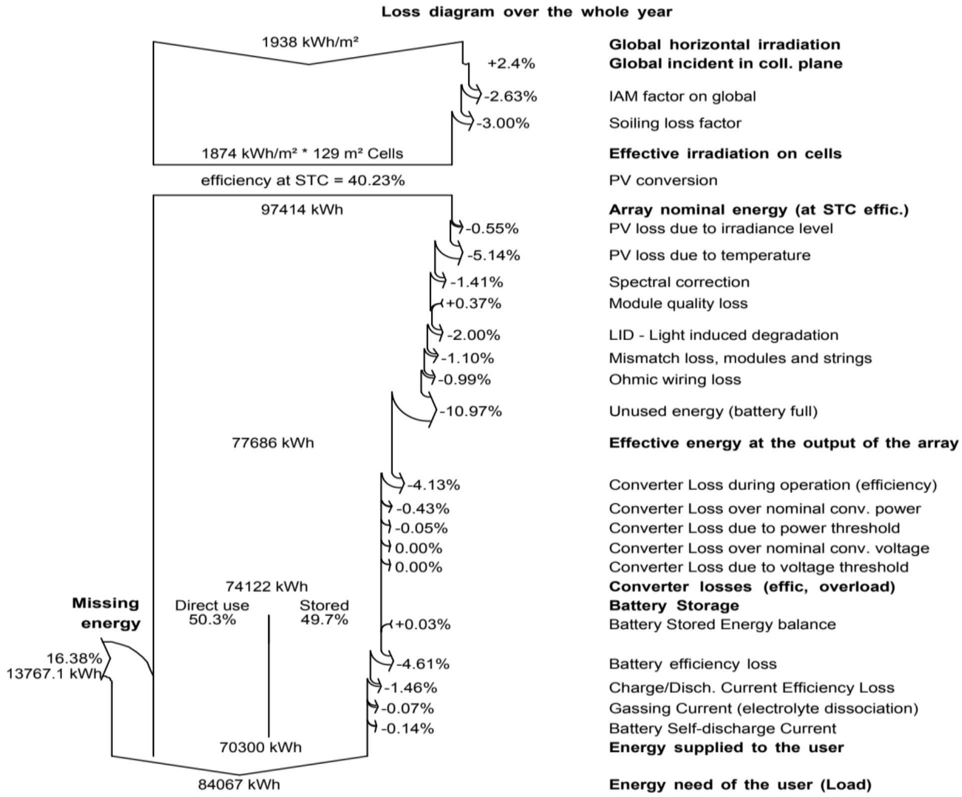

Figure 4. 2: Loss diagram for site over the whole year.

4.2. Multi-Purpose Solar PV Injera baking System Project

The main results obtained from PVsyt analysis are described below by system component type;

4.2.1. Solar Panels

Since solar panels are the only source of energy production for this project, they must deliver enough energy to satisfy the load demand of the community. The total amount of installed power to operate Indode site is 725kW; with total number of Solar Panels is 1,812 to cover the demanded energy supply. A single solar panel will cost 3,800 Birr, with an initial cost of 6,885,600 Birr for the total solar panels needed for the project.

The PVsyst analysis shows that each solar array will consist of 151 panel strings, each string has 12 panels arranged in series with the arrays passing through a DC combiner Box and then monitored by the MPPT. For every 48panels, a DC Combiner will be installed and connected to the MPPT tracker.

Technology	Unit PV nominal power	No of PV modules			Global array power, nominal(STC)	Power at operating condition (50°c)	Total Module area	Initial cost (Birr)
		Total	In series	In parallel				
Si-mono, 72 cells	400Wp	1812	12	151 strings	725kW	657kW	4062m^2	6,885,600

Table 4. 5: PV panel details

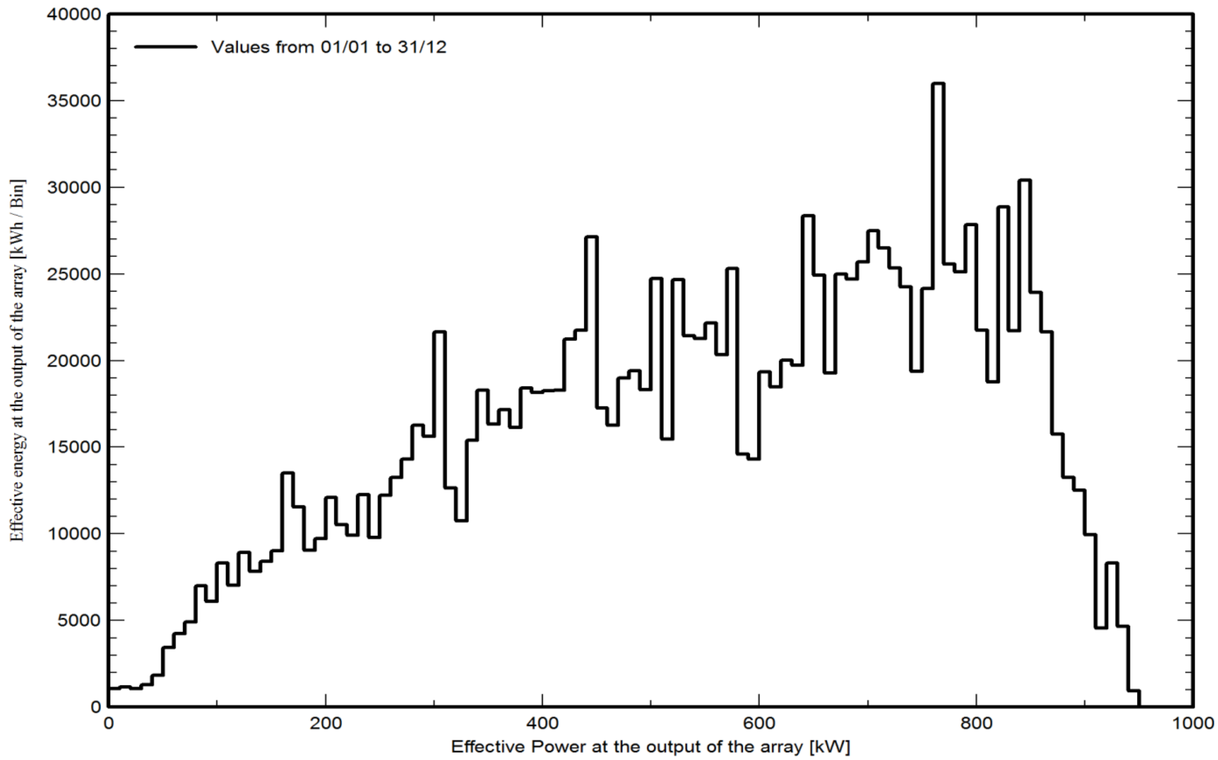

Figure 4. 3: Array Power distribution

4.2.2. Battery Bank

From the PVsyst analysis result, the total number of batteries required to fully secure and maintain the performance of Indode's solar PV system project is 1028, of which 4 batteries are connected in series and while 257 batteries are in parallel. The total storage capacity of the battery bank is 128,500Ah. Since it is assumed that the site shall not be cloudy more than a day, the autonomy of the battery is taken to be 24 hours. A single battery has 12V and the 4 batteries are arranged in parallel because their voltage will be summed to give the battery pack voltage, 48V.

Technology	Unit battery capacity	Battery bank capacity	No of batteries			Autonomy	Daily storage	Initial cost (Birr)
			Total	In series	In parallel			
Lead-acid, sealed	12V/ 500Ah	48V/ 128,500Ah	1028	4	257	24h	4934.4KWh	12,850,000

Table 4. 6: Battery bank details

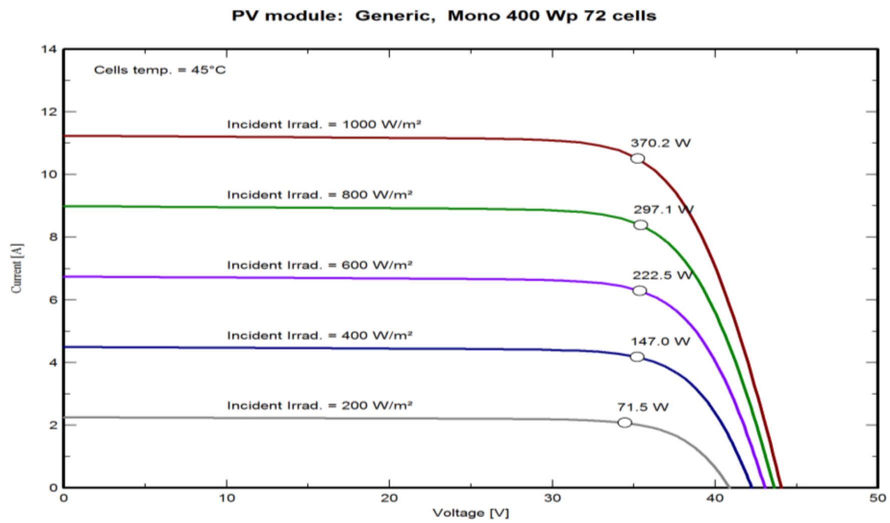

Figure 4. 4: Current Vs Voltage at different incid. Irra. values for a single PV module

The profile for this battery model has been created with PVSyst according to the manufacturer’s specifications to obtain the following graph, which shows different discharge times for different discharge currents.

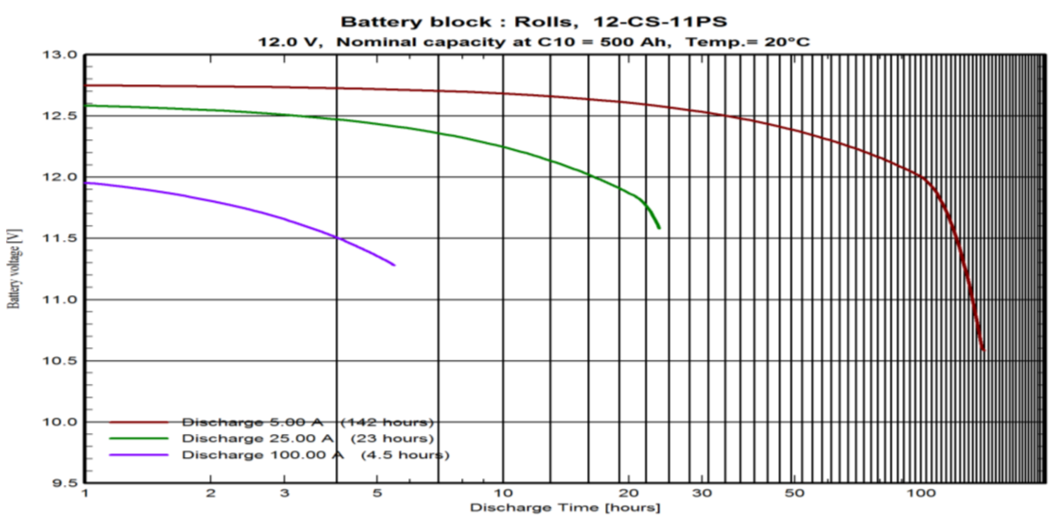

Figure 4. 5: Battery bank voltage Vs discharge time

4.2.3. Inverters

According to the manufacturer's data, the selected inverter has the following technical information:

Model	Sunny 15000TL inverter
Manufacturer	SMA Solar Technology
Maximum dc power	15000W
Maximum power point voltage range	360V-800V
Rated input voltage	600V
Minimum input voltage	150V
Maximum input current	40A/16A
Maximum efficiency	98.2%
Rated power	15000W at 230V 50Hz
Nominal AC voltage	220/380V

Table 4. 7: Selected Inverter data

The size of the selected inverter shall be 25%-30% bigger than the system power to satisfy the system requirements[14].

$$Inverter\ size = \frac{130\%\ of\ the\ system\ power}{100} = \frac{130 * 725Kw}{100} = 942.5KW$$

$$No\ of\ Inverters = \frac{inverter\ size}{Rated\ power\ of\ the\ inverter} = \frac{942500}{15000} = 62.83 \cong 63\ inverters$$

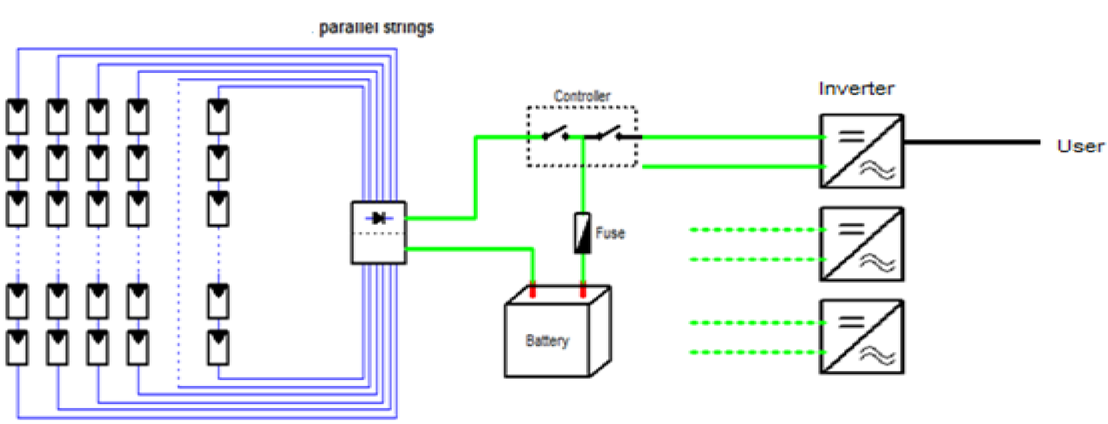

Figure 4. 6: Wiring layout from PVsyst

4.2.4. Summary of Sizing Results

s/no	System components	Description	Simulation Results
1	Estimated load		4926KWh/day
2	PV array	Type	Si-mono, 400Wp
		PV array capacity	725KW
		No of modules (in series)	12
		No of modules (in parallel)	151 strings
		Total no of modules	1812
3	Battery bank	Type	Lead-acid, sealed
		Battery bank capacity	48V/ 128,500Ah
		No of batteries (in series)	4
		No of batteries (in parallel)	257
		Total no of batteries	1028
4	MPP Charge controller	Type	Universal controller with MPPT convertor
		Capacity	MPPT 1000W,48V
		No of charge controllers	1
5	Inverter	Capacity	15KW
		No of inverters	63

Table 4. 8: Summary of sizing results

4.2.5. Analysis of Energy Production

The energy analysis of PVsyst software indicates that 76% of the energy produced from the system is supplied to the user while the contribution of the system and battery charging losses is 24%.

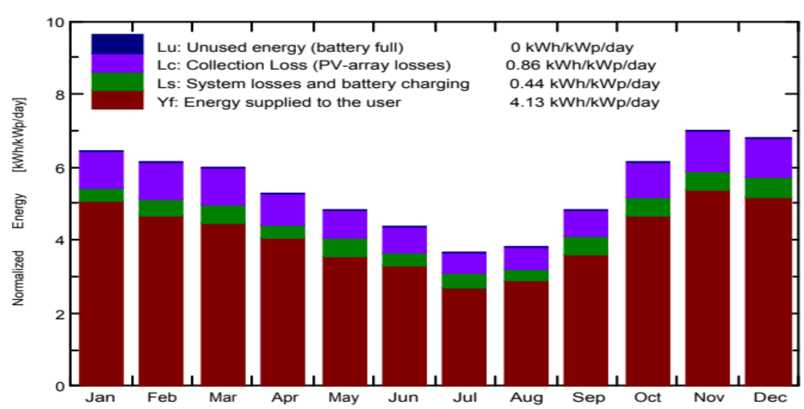

Figure 4. 7: Normalized Productions(per installed KWp)

4.2.5.1. The PV System Losses

In general, solar PV system failed to generate 100% of the energy delivered from the sun because of some losses occurred during operation of the system[27].The analysis result in the figure below illustrates the detail losses which occur in the designed solar PV system with the collector plane received an effective irradiance of cells about 1938 kWh/m^2 of global incident radiation while the effectiveness plane receives the irradiances only at 1874 kWh/m^2. Even though the array nominal energy (at STC) of the system is 1,357,796kWh, the loss due to ambient temperature, solar incidence, manufactures mismatch, wiring and others; the effective energy at the output of the array is 1,209,840kWh. Over the whole year, the energy missed (battery full cases) is 821,841 kWh, while 1,092,719kWh energy is supplied to the end users.

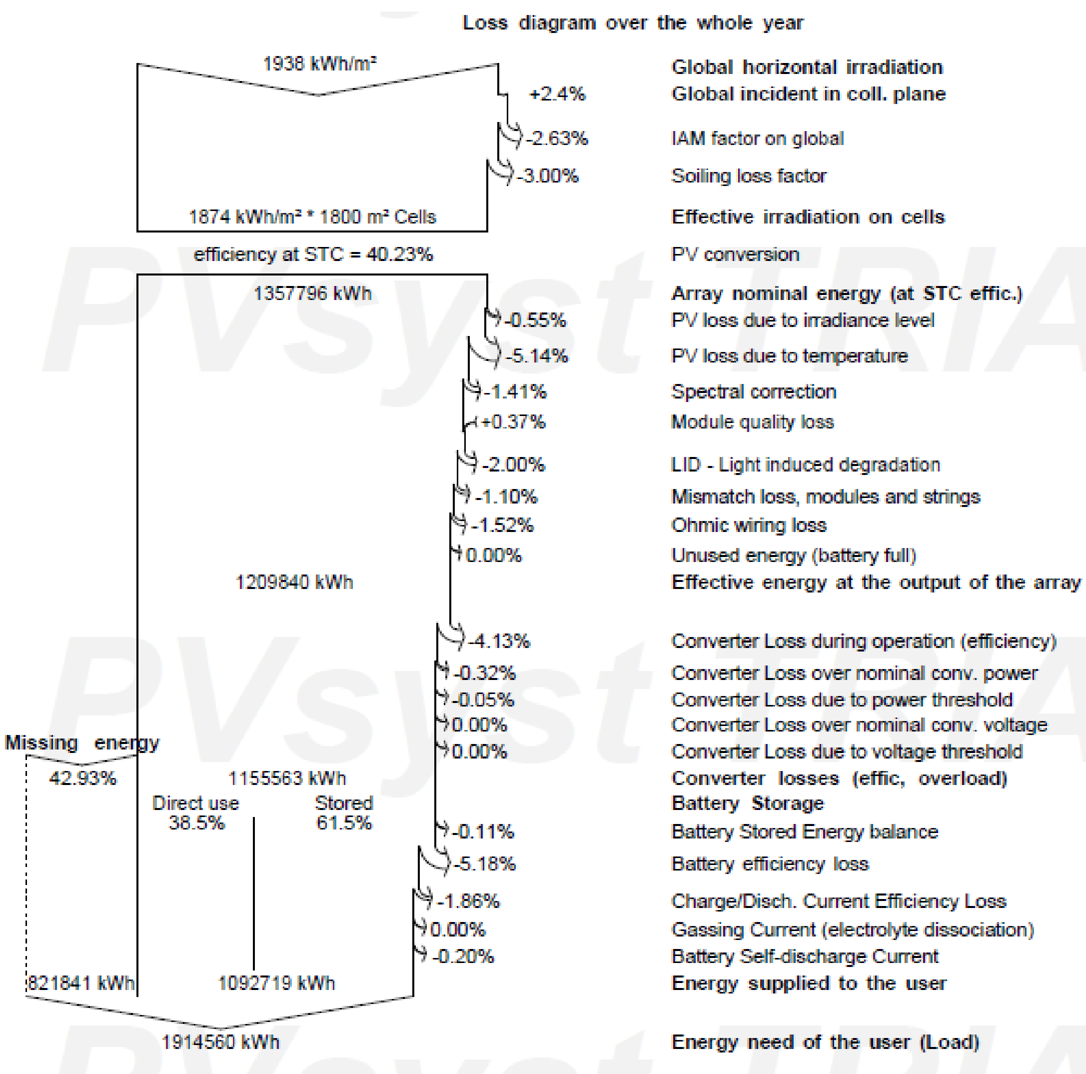

Figure 4. 8: Loss diagram for site over the whole year.

4.2.6. Project Area

Based on the simulation result of PVsyst software, a total of 1,812 panels are used for the solar PV system of Indode project and the total area needed for the installation is 4,062 m^2.

Chapter 5: Economic and Environmental Analysis

5.1.Economic Analysis for a single PV Powered Kitchen

The financial modeling is done to determine the proposed kitchen cost there by considering item procurement, installation and various fixed & operational costs incurred during its life and compared with the firewood cost considering the same baking activity.

5.1.1. Installation Costs

5.1.1.1. PV Modules

From the PVsyst analysis result we can understand that 130 PV modules are required to meet the energy need of Indode communities. These modules have a total purchasing cost of 494,000 Birr and the supports for each module costs a total of 65,000 Birr.

5.1.1.2. Battery Bank

The sizing analysis result shows that the battery bank should have 44 batteries with an initial investment cost of 550,000 Birr. According to the selected battery manufacturer, the battery bank should be replaced around every 12 years and this will have a provisional replacement cost of 45,833.33 Birr per year.

5.1.1.3. DC Combiners and Charge Controllers

A DC combiner is needed for every string. In order to install 150 solar panels, a universal Charge controller with MPPT converter is selected for the system. These devices usually have similar life span as the PV panels which have 25-years life span. Since the project's lifetime has been fixed in 25 years, no replacement costs shall be considered for combiners and charge controllers. The cost of the charge controls for the system is 15,000 Birr.

5.1.1.4. Inverter

The selected inverter must have 48 VDC, 220 VAC, and 50 Hz. From the current market assessment, the inverters will have a total cost of 52,500 Birr.

5.1.1.5. Hardware cost summary

The total cost of the hardware required for the solar PV system installed at Indode village is as described in the following table:

S/no	Hardware description	Total cost (Birr)	Remark
1	PV panel	494,000	
2	Inverter	52,500	
3	Charge controller	15,000	
4	Battery bank	550,000	
5	Module supports	65,000	
	Total cost	**1,176,500**	

Table 5. 1: Hardware cost summary

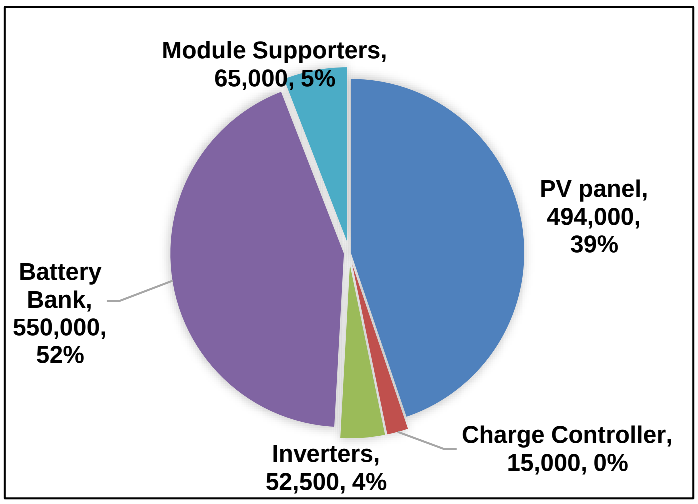

Figure 5. 1: Hardware cost distribution

5.1.2. Operating costs

Since maintenance for PV panels consists cleaning and which will be done by community member coordination and some experts, the PV panel cleaning service cost is not considered. Maintenance costs have not been planned for the PV panels but a technician will be hired with annual salary of 36,000 Birr to operate the system and do some corrective maintenance tasks. Collecting monthly bills and carrying out financial activities will be the responsibility of this person.

5.1.3. Cost of Energy and Economic Indicators

5.1.3.1.Levelized Cost of Energy

The PVsyst analysis result indicates that the LCOE of the single kitchen project is 1.16 Birr/kWh which indicates the electricity price that would equalize the lifetime cash flows over the 25-years lifetime of the kitchen.

Even though there is a different tariff set for residential use, low and high voltage industries and street lights, the recently amended energy tariff by Ethiopian Electric Utility shows that the general tariff (flat rate) will be 2.124 Birr/kWh per month with a service charge of 54 Birr(for a postpaid service) to be implemented as of December, 2021 and onwards[33]. Therefore, the simulation is done with the assumption that the electric tariff is 2.20 Birr/kWh (the minimum energy cost set for the PVsyst software analysis) at the beginning of the project operation and it increases by 15% every year.

5.1.3.2.Cash Flow

The cumulative cash flow of the kitchen throughout its 25 years of life-time is shown in Figure below. The project shall be economically feasible only if its overall earnings exceed its overall costs within a time period up to the lifetime of the system. The PVsyst generated cumulative cash flow graph indicates that the overall earnings are exceeding the overall cost of the project during its life span. The yearly net profit graph describes that there is an increase in profit from the beginning of the project operation to the year 2037, but a decrease in profit from 2034 to the end of the project life time due to battery bank replacement costs.

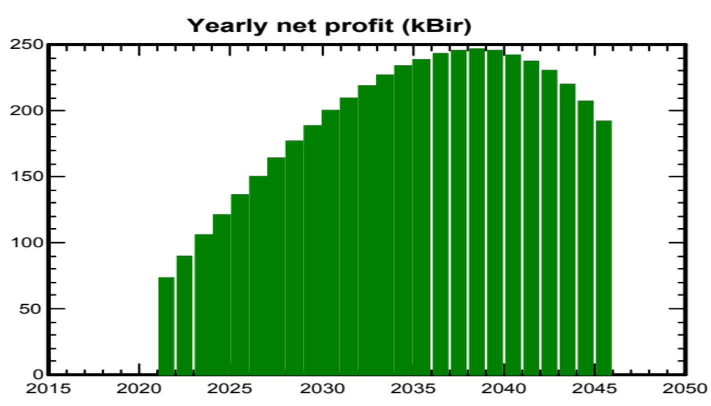

Figure 5. 2: Yearly net profit(kBirr)

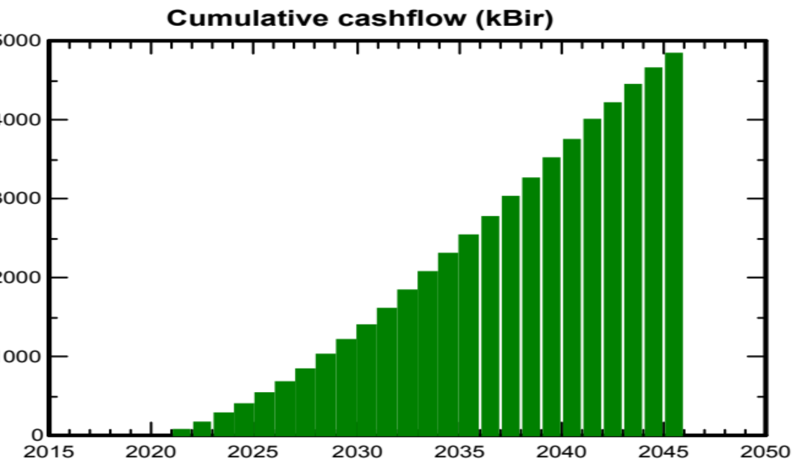

Figure 5. 3: Cumulative cash flow(kBirr)

5.1.3.3.Payback period

The PVsyst economic analysis result shows that the cost of the single kitchen project installation is 1,176,500Birr and will have a pay-back time of 8.8 years. This means that the earnings of the kitchen will never exceed the investment cost in this years and the pay back is acceptable for a 25-year lifetime kitchen.

Detailed economic results (Bir)

	Run. costs	Self-cons. saving	Cumul. profit	% amorti.
2021	81'833	154'660	72'826	6.2%
2022	88'380	177'858	162'305	13.8%
2023	95'450	201'057	267'912	22.8%
2024	103'086	224'256	389'082	33.1%
2025	111'333	247'455	525'204	44.6%
2026	120'240	270'654	675'618	57.4%
2027	129'859	293'853	839'612	71.4%
2028	140'248	317'052	1'016'416	86.4%
2029	151'468	340'251	1'205'199	102.4%
2030	163'585	363'450	1'405'064	119.4%
2031	176'672	386'649	1'615'041	137.3%
2032	190'806	409'848	1'834'083	155.9%
2033	206'070	433'047	2'061'060	175.2%
2034	222'556	456'246	2'294'749	195.0%
2035	240'360	479'445	2'533'834	215.4%
2036	259'589	502'644	2'776'888	236.0%
2037	280'356	525'843	3'022'374	256.9%
2038	302'785	549'041	3'268'631	277.8%
2039	327'008	572'240	3'513'864	298.7%
2040	353'168	595'439	3'756'135	319.3%
2041	381'422	618'638	3'993'352	339.4%
2042	411'935	641'837	4'223'253	359.0%
2043	444'890	665'036	4'443'399	377.7%
2044	480'481	688'235	4'651'153	395.3%
2045	518'920	711'434	4'843'667	411.7%
Total	**5'982'503**	**10'826'169**	**4'843'667**	**411.7%**

Table 5. 2**:** Detailed Economic Analysis

5.1.3.4. Net Present Value and Return on Investment

With the assumption that the kitchen project has no initial investment and pay-back time restrictions, the Net Present Value (NPV) and Return On Investment(ROI) the single kitchen are shown below. Therefore, the project shall be accomplished as long as NPV value is positive to assure its economic viability. From the PVsyst analysis result, the NPV of the project is 4,843,554.85 Birr and it is positive. This assures us that the project is financially wise to implement it for Indode's community. The ROI of the project is 411.7% and it is higher than the expected inflation rate (8% per year) assumed for the simulation.

Economic indicator	**Result**
NPV	4,843,554.85 Birr
ROI	411.7%

Table 5. 3:Economic indicators

5.1.3.5. Performance Ratio (PR)

The PVsyst simulation result (as indicated in table below) shows that the average monthly performance ratio (PR) of the system is 68.1% and 31.9% the energy produced is lost due to different system losses. Literature reviews show that the accepted range of performance ratio of solar PV systems is from 60% to 90%[34][35][36]. Thus, the performance ratio (68.1%) of the kitchen is within the accepted range.

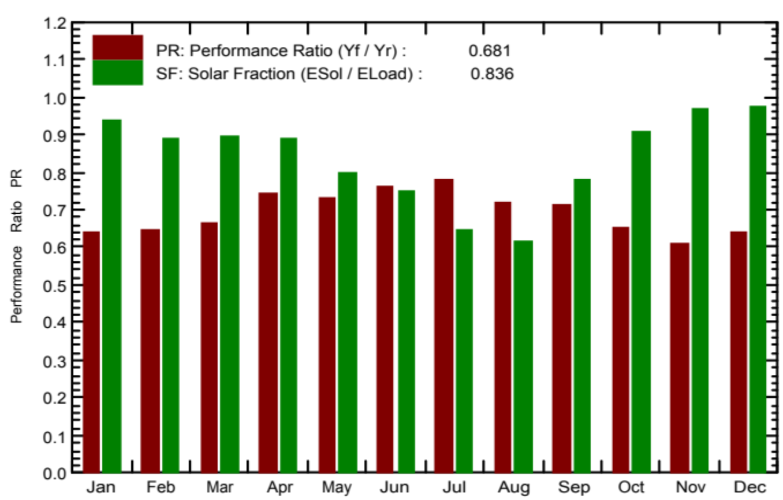

Figure 5. 4: Performance Ratio(PR)

5.1.4. Cost Comparison between Firewood and Single solar PV powered Kitchen

5.1.4.1. Firewood as Energy Source for Injera Baking

Indode's community use fuelwood to bake Injera. A single Injera with an average diameter of 52 cm weights 310 g [30]. Researchers conducted a study on specific fuelwood consumption of different Injera baking methods and determined that the average specific fuel consumption of three-stone open fire, Mirt stove, Gonziye, Awuramba , Sodo is 929 g, 535g, 617 g, 573 g, 900 g/kg of Injera, respectively [30]. Market assessment of fuelwood current price was carried out taking five packs of Eucalyptus firewood from the market and weighed to get the price of Eucalyptus in terms of kilograms. The average Eucalyptus firewood price is found to be 5.20 Birr /kg. The table below shows that the operation of a single community kitchen which uses three stone- open fire Method, Mirt stove, Gonzie stove, Awuramba stove, Sodo stove will be 84,204.53, 97,110.65, 90,185.42, 97,110.65, 146,216.84 Birr/year, respectively. Assuming 8% price inflation/year and 25 years of service life for the community kitchen, the estimated average annual fuelwood cost for operation of Mirt Stove, Auramba Stove, Gonze Stove, Sodo Stove, Open Fire Method is 246,234.06, 260,116.17, 283,974.61, 414,225.52, 427,572.79 Birr, respectively.

Type of Mitad/baking method	Aver. Spec. fuelwood consumption (g/kg of Injera)	Total no of Injera /day/ Kitchen	Weight of a single Injera (kg)	Total weight of Injera/ day/ kitchen (kg)	Amount of wood needed /day /kitchen(kg)	Price of fire wood per Kg (Birr)	Total Price of wood consumed/ day/ Kitchen (Birr)	Total Wood Consumed/ year/Kitchen (Birr)
Three stone- open fire Method	929	267.5	0.31	82.925	77.04	5.2	400.59	146,216.84
Mirt stove	535	267.5	0.31	82.925	44.36	5.2	230.70	84,204.53
Gonzie stove	617	267.5	0.31	82.925	51.16	5.2	266.06	97,110.65
Awuramba stove	573	267.5	0.31	82.925	47.52	5.2	247.08	90,185.42
Sodo stove	900	267.5	0.31	82.925	74.63	5.2	388.09	141,652.49

Table 5. 4:Yearly Fuelwood Consumption for a Single Kitchen by Baking Method

year	Estimated Yearly Cost(Birr)				
	Mirt Stove	**Auramba**	**Gonze**	**Sodo**	**Open Fire**
2021	84,204.53	90,185.42	97,110.65	141,652.49	146,216.84
2022	90,940.90	97,400.25	104,879.50	152,984.68	157,914.19
2023	98,216.17	105,192.27	113,269.86	165,223.46	170,547.33
2024	106,073.46	113,607.65	122,331.45	178,441.34	184,191.11
2025	114,559.34	122,696.26	132,117.96	192,716.64	198,926.40
2026	123,724.08	132,511.96	142,687.40	208,133.97	214,840.51
2027	133,622.01	143,112.92	154,102.39	224,784.69	232,027.75
2028	144,311.77	154,561.95	166,430.59	242,767.47	250,589.97
2029	155,856.71	166,926.91	179,745.03	262,188.86	270,637.17
2030	168,325.25	180,281.06	194,124.63	283,163.97	292,288.15
2031	181,791.27	194,703.55	209,654.61	305,817.09	315,671.20
2032	196,334.57	210,279.83	226,426.97	330,282.46	340,924.89
2033	212,041.34	227,102.22	244,541.13	356,705.05	368,198.88
2034	229,004.65	245,270.40	264,104.42	385,241.46	397,654.79
2035	247,325.02	264,892.03	285,232.78	416,060.78	429,467.18
2036	267,111.02	286,083.39	308,051.40	449,345.64	463,824.55
2037	288,479.90	308,970.06	332,695.51	485,293.29	500,930.52
2038	311,558.29	333,687.67	359,311.15	524,116.75	541,004.96
2039	336,482.95	360,382.68	388,056.04	566,046.09	584,285.36
2040	363,401.59	389,213.29	419,100.53	611,329.78	631,028.18
2041	392,473.72	420,350.36	452,628.57	660,236.16	681,510.44
2042	423,871.62	453,978.38	488,838.85	713,055.05	736,031.27
2043	457,781.35	490,296.66	527,945.96	770,099.46	794,913.78
2044	494,403.85	529,520.39	570,181.64	831,707.42	858,506.88
2045	533,956.16	571,882.02	615,796.17	898,244.01	927,187.43
	6,155,851.51	**6,502,904.15**	**7,099,365.21**	**10,355,638.06**	**10,689,319.73**
Average	**246,234.06**	**260,116.17**	**283,974.61**	**414,225.52**	**427,572.79**

Table 5. 5: Lifecycle Fuelwood Cost by Baking Method

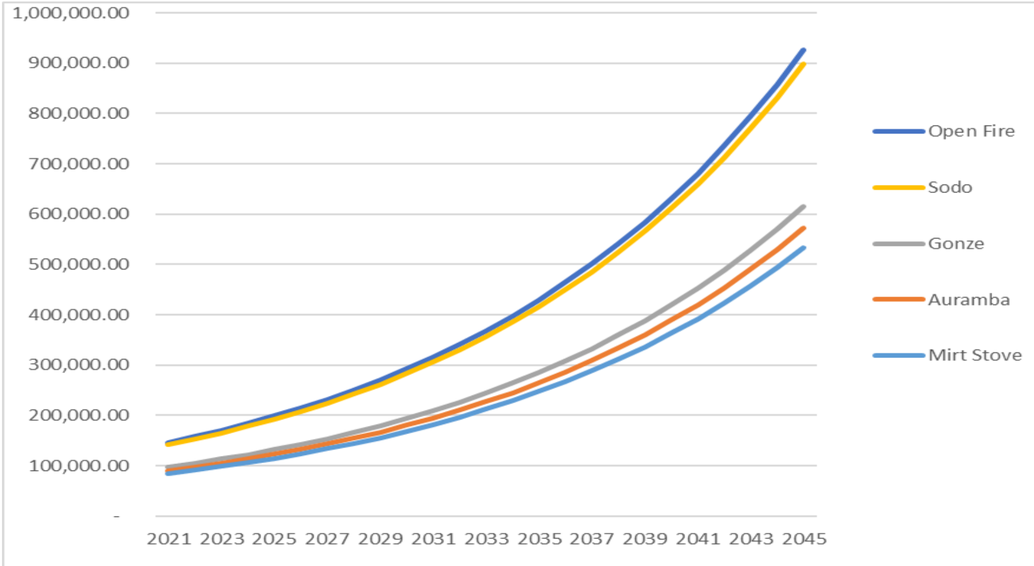

Figure 5. 5: Lifecycle Fuelwood Cost By Baking Method

5.1.4.2. Cost Comparison between Fuel Wood and Solar PV installation

The PVsyst simulation result shows that the average annual operational cost for a single solar PV powered kitchen is 239,300.31 Birr and the estimated average annual fuel wood cost for Mirt Stove, Auramba Stove, Gonze Stove, Sodo Stove, Open Fire Method is 246,234.06, 260,116.17, 283,974.61, 414,225.52, 427,572.79 Birr respectively which are much higher than the cost of PV system operation cost. Figure 4.17 shows that Mirt Stove is lowest to consume fuelwood than the other stove types, but the solar PV powered kitchen is still the power source with the lest annual average operational cost of all energy sources.

year	Estimated Yearly Cost(Birr)					
	Mirt Stove	Auramba	Gonze	Sodo	Open Fire	Solar PV Kitchen
2021	84,204.53	90,185.42	97,110.65	141,652.49	146,216.84	81,833.40
2022	90,940.90	97,400.25	104,879.50	152,984.68	157,914.19	88,380.07
2023	98,216.17	105,192.27	113,269.86	165,223.46	170,547.33	95,450.48
2024	106,073.46	113,607.65	122,331.45	178,441.34	184,191.11	103,086.52
2025	114,559.34	122,696.26	132,117.96	192,716.64	198,926.40	111,333.44
2026	123,724.08	132,511.96	142,687.40	208,133.97	214,840.51	120,240.11
2027	133,622.01	143,112.92	154,102.39	224,784.69	232,027.75	129,859.32
2028	144,311.77	154,561.95	166,430.59	242,767.47	250,589.97	140,248.07
2029	155,856.71	166,926.91	179,745.03	262,188.86	270,637.17	151,467.91
2030	168,325.25	180,281.06	194,124.63	283,163.97	292,288.15	163,585.35
2031	181,791.27	194,703.55	209,654.61	305,817.09	315,671.20	176,672.17
2032	196,334.57	210,279.83	226,426.97	330,282.46	340,924.89	190,805.95
2033	212,041.34	227,102.22	244,541.13	356,705.05	368,198.88	206,070.42
2034	229,004.65	245,270.40	264,104.42	385,241.46	397,654.79	222,556.06
2035	247,325.02	264,892.03	285,232.78	416,060.78	429,467.18	240,360.54
2036	267,111.02	286,083.39	308,051.40	449,345.64	463,824.55	259,589.38
2037	288,479.90	308,970.06	332,695.51	485,293.29	500,930.52	280,356.53
2038	311,558.29	333,687.67	359,311.15	524,116.75	541,004.96	302,785.06
2039	336,482.95	360,382.68	388,056.04	566,046.09	584,285.36	327,007.86
2040	363,401.59	389,213.29	419,100.53	611,329.78	631,028.18	353,168.49
2041	392,473.72	420,350.36	452,628.57	660,236.16	681,510.44	381,421.97
2042	423,871.62	453,978.38	488,838.85	713,055.05	736,031.27	411,935.73
2043	457,781.35	490,296.66	527,945.96	770,099.46	794,913.78	444,890.59
2044	494,403.85	529,520.39	570,181.64	831,707.42	858,506.88	480,481.83
2045	533,956.16	571,882.02	615,796.17	898,244.01	927,187.43	518,920.38
Total	**6,155,851.51**	**6,502,904.15**	**7,099,365.21**	**10,355,638.06**	**10,689,319.73**	**5,982,507.63**
Average	**246,234.06**	**260,116.17**	**283,974.61**	**414,225.52**	**427,572.79**	**239,300.31**

Table 5. 6: Estimated Lifecycle Cost Comparison By Energy Source.

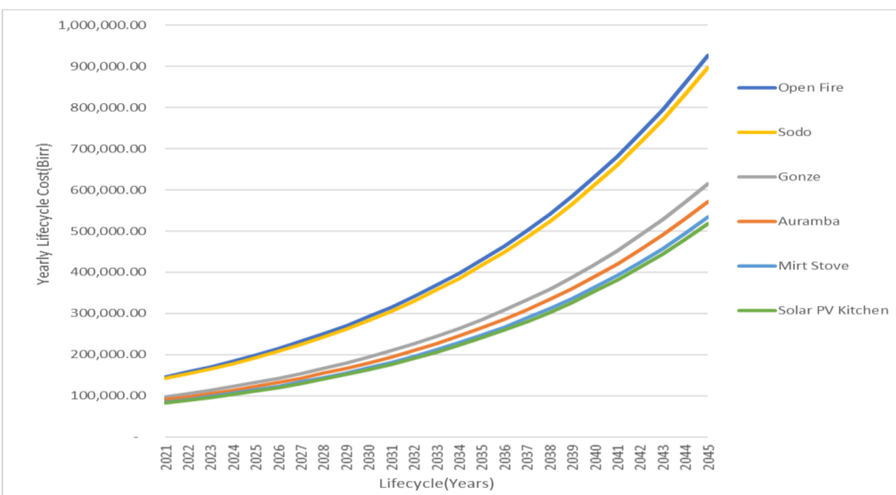

Figure 5. 6: Estimated Lifecycle Cost Comparison By Energy Source.

5.2. Economic Analysis for Multi-purpose PV powered Injera Baking System Project

The financial modeling of the multi-purpose solar PV Injera baking system project for Indode's community is carried out to determine the proposed project cost there by considering item procurement, installation and various fixed & operational costs incurred during its life and compared with the firewood cost considering the same baking activity.

Firewood has costs, while the costs related to the PV power generation are almost zero; only the initial investment is put in to consideration of component costs such as purchase of PV modules, MPPT, Inverter, battery, DC combiner, wiring and supports with the addition of other direct costs such as installation, labor and transportation costs. Moreover, Increasing solar energy utilization capacity involves reducing fossil fuel generation and consequently reduces operating costs and greenhouse gases emissions [32].

Because of requirement of high project cost, off-grid PV systems for rural population require policy intervention; in other words, allocating public funds for covering both the initial investment and the operation & maintenance cost of the systems or a subsidizing mechanism for rural electrification which can promote local economic development. Due to lack of experienced local expertise, other prior technological experiences in remote areas have shown that productive uses of off-grid PV systems require government programs, offering co-operation and training to enhance the reliability of the systems for their sustainability[10].

5.2.1. Installation Costs

5.2.1.1. PV Modules

From the PVsyst analysis result we can understand that 1,812PV modules are required to meet the energy need of Indode communities. These modules have a total purchasing cost of 6,885,600Birr and the supports for each module costs a total of 906,000 Birr.

5.2.1.2. Battery Bank

The sizing analysis result shows that the battery bank should have 1,028 batteries with an initial investment cost of 12,850,000 Birr. According to the selected battery manufacturer, the battery bank should be replaced around every 12 years and this will have a provisional replacement cost of 1,070,833.33 Birr per year.

5.2.1.3. DC Combiners and Charge Controllers

A DC combiner is needed for every string. In order to install 1,812 solar panels, a universal Charge controller with MPPT converter is selected for the system. These devices usually have similar life span as the PV panels which have 25-years life span. Since the project's lifetime has been fixed in 25 years, no replacement costs shall be considered for combiners and charge controllers. The cost of the charge controls for the system is 25,000 Birr.

5.2.1.4. Inverter

The selected inverter must be able to handle the maximum expected power of AC loads and the specifications (discussed under 4.2.3) of the required inverter are 48 VDC, 220 VAC, and 50 Hz. From the current market assessment, the inverters will have a total cost of 661,500 Birr.

5.2.1.5. Hardware cost summary

The total cost of the hardware required for the solar PV system installed at Indode village is as described in Table 5.7:

S/no	Hardware description	Total cost (Birr)	Remark
1	PV panel	6,885,600	
2	Inverter	661,500	
3	Charge controller	25,000	
4	Battery bank	12,850,000	
5	Module supports	906,000	
	Total cost	**21,328,100**	

Table 5. 7: Hardware cost summary

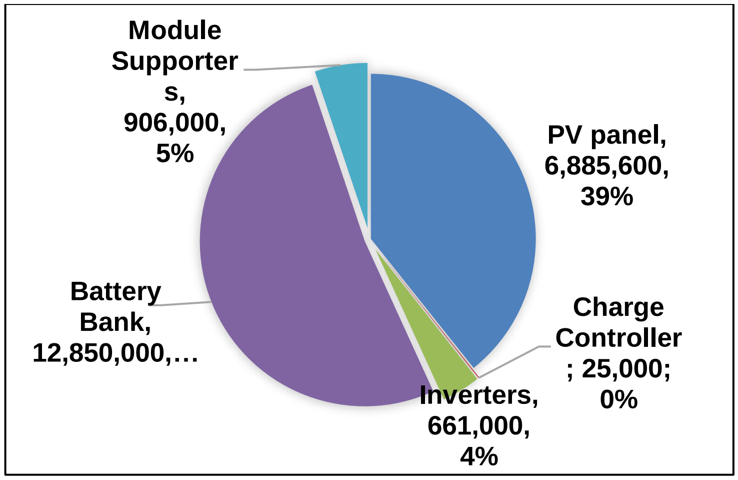

Figure 5. 7: Hardware cost distribution

5.2.2. Operating costs

Since maintenance for PV panels consists cleaning and which will be done by community members coordination and some experts, the PV panel cleaning service cost is not considered. Maintenance costs have not been planned for the PV panels but a technician will be hired with annual salary of 36,000 Birr to operate the system and do some corrective maintenance tasks. To collect monthly bills and carryout financial activities, accounting personnel is required. The accountant is also responsible for administration activities and he/she will be paid an annual salary of 36,000 Birr.

5.2.3. Cost of Energy and Economic Indicators

5.2.3.1. Levelized Cost of Energy

The assessment of the economic lifetime energy production cost shall be conducted; and this cost denoted as the Levelized Cost of Energy (LCOE) which allows energy produced to be compared with other alternatives[37].

$$\text{LCOE} = \frac{\text{Total Life Cycle Cost}}{\text{Total life time Energy Production}}$$

The PVsyst analysis result indicates that the LCOE of the project is1.05 Birr/kWh which indicates the electricity price that would equalize the lifetime cash flows over the 25-years lifetime of the solar PV project.

Even though there is a different tariff set for residential use, low and high voltage industries and street lights, the recently amended energy tariff by Ethiopian Electric Utility shows that the general tariff (flat rate) will be 2.124 Birr/KWh per month with a service charge of 54 Birr(for a postpaid service) to be implemented as of December, 2021 and onwards[33]. The simulation is done with the assumption that the electric tariff is 2.20Birr/kWh (the minimum energy cost set for the PVsyst software analysis) at the beginning of the project operation and it increases by 10% every year.

5.2.3.2. Cash Flow

The cumulative cash flow of Indode's solar PV system throughout its 25 years of life-time is shown in Figure below. The project shall be economically feasible only if its overall earnings exceed its overall costs within a time period up to the lifetime of the system. The PVsyst generated cumulative cash flow graph indicates that the overall earnings are exceeding the overall cost of the project during its life span. The yearly net profit graph describes that there is an increase in profit from the beginning of the project operation to the year 2038, but a decrease in profit from 2038 to the end of the project life time due to battery bank replacement costs.

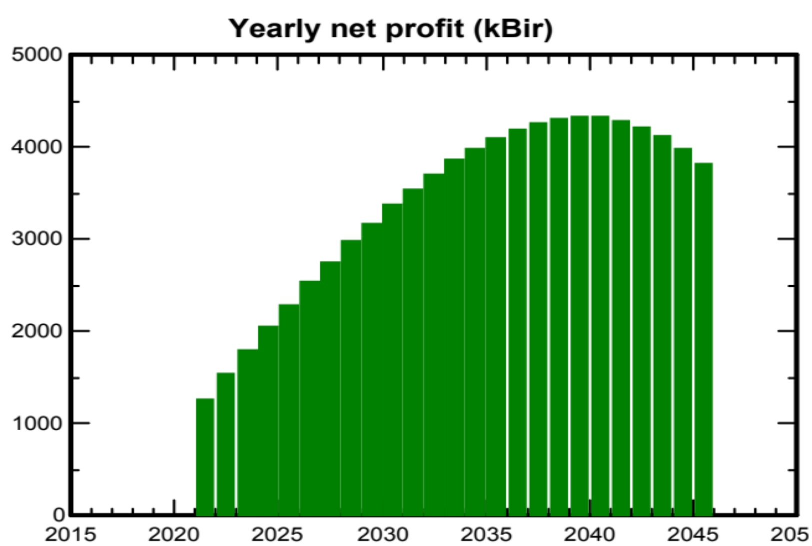

Figure 5. 8: Yearly net profit(kBirr)

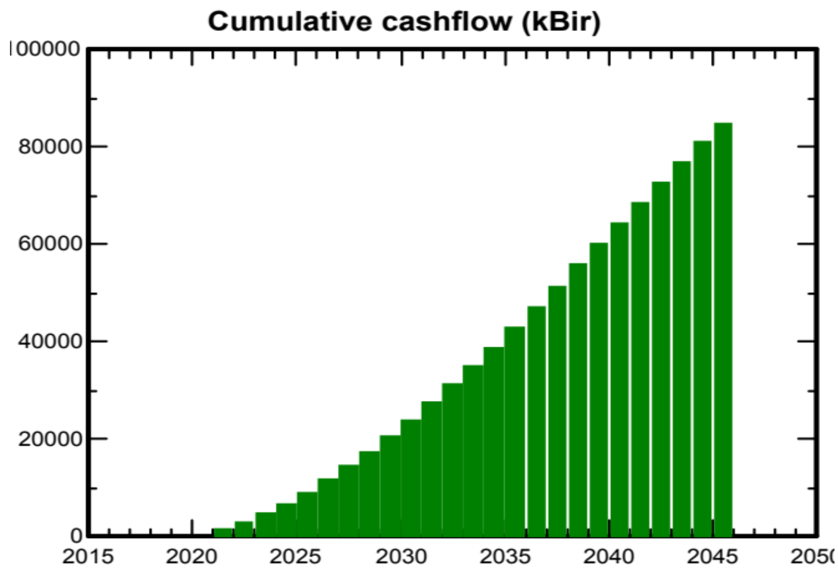

Figure 5. 9: Cumulative cash flow(kBirr)

5.2.3.3. Payback period

The payback period of a project is usually defined as the duration for which the project is capable of generating revenue from its production to the meet the cost of investment. The relatively large initial cost means that in this period earnings will never exceed the costs. The PVsyst economic analysis result shows that the cost of the solar PV project installation is 21,328,100Birr and the solar PV system of Indode's village site will have a pay-back time of 9.3 years. This means that the earnings of the project will never exceed the investment cost in this years and the pay back of the project is acceptable for a 25-year lifetime project.

Detailed economic results (Bir)

	Run. costs	Self-cons. saving	Cumul. profit	% amorti.
2021	1'142'833	2'403'984	1'261'151	5.9%
2022	1'234'260	2'764'582	2'791'473	13.1%
2023	1'333'001	3'125'180	4'583'652	21.5%
2024	1'439'641	3'485'777	6'629'788	31.1%
2025	1'554'812	3'846'375	8'921'351	41.8%
2026	1'679'197	4'206'973	11'449'126	53.7%
2027	1'813'533	4'567'570	14'203'164	66.6%
2028	1'958'615	4'928'168	17'172'716	80.5%
2029	2'115'305	5'288'765	20'346'177	95.4%
2030	2'284'529	5'649'363	23'711'011	111.2%
2031	2'467'291	6'009'961	27'253'680	127.8%
2032	2'664'675	6'370'558	30'959'564	145.2%
2033	2'877'849	6'731'156	34'812'871	163.2%
2034	3'108'077	7'091'754	38'796'548	181.9%
2035	3'356'723	7'452'351	42'892'177	201.1%
2036	3'625'261	7'812'949	47'079'865	220.7%
2037	3'915'281	8'173'547	51'338'131	240.7%
2038	4'228'504	8'534'144	55'643'771	260.9%
2039	4'566'784	8'894'742	59'971'729	281.2%
2040	4'932'127	9'255'340	64'294'941	301.5%
2041	5'326'697	9'615'937	68'584'181	321.6%
2042	5'752'833	9'976'535	72'807'883	341.4%
2043	6'213'060	10'337'133	76'931'956	360.7%
2044	6'710'104	10'697'730	80'919'582	379.4%
2045	7'246'913	11'058'328	84'730'997	397.3%
Total	**83'547'905**	**168'278'902**	**84'730'997**	**397.3%**

Table 5. 8: Detailed Economic Analysis

5.2.3.4. Net Present Value and Return on Investment

The two most economic indicators, the Net Present Value (NPV) and Return On Investment (ROI) of Indode solar PV system are shown below in the table based on the cash-flow illustrated in section 5.2.3.2. During the analysis, it is assumed that the project has no initial investment and pay-back time restrictions. Therefore, the project shall be accomplished as long as NPV value is positive to assure its economic viability. From the PVsyst analysis result, the NPV of the project is 84,730,977.18 Birr and it is positive. This assures us that the project is financially wise to implement it for Indode's community. The ROI of the project is 397.3% and it is higher than the expected inflation rate (8% per year) assumed for the simulation.

Economic indicator	Result
NPV	84,730,977.18
ROI	397.3%

Table 5. 9:Economic Indicators

5.2.3.5. Performance Ratio (PR)

The performance ratio (PR) of a solar PV system is a non-dimensional and the key parameter to determine the level of the availability of the system[38][23]. The PVsyst simulation result (as indicated in table below) shows that the average monthly performance ratio(PR) of the system is 76% and 24% the energy produced is lost due to different system losses. Literature reviews show that the accepted range of performance ratio of solar PV systems is from 60% to 90%[34][35][36]. Thus, the performance ratio (76%) of Indode's solar PV project is within the accepted range.

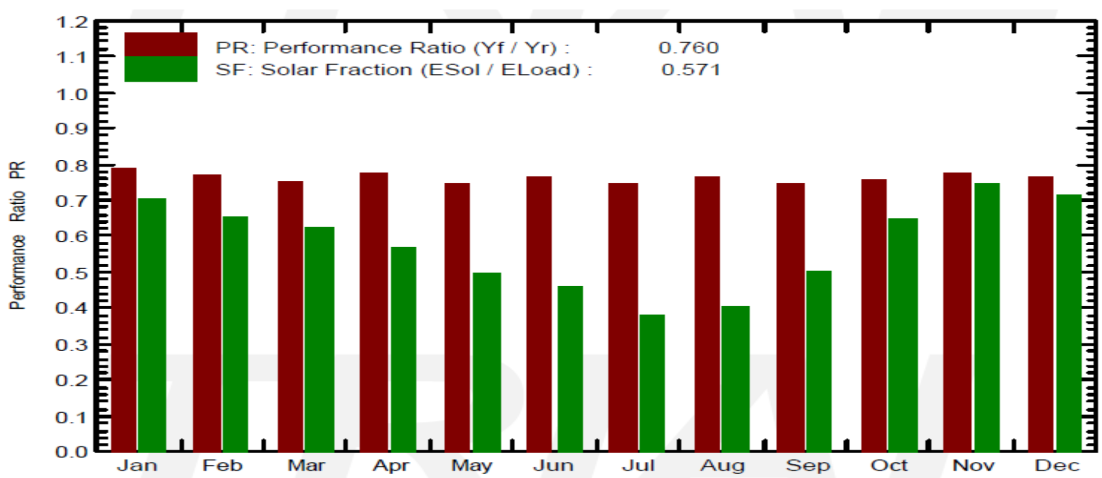

Figure 5. 10: Performance Ratio(PR)

5.2.4. Cost Comparison between Fuelwood and Solar PV System Project

5.2.4.1. Firewood as Energy Source for Injera Baking

Since Indode's community use fuelwood to bake Injera, the amount of fuel needed in a year and its cost has to be determined to study the economic viability. Studies by researchers prove that the specific fuelwood consumption of different Injera baking methods and determined that the average specific fuel consumption of three-stone open fire, Mirt stove, Gonziye, Awuramba , Sodo is 929 g, 535g, 617 g, 573 g, 900 g/kg of Injera, respectively [30]; and a single Injera with an average diameter of 52 cm weights 310 g [30]. The market assessment result gave us that the average Eucalyptus firewood price is 5.20 Birr /kg. Assuming that the whole community uses the same stove type, the analysis result showed us that the initial annual fuel wood cost if the community uses three stone- open fire Method, Mirt stove, Gonzie stove, Awuramba stove, Sodo stove will be 842,045.33, 901,854.15, 971,106.48, 1,416,524.85, 1,462,168.43 Birr/year, respectively, as shown in table 5.11. With assumption that the community operates the 10 kitchens using fuelwood and 8% fuelwood price inflation/year and projecting the estimation for 25 years, the average annual fuelwood cost for Mirt Stove, Auramba Stove, Gonze Stove, Sodo Stove, Open Fire Method is 2,462,340.61, 2,601,161.66, 2,839,746.08, 4,142,255.23, 4,275,727.89 Birr, respectively.

Type of Mitad/baking method	Aver. Spec. fuelwood consumption (g/kg of Injera)	Total no of Injera /day	Weight of a single Injera (kg)	Total weight of Injera/day (kg)	Amount of wood needed/ day(kg)	Price of fire wood per Kg (Birr)	Total Price of wood consumed/ day(Birr)	Total Wood Consumed/ year(Birr)
Three stone- open fire Method	929	2675	0.31	829.25	770.37	5.2	4005.94	1,462,168.43
Mirt stove	535	2675	0.31	829.25	443.65	5.2	2306.97	842,045.33
Gonzie stove	617	2675	0.31	829.25	511.65	5.2	2660.57	971,106.48
Awuramba stove	573	2675	0.31	829.25	475.16	5.2	2470.83	901,854.15
Sodo stove	900	2675	0.31	829.25	746.33	5.2	3880.89	1,416,524.85

Table 5. 10: Yearly Fuelwood Consumption of the Community by Baking Method

year	Estimated Yearly Cost(Birr)				
	Mirt Stove	Auramba	Gonze	Sodo	Open Fire
2021	842,045.33	901,854.15	971,106.48	1,416,524.85	1,462,168.43
2022	909,408.95	974,002.49	1,048,795.00	1,529,846.84	1,579,141.90
2023	982,161.67	1,051,922.69	1,132,698.60	1,652,234.59	1,705,473.26
2024	1,060,734.60	1,136,076.50	1,223,314.49	1,784,413.35	1,841,911.12
2025	1,145,593.37	1,226,962.62	1,321,179.65	1,927,166.42	1,989,264.00
2026	1,237,240.84	1,325,119.63	1,426,874.02	2,081,339.73	2,148,405.13
2027	1,336,220.11	1,431,129.20	1,541,023.94	2,247,846.91	2,320,277.54
2028	1,443,117.72	1,545,619.54	1,664,305.85	2,427,674.67	2,505,899.74
2029	1,558,567.14	1,669,269.10	1,797,450.32	2,621,888.64	2,706,371.72
2030	1,683,252.51	1,802,810.63	1,941,246.35	2,831,639.73	2,922,881.45
2031	1,817,912.71	1,947,035.48	2,096,546.06	3,058,170.91	3,156,711.97
2032	1,963,345.72	2,102,798.32	2,264,269.74	3,302,824.58	3,409,248.93
2033	2,120,413.38	2,271,022.18	2,445,411.32	3,567,050.55	3,681,988.84
2034	2,290,046.45	2,452,703.96	2,641,044.22	3,852,414.59	3,976,547.95
2035	2,473,250.17	2,648,920.27	2,852,327.76	4,160,607.76	4,294,671.79
2036	2,671,110.18	2,860,833.89	3,080,513.98	4,493,456.38	4,638,245.53
2037	2,884,799.00	3,089,700.61	3,326,955.10	4,852,932.89	5,009,305.17
2038	3,115,582.91	3,336,876.65	3,593,111.51	5,241,167.52	5,410,049.58
2039	3,364,829.55	3,603,826.79	3,880,560.43	5,660,460.92	5,842,853.55
2040	3,634,015.91	3,892,132.93	4,191,005.27	6,113,297.80	6,310,281.84
2041	3,924,737.18	4,203,503.56	4,526,285.69	6,602,361.62	6,815,104.38
2042	4,238,716.16	4,539,783.85	4,888,388.54	7,130,550.55	7,360,312.73
2043	4,577,813.45	4,902,966.56	5,279,459.63	7,700,994.59	7,949,137.75
2044	4,944,038.53	5,295,203.88	5,701,816.40	8,317,074.16	8,585,068.77
2045	5,339,561.61	5,718,820.19	6,157,961.71	8,982,440.09	9,271,874.27
	61,558,515.15	**65,029,041.51**	**70,993,652.05**	**103,556,380.63**	**106,893,197.33**
Average	**2,462,340.61**	**2,601,161.66**	**2,839,746.08**	**4,142,255.23**	**4,275,727.89**

Table 5. 11: Lifecycle Fuelwood Cost by Baking Method

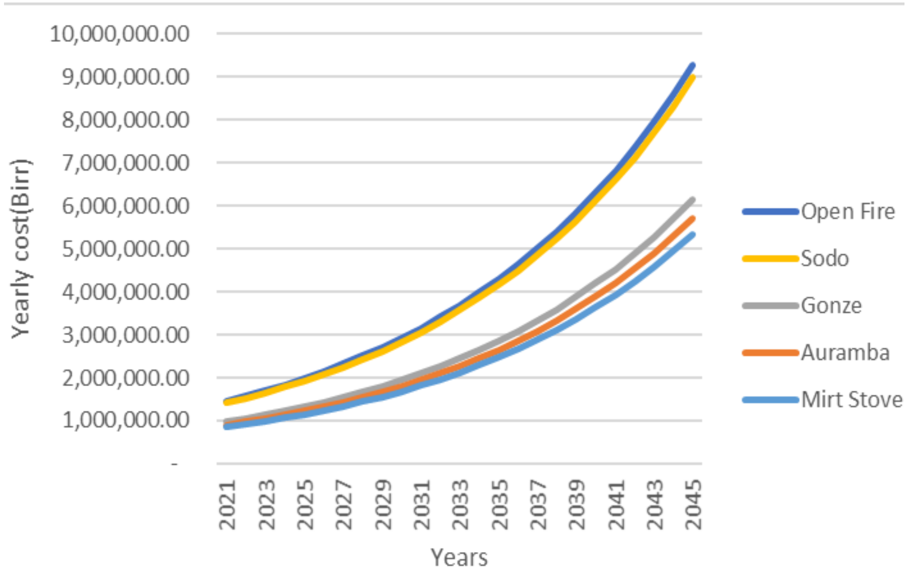

Figure 5. 11: Lifecycle Fuelwood Cost by Baking Method

5.2.4.2. Comparison between Fuel Wood and Solar PV Injera Baking System Project

The PVsyst simulation result shows that the average annual operational cost for the solar PV powered single injera baking kitchen is 239,300.31 Birr and it will be 2,393,003.1 Birr for 10 kitchens. From table 5.12, the estimated average annual fuel wood cost for Mirt Stove, Auramba Stove, Gonze Stove, Sodo Stove, Open Fire Method is 2,462,340.61, 2,601,161.66, 2,839,746.08, 4,142,255.23 Birr, respectively, which are much higher than the cost of solar PV powered Injera baking kitchens operation cost. Figure 5.12 shows that Mirt Stove is lowest to consume fuelwood than the other stove types, but the solar PV powered kitchens are still the power source with the least annual average operational cost.

year	Estimated Yearly Cost(Birr)					
	Mirt Stove	Auramba	Gonze	Sodo	Open Fire	Solar PV Project
2021	842,045.33	901,854.15	971,106.48	1,416,524.85	1,462,168.43	818,334.00
2022	909,408.95	974,002.49	1,048,795.00	1,529,846.84	1,579,141.90	883,800.72
2023	982,161.67	1,051,922.69	1,132,698.60	1,652,234.59	1,705,473.26	954,504.78
2024	1,060,734.60	1,136,076.50	1,223,314.49	1,784,413.35	1,841,911.12	1,030,865.16
2025	1,145,593.37	1,226,962.62	1,321,179.65	1,927,166.42	1,989,264.00	1,113,334.37
2026	1,237,240.84	1,325,119.63	1,426,874.02	2,081,339.73	2,148,405.13	1,202,401.12
2027	1,336,220.11	1,431,129.20	1,541,023.94	2,247,846.91	2,320,277.54	1,298,593.21
2028	1,443,117.72	1,545,619.54	1,664,305.85	2,427,674.67	2,505,899.74	1,402,480.67
2029	1,558,567.14	1,669,269.10	1,797,450.32	2,621,888.64	2,706,371.72	1,514,679.12
2030	1,683,252.51	1,802,810.63	1,941,246.35	2,831,639.73	2,922,881.45	1,635,853.45
2031	1,817,912.71	1,947,035.48	2,096,546.06	3,058,170.91	3,156,711.97	1,766,721.73
2032	1,963,345.72	2,102,798.32	2,264,269.74	3,302,824.58	3,409,248.93	1,908,059.47
2033	2,120,413.38	2,271,022.18	2,445,411.32	3,567,050.55	3,681,988.84	2,060,704.22
2034	2,290,046.45	2,452,703.96	2,641,044.22	3,852,414.59	3,976,547.95	2,225,560.56
2035	2,473,250.17	2,648,920.27	2,852,327.76	4,160,607.76	4,294,671.79	2,403,605.41
2036	2,671,110.18	2,860,833.89	3,080,513.98	4,493,456.38	4,638,245.53	2,595,893.84
2037	2,884,799.00	3,089,700.61	3,326,955.10	4,852,932.89	5,009,305.17	2,803,565.35
2038	3,115,582.91	3,336,876.65	3,593,111.51	5,241,167.52	5,410,049.58	3,027,850.57
2039	3,364,829.55	3,603,826.79	3,880,560.43	5,660,460.92	5,842,853.55	3,270,078.62
2040	3,634,015.91	3,892,132.93	4,191,005.27	6,113,297.80	6,310,281.84	3,531,684.91
2041	3,924,737.18	4,203,503.56	4,526,285.69	6,602,361.62	6,815,104.38	3,814,219.70
2042	4,238,716.16	4,539,783.85	4,888,388.54	7,130,550.55	7,360,312.73	4,119,357.28
2043	4,577,813.45	4,902,966.56	5,279,459.63	7,700,994.59	7,949,137.75	4,448,905.86
2044	4,944,038.53	5,295,203.88	5,701,816.40	8,317,074.16	8,585,068.77	4,804,818.33
2045	5,339,561.61	5,718,820.19	6,157,961.71	8,982,440.09	9,271,874.27	5,189,203.80
	61,558,515.15	**65,930,895.67**	**70,993,652.05**	**103,556,380.63**	**106,893,197.33**	**59,825,076.27**
Average	**2,462,340.61**	**2,637,235.83**	**2,839,746.08**	**4,142,255.23**	**4,275,727.89**	**2,393,003.05**

Table 5. 12: Estimated yearly cost of fuelwood by energy source type.

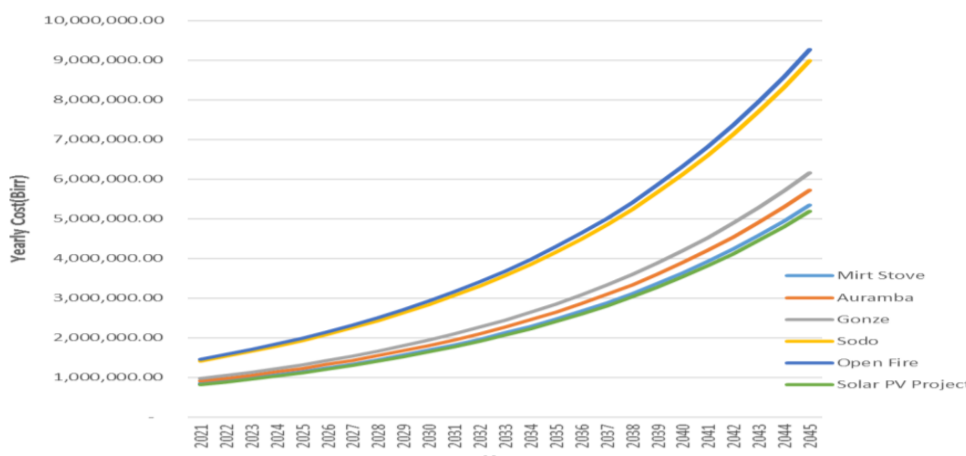

Figure 5. 12: Estimated yearly cost of fuelwood by energy source type.

5.3. Environmental Analysis

5.3.1. Positive Environmental Impacts

Indode village households use wood, cow dung, kerosene for cooking, heating and lightning; which has a high contribution in environmental pollution. Solar PV systems have relatively very low environmental impact that they bring a positive impact in terms of pollution reduction and climate change mitigation[10]. Cooking using biomass produces Green House Gas (GHG) emissions which are causes for air pollution[39]. As fuel wood is collected from forests, deforestation is also the other environmental problem in rural areas.

Considering the 10 kitchens and assuming that the whole community uses the same method of Injera baking or stove type, the annual fuelwood consumption of Indode village is calculated in table 5.14. and the result is 281,186.24 Kg/yr, 161,931.79 Kg/yr, 186,751.25 Kg/yr, 173,433.49 Kg/yr, 272,408.63 Kg/yr for Three stone- open fire Method, Mirt stove, Gonzie stove, Awuramba stove, Sodo stove, respectively.

Fuel Type	**Parameter**	**Value**
Fuelwood	Net calorific value	15MJ/Kg
	Emission factor	81.6tCO_2/TJ

Table 5. 13: Parameters for calculating carbon emissions[21]

Type of Mitad/baking method	Aver. Spec. fuelwood consumption (g/kg of Injera)	Total no of Injera /day	Weight of a single Injera(kg)	Total weight of Injera/day (kg)	Amount of wood needed/ day(kg)	Total Wood Consumed/ year(Kg)
Three stone- open fire Method	929	2675	0.31	829.25	770.37	281,186.24
Mirt stove	535	2675	0.31	829.25	443.65	161,931.79
Gonzie stove	617	2675	0.31	829.25	511.65	186,751.25
Awuramba stove	573	2675	0.31	829.25	475.16	173,433.49
Sodo stove	900	2675	0.31	829.25	746.33	272,408.63

Table 5. 14:Excel generated annual wood consumption for Injera baking

The annual carbon emission can be calculated by[39];

$$E=FW*NCV*EF$$

Where,

E = Carbon emission from fuelwood.

FW = Quantity of fuelwood consumed.

NCV = Net caloric value of fuelwood.

EF = CO_2 emission factor for fuelwood.

Type of Mitad/baking method	Total Wood Consumed/ year(ton)	Net calorific value of fuelwood (TJ/ton)	Emission factor of fuelwood (tCo2/TJ)	Total GHG emission (tCo2)	Total GHG emission (tCo2)/ household /year
Three stone- open fire Method	281.19	0.015	81.6	344.17	1.07
Mirt stove	161.93	0.015	81.6	198.20	0.62
Gonzie stove	186.75	0.015	81.6	228.58	0.71
Awuramba stove	173.43	0.015	81.6	212.28	0.66
Sodo stove	272.41	0.015	81.6	333.43	1.04

Table 5. 15: Excel generated annual carbon emission by stove type.

Applying the above formula on Excel spreadsheet the annual carbon emission for the traditional methods of Injera baking is determined. Therefore, depending on the stove type, replacing the traditional energy source for Injera baking with the off-grid solar PV system can save carbon emission of 1.07 $tCo_{2/}$/household/year, 0.62 $tCo_{2/}$/household/year, 0.71 $tCo_{2/}$/household/year, 0.66 $tCo_{2/}$/household/year, 1.04 $tCo_{2/}$/household/year for Three stone- open fire Method, Mirt stove, Gonzie stove, Awuramba stove, Sodo stove, respectively. Previous studies show that open three-point stoves have an emission of 1.1 t CO2e per year per household[39] and the policy research working paper of World Bang in 2015 indicates that improved cooking stoves save 0.94 tons of CO2 emissions per household(stove) per year[40].

5.3.2. Negative Environmental Impacts

Although off-grid PV systems are an alternative for reducing negative environmental impacts, it needs economic and institutional policies that provide regulations and incentives, as well as an appropriate infrastructure to encourage increase their positive impact on the environmental[10]. The lack of awareness, policies and technological capabilities in Ethiopia to ensuring recycling and proper disposal of PV modules and batteries after the end of their service life may result in burying of batteries which release acid substances into nearby lakes and rivers[19]. The other negative impact is that Large-scale solar PV systems need large areas of land for their installation and operation facilities.

Chapter 6: Conclusions and Future Work

6.1. Conclusion

The design of off- grid stand-alone solar PV system for the community of Indode village considering its social and energy source situation is the main objective of this thesis; targeting to help such community become more independent in energy supply for different activities; mainly for Injera baking which consumes the major portion of the cooking fuel. To answer the thesis's main question that the project is whether technically and economically feasible to meet the energy need of off-grid communities in Ethiopia, the study and dimensioning of the specifically selected site, Indode community, has been carried out using PVsyst software simulation tool for the appropriate sizing and dimensioning results of the system. The wiring of the proposed system should be studied again as no actual data for specific installation distances between components have not been taken and included. However, it is clear that these factors have no a significant impact on the project's feasibility study.

The analysis result for the single kitchen shows that the investment of solar PV powered community kitchen is techno-economically more viable than the current practice of the community which uses fuel wood for baking Injera.

The PVsyst analysis results of the economic indicators assures that the solar PV system project for off-grid communities is economically feasible for Injera baking, there by powering other village facilities such as homes, offices, schools and health centers. This will diminish the major bio-mass costs currently experienced for Injera baking in the village. Furthermore, the economic evaluation result shows that the investment cost will be recovered with a specified payback period annual profit that can be used for re-investing in the community to guarantee the sustainability of the energy supply after the end of the life span of this project. The project will strengthen the alternative energy independency of Indode's community by reducing the need for constant supply of fire wood & bio-mass fuel for baking and other cooking activities. Applying this project, not only Injera baking, some major activities which need energy for further growth and life standard improvement of the community will be assisted by sustainable sources of solar energy. On the other way, as solar PV systems have very little negative impact on environmental pollution, the carbon released from fire wood and other bio-fuels will be minimized in the surrounding of the village.

6.2. Future Work

The PVsyst analysis results and other investigations of the proposed solar PV system are considered valid and feasible but some further design and sizing improvements of the system can be carried out so as to get more accurate results in the analysis based on the following features of the project:

- Since the meteorological data taken from Meteonorm is satellite -based; it is not a data recorded using intentionally arranged local instruments by an authorized institution in Ethiopia. Therefore, actual data can be taken from Ethiopian metrology Agency to compare the result found using the data from Meteonorm website.
- By knowing the configuration of the components of the solar PV project and the installation distance in between, DC side and AC side (distribution) cables shall be properly sized and their voltage drop determined.
- To make this study applicable to all off-grid communities in the country, the proposed system is a stand-alone solar PV system. But, the national grid-line is passing nearby Indode’s community. Thus, the technical and economic feasibility of connecting the proposed system with the national-grid shall be studied and compared whether a stand-alone or a grid-connected solar PV system is a better energy source alternative to the community.

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Annex I: Interview and Data Collection Details

The study is carried out applying mandatory steps and procedures combined with the data collection process based on solar energy resource available on Indode Village. Design and optimization of solar PV systems require specific primary input data such as site coordinates, load demand and profile, and climatological data of the site.

The selected off-grid community, the Indode village, is located in Oromia Special Zone, Akaki Woreda Administration, Hechu Kebele. To be able to analyze the energy problem of the community and select the site, a journey to Indode village was made to contact villagers and governmental officials. Information is collected via interviews in the village and administration offices. The executive of the Indode Administration zone, Ato Birhanu, was contacted in person and a lot of information was collected from him and his deputy, Ato Tadu. The officials were very happy that the idea of bringing solar energy to their community surprised them. Besides the governmental officials, I organized an interview with selected community peoples to gather information in detail. The proper location of the Injera baking kitchens and the PV station was determined in relation to the location and placement of the individual households. After collecting site data; the design, sizing and simulation of the system was carried out.

1. **Selected site name and location**
   - Indode village, which is located in Oromia Special Zone, Akaki Woreda Administration, Hechu Kebele.
2. **Meeting governmental officials**
   - Name: Ato Birhane, Chief Administrative Officer for Indode Administration zone, mobile no: 0945792781
   - Name: Ato Tadu, Deputy Administrative Officer for Indode Administration zone, mobile no: 0910705522
3. **Community member interviews**

In addition to the information gathered from governmental officials, the following questionnaires were prepared and three community members were interviewed for more information about cooking habits, way of living, available energy sources, etc. of Indode community.

1. How many family members do you have?
2. How frequently do you bake Injera with enough quantity to feed your family until the next baking cycle?
3. Which energy source do you use for baking Injera? How/where do you get this energy source?
4. Besides baking injera, for which purpose you use wood/biomass fuel?
5. How many minutes it takes before your Mitad gets hot enough? how do you know this hotness?
6. The number of meals you prepare in a day?
7. How many Birr and time do you spend a day to collect the traditional fuel/wood or biomass?
8. What is your family's income and means of earning?
9. If the government (or by other means) brings solar energy source facility to this community for Ingera baking and other purposes, what will be your feeling?

Response 1

1. 3membersinthefamily.
2. Every3or4days; it may be shorter time if guests and close families visit them.
   15-20 Ingera for every baking cycle.
3. wood and Cow dung. Searching on the roads and surroundings and collecting the cow or donkey dung. In the rainy season, collection is very difficult as the surrounding is wet.
4. Bread and Injera baking, boiling activities.
5. 10minutes.
6. 3 meals in a day.
7. 2-3 hours a day
8. Her husband is a governmental worker and she doesn't know his salary. They

have additional income from farming too.

9. Very much happy.

Response 2

1. Four family members; wife, husband and two children.
2. Averagely every 3 days, 20 Injera in every baking cycle.
3. Cow dung, straw, horse dung, & wood. She has oxen to easily gather the energy.
4. Bread and injera, other boiling activities.
5. Her Mitad takes 5 minutes to get hot.
6. 3 meals a day.
7. It takes 2-4 hours.
8. Her husband is a farmer and has two oxen for ploughing. She does not know their daily income.
9. Very interesting.

Response 3

1. 2 family members (She & her husband).
2. Averagely every 4 days with nearly15 Injera in every baking cycle.
3. Cow dung, straw, horse dung, wood. she has cows, a donkey and oxen.
4. Bread and injera, other boiling activities.
5. It usually takes 5-8 minutes to get hot based on the amount of fuel supply.
6. 3 meals a day.
7. Even if she has her own cows and oxen, she sometimes goes away to collect fuel and may take 2-3 hours.
8. Since they are farmers and their income is seasonal, she does not know their actual daily income.

9. Very happy as it creates easy life for her family and the community as a whole.

Annex II: PVsyst Simulation Results I

PVSYST 7.0.6		11/10/20	Page 1/10

Stand alone system: Simulation parameters

Project : **Indode Village Stand Alone Solar PV Project for a Single Kitchen**

Geographical Site	**Indode Village**		Country	**Ethiopia**
Situation	Latitude	8.85° N	Longitude	38.77° E
Time defined as	Legal Time	Time zone UT+3	Altitude	2115 m
	Albedo	0.20		
Meteo data:	**Indode Solar PV Project**	Meteonorm 7.2, Sat=42% - Synthetic		

Simulation variant : **New simulation variant**

Simulation date 11/10/20 07h33

Simulation parameters	System type	**Stand alone system with batteries**		
Collector Plane Orientation	Tilt	18°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
			Circumsolar	with diffuse
User's needs :	Daily household consumers	Constant over the year		
	average	230 kWh/Day		

PV Array Characteristics

PV module Si-mono	Model	**Mono 400 Wp 72 cells**		
Original PVsyst database	Manufacturer	Generic		
Number of PV modules	In series	10 modules	In parallel	13 strings
Total number of PV modules	nb. modules	130	Unit Nom. Power	400 Wp
Array global power	Nominal (STC)	**52.0 kWp**	At operating cond.	47.1 kWp (50°C)
Array operating characteristics (50°C)	U mpp	345 V	I mpp	137 A
Total area	Module area	**291 m²**	Cell area	129 m²

System Parameter	System type	**Stand alone system**		
Battery	Model	**12-CS-11PS**		
	Manufacturer	Rolls		
Battery Pack Characteristics	Nb. of units	4 in series x 11 in parallel		
	Voltage	48 V	Nominal Capacity	5500 Ah
	Discharging min. SOC	20.0%	Stored energy	211.2 kWh
	Temperature	Fixed (20°C)		
Controller	Model	Universal controller with MPPT converter		
	Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/Elem.
Converter	Maxi and EURO efficiencies	97.0 / 95.0%		
Battery Management control	Threshold commands as	SOC calculation		
	Charging	SOC = 0.92 / 0.75	approx.	56.1 / 49.5 V
	Discharging	SOC = 0.20 / 0.45	approx.	45.4 / 48.3 V

PV Array loss factors

Array Soiling Losses — Average loss Fraction 3.0 %

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%

Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	32 mΩ	Loss Fraction	1.1 % at STC
Serie Diode Loss	Voltage drop	0.7 V	Loss Fraction	0.2 % at STC

Stand alone system: Simulation parameters

LID - Light Induced Degradation	Loss Fraction	2.0 %
Module Quality Loss	Loss Fraction	-0.4 %
Module mismatch losses	Loss Fraction	1.0 % at MPP
Strings Mismatch loss	Loss Fraction	0.10 %

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

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

Spectral correction FirstSolar model. Precipitable water estimated from relative humidity

Coefficient Set	C0	C1	C2	C3	C4	C5
Monocrystalline Si	0.85914	-0.02088	-0.0058853	0.12029	0.026814	-0.001781

Stand alone system: Detailed User's needs

Project : **Indode Village Stand Alone Solar PV Project for a Single Kitchen**

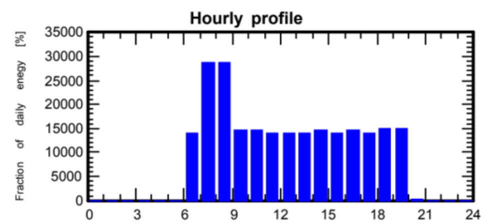
Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone system with batteries**		
PV Field Orientation	tilt	18°	azimuth	0°
PV modules	Model	Mono 400 Wp 72 cells	Pnom	400 Wp
PV Array	Nb. of modules	130	Pnom total	**52.0 kWp**
Battery	Model	12-CS-11PS	Technology	Lead-acid, sealed, plates
Battery pack	Nb. of units	44	Voltage / Capacity	**48 V / 5500 Ah**
User's needs	Daily household consumers	Constant over the year	Global	84.1 MWh/year

Daily household consumers, Constant over the year, average = 230 kWh/day

Annual values

	Number	Power	Use	Energy
Lamps	2	40W/lamp	4H/day	320Wh/day
Water heater/kettle	1	1500W/app	4H/day	6000Wh/day
Injera Baking Mitad	8	3500W/app	8H/day	224000Wh/day
Total daily energy				230320Wh/day



Stand alone system: Main results

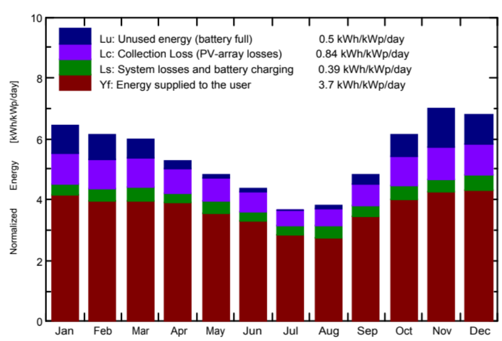
Project : **Indode Village Stand Alone Solar PV Project for a Single Kitchen**

Simulation variant : **New simulation variant**

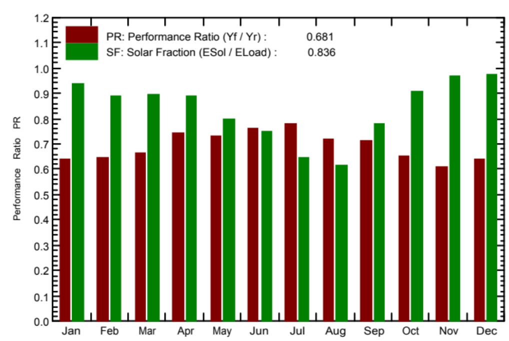
Main system parameters	System type	**Stand alone system with batteries**		
PV Field Orientation	tilt	18°	azimuth	0°
PV modules	Model	Mono 400 Wp 72 cells	Pnom	400 Wp
PV Array	Nb. of modules	130	Pnom total	**52.0 kWp**
Battery	Model	12-CS-11PS	Technology	Lead-acid, sealed, plates
Battery pack	Nb. of units	44	Voltage / Capacity	**48 V / 5500 Ah**
User's needs	Daily household consumers	Constant over the year	Global	84.1 MWh/year

Main simulation results				
System Production	**Available Energy**	**83699 kWh/year**	Specific prod.	1610 kWh/kWp/year
	Used Energy	70300 kWh/year	Excess (unused)	9577 kWh/year
	Performance Ratio PR	68.12 %	Solar Fraction SF	83.62 %
Loss of Load	Time Fraction	12.8 %	Missing Energy	13767 kWh/year
Battery aging (State of Wear)	Cycles SOW	92.9%	Static SOW	93.3%
	Battery lifetime	14.2 years		
Investment	Global	1'176'500.00 Bir	Specific	22.6 Bir/Wp
Yearly cost	Annuities	0.00 Bir/yr	Running Costs	239'300.10 Bir/yr
LCOE		**1.16 Bir/kWh**	Payback period	**8.8 years**

Normalized productions (per installed kWp): Nominal power 52.0 kWp



Performance Ratio PR and Solar Fraction SF



New simulation variant

Balances and main results

	GlobHor	GlobEff	E_Avail	EUnused	E_Miss	E_User	E_Load	SolFrac
	kWh/m²	kWh/m²	kWh	kWh	kWh	kWh	kWh	ratio
January	174.0	189.9	8492	1500	451	6689	7140	0.937
February	157.9	162.6	7205	1157	710	5739	6449	0.890
March	183.2	174.9	7770	947	768	6372	7140	0.892
April	166.9	149.7	6686	402	779	6130	6910	0.887
May	166.1	140.4	6264	169	1433	5707	7140	0.799
June	147.4	122.3	5491	106	1750	5160	6910	0.747
July	126.1	106.9	4804	0	2523	4617	7140	0.647
August	126.2	111.0	4966	159	2739	4401	7140	0.616
September	147.2	136.8	6134	480	1516	5394	6910	0.781
October	180.3	180.9	8049	1184	673	6467	7140	0.906
November	184.7	199.6	8874	1924	250	6659	6910	0.964
December	177.8	199.4	8963	1549	175	6965	7140	0.976
Year	1938.0	1874.5	83699	9577	13767	70300	84067	0.836

Legends:
- GlobHor: Global horizontal irradiation
- GlobEff: Effective Global, corr. for IAM and shadings
- E_Avail: Available Solar Energy
- EUnused: Unused energy (battery full)
- E_Miss: Missing energy
- E_User: Energy supplied to the user
- E_Load: Energy need of the user (Load)
- SolFrac: Solar fraction (EUsed / ELoad)

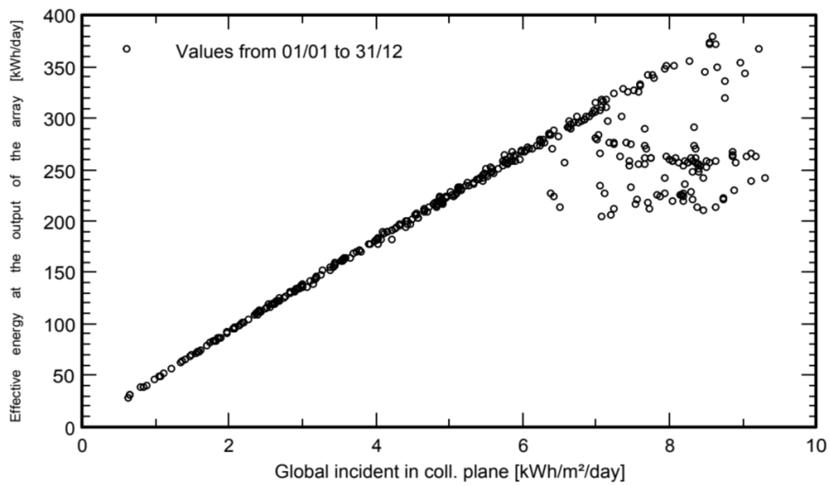
Stand alone system: Special graphs

Project : **Indode Village Stand Alone Solar PV Project for a Single Kitchen**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone system with batteries**		
PV Field Orientation	tilt	18°	azimuth	0°
PV modules	Model	Mono 400 Wp 72 cells	Pnom	400 Wp
PV Array	Nb. of modules	130	Pnom total	**52.0 kWp**
Battery	Model	12-CS-11PS	Technology	Lead-acid, sealed, plates
Battery pack	Nb. of units	44	Voltage / Capacity	**48 V / 5500 Ah**
User's needs	Daily household consumers	Constant over the year	Global	84.1 MWh/year

Daily Input/Output diagram



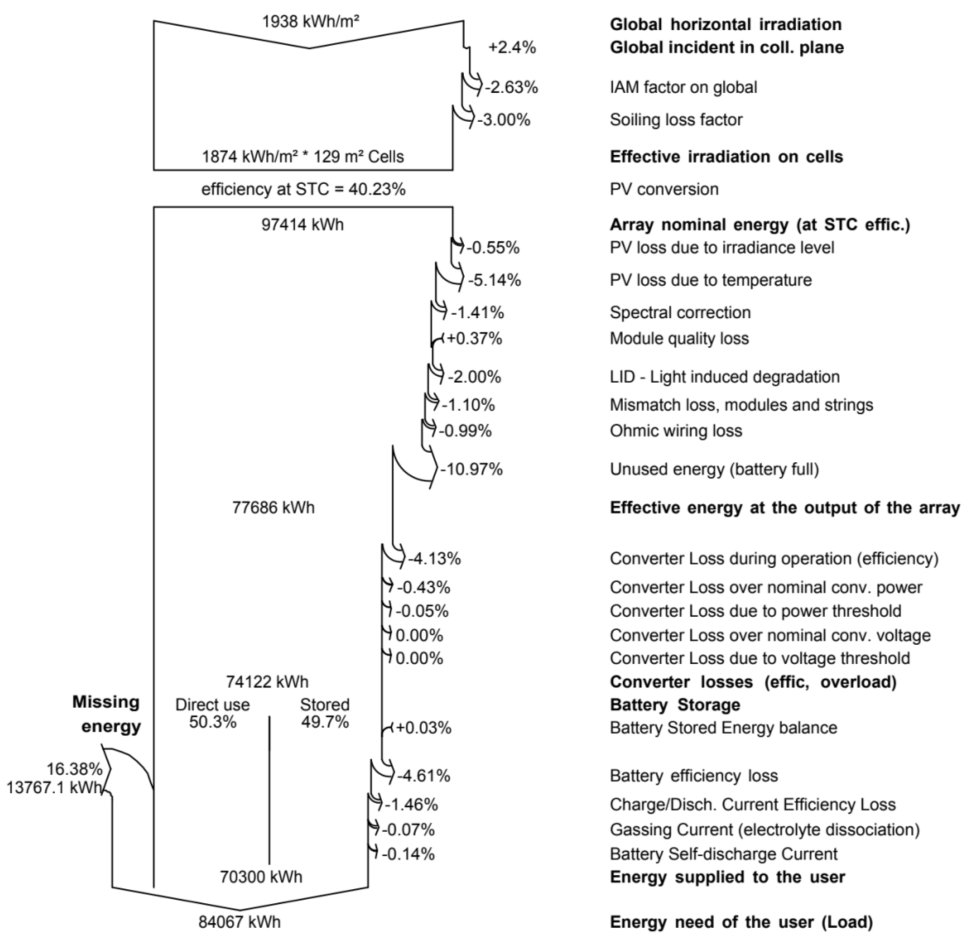
Stand alone system: Loss diagram

Project : **Indode Village Stand Alone Solar PV Project for a Single Kitchen**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone system with batteries**		
PV Field Orientation	tilt	18°	azimuth	0°
PV modules	Model	Mono 400 Wp 72 cells	Pnom	400 Wp
PV Array	Nb. of modules	130	Pnom total	**52.0 kWp**
Battery	Model	12-CS-11PS	Technology	Lead-acid, sealed, plates
Battery pack	Nb. of units	44	Voltage / Capacity	**48 V / 5500 Ah**
User's needs	Daily household consumers	Constant over the year	Global	84.1 MWh/year

Loss diagram over the whole year



Stand alone system: Cost of the system

Project : **Indode Village Stand Alone Solar PV Project for a Single Kitchen**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone system with batteries**		
PV Field Orientation	tilt	18°	azimuth	0°
PV modules	Model	Mono 400 Wp 72 cells	Pnom	400 Wp
PV Array	Nb. of modules	130	Pnom total	**52.0 kWp**
Battery	Model	12-CS-11PS	Technology	Lead-acid, sealed, plates
Battery pack	Nb. of units	44	Voltage / Capacity	**48 V / 5500 Ah**
User's needs	Daily household consumers	Constant over the year	Global	84.1 MWh/year

Installation costs

PV modules			
Mono 400 Wp 72 cells	130 units	3'800.00 Bir/unit	494'000.00 Bir
Supports for modules	130 units	500.00 Bir/unit	65'000.00 Bir
Batteries	44 units	12'500.00 Bir/unit	550'000.00 Bir
Controllers			15'000.00 Bir
Inverters	5 units	10'500.00 Bir/unit	52'500.00 Bir
		Total	**1'176'500.00 Bir**
		Depreciable asset	1'176'500.00 Bir

Operating costs

Maintenance		
Salaries		36'000.00 Bir/year
Provision for battery replacement		45'833.33 Bir/year
	Total (OPEX)	**81'833.33 Bir/year**
	Including inflation (8.00%)	**239'300.10 Bir/year**

System summary

Total installation cost	**1'176'500.00 Bir**
Operating costs (incl. inflation 8.00%/year)	**239'300.10 Bir/year**
Used solar energy	**70.3 MWh/year**
Excess energy (battery full)	**9.6 MWh/year**
Used energy cost	**2.216 Bir/kWh**

Stand alone system: Financial analysis

Project : **Indode Village Stand Alone Solar PV Project for a Single Kitchen**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone system with batteries**		
PV Field Orientation	tilt	18°	azimuth	0°
PV modules	Model	Mono 400 Wp 72 cells	Pnom	400 Wp
PV Array	Nb. of modules	130	Pnom total	**52.0 kWp**
Battery	Model	12-CS-11PS	Technology	Lead-acid, sealed, plates
Battery pack	Nb. of units	44	Voltage / Capacity	**48 V / 5500 Ah**
User's needs	Daily household consumers	Constant over the year	Global	84.1 MWh/year

Financial parameters

Simulation period

Project lifetime	25 years	Start year	2021

Production variation	Aging tool results	
Income variation over time		
Inflation	8.00	%/year
Production variation	Aging tool results	%/year
Discount rate	12.00	

Self-consumption

Consumption tariff	2.20	Bir/kWh
Tariff evolution	+15.0	%/year

Return on investment

Payback period	**8.8**	**years**
Net present value (NPV)	**4'843'666.97**	**Bir**
Return on investment (ROI)	**411.7**	**%**

Stand alone system: Financial analysis

Project : **Indode Village Stand Alone Solar PV Project for a Single Kitchen**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone system with batteries**		
PV Field Orientation	tilt	18°	azimuth	0°
PV modules	Model	Mono 400 Wp 72 cells	Pnom	400 Wp
PV Array	Nb. of modules	130	Pnom total	**52.0 kWp**
Battery	Model	12-CS-11PS	Technology	Lead-acid, sealed, plates
Battery pack	Nb. of units	44	Voltage / Capacity	**48 V / 5500 Ah**
User's needs	Daily household consumers	Constant over the year	Global	84.1 MWh/year

Detailed economic results (Bir)

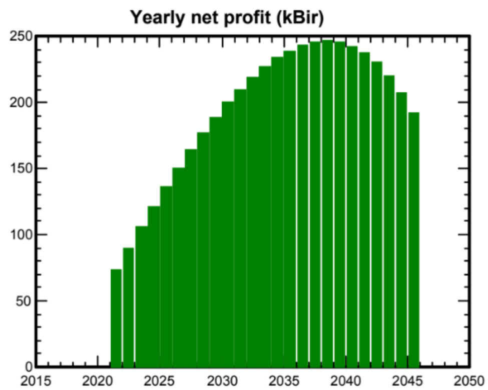
	Run. costs	Self-cons. saving	Cumul. profit	% amorti.
2021	81'833	154'660	72'826	6.2%
2022	88'380	177'858	162'305	13.8%
2023	95'450	201'057	267'912	22.8%
2024	103'086	224'256	389'082	33.1%
2025	111'333	247'455	525'204	44.6%
2026	120'240	270'654	675'618	57.4%
2027	129'859	293'853	839'612	71.4%
2028	140'248	317'052	1'016'416	86.4%
2029	151'468	340'251	1'205'199	102.4%
2030	163'585	363'450	1'405'064	119.4%
2031	176'672	386'649	1'615'041	137.3%
2032	190'806	409'848	1'834'083	155.9%
2033	206'070	433'047	2'061'060	175.2%
2034	222'556	456'246	2'294'749	195.0%
2035	240'360	479'445	2'533'834	215.4%
2036	259'589	502'644	2'776'888	236.0%
2037	280'356	525'843	3'022'374	256.9%
2038	302'785	549'041	3'268'631	277.8%
2039	327'008	572'240	3'513'864	298.7%
2040	353'168	595'439	3'756'135	319.3%
2041	381'422	618'638	3'993'352	339.4%
2042	411'935	641'837	4'223'253	359.0%
2043	444'890	665'036	4'443'399	377.7%
2044	480'481	688'235	4'651'153	395.3%
2045	518'920	711'434	4'843'667	411.7%
Total	**5'982'503**	**10'826'169**	**4'843'667**	**411.7%**

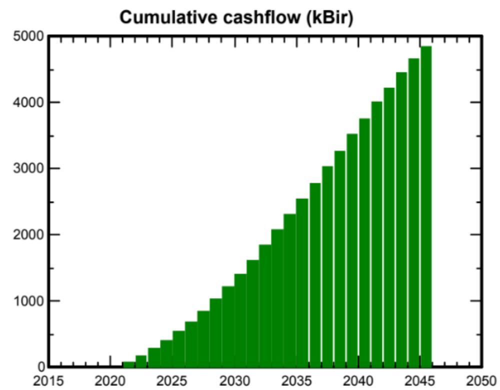
Stand alone system: Financial analysis

Project : **Indode Village Stand Alone Solar PV Project for a Single Kitchen**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone system with batteries**		
PV Field Orientation	tilt	18°	azimuth	0°
PV modules	Model	Mono 400 Wp 72 cells	Pnom	400 Wp
PV Array	Nb. of modules	130	Pnom total	**52.0 kWp**
Battery	Model	12-CS-11PS	Technology	Lead-acid, sealed, plates
Battery pack	Nb. of units	44	Voltage / Capacity	**48 V / 5500 Ah**
User's needs	Daily household consumers	Constant over the year	Global	84.1 MWh/year





Annex III: PVsyst Simulation Results II

	PVSYST 7.0.6		11/10/20	Page 1/10

Stand alone system: Simulation parameters

Project : **Indode Village-Community Stand Alone Solar PV Project**

Geographical Site **Indode Village** Country **Ethiopia**

Situation Latitude 8.85° N Longitude 38.77° E
Time defined as Legal Time Time zone UT+3 Altitude 2115 m
Albedo 0.20

Meteo data: **Indode Solar PV Project** Meteonorm 7.2, Sat=42% - Synthetic

Simulation variant : **New simulation variant**
Simulation date 23/08/20 15h40

Simulation parameters System type **Stand alone system with batteries**

Collector Plane Orientation Tilt 18° Azimuth 0°

Models used Transposition Perez Diffuse Perez, Meteonorm
Circumsolar with diffuse

User's needs : Daily household consumers Constant over the year
average 5245 kWh/Day

PV Array Characteristics
PV module Si-mono Model **Mono 400 Wp 72 cells**
Original PVsyst database Manufacturer Generic
Number of PV modules In series 12 modules In parallel 151 strings
Total number of PV modules nb. modules 1812 Unit Nom. Power 400 Wp
Array global power Nominal (STC) **725 kWp** At operating cond. 657 kWp (50°C)
Array operating characteristics (50°C) U mpp 414 V I mpp 1588 A
Total area Module area **4062 m²** Cell area 1800 m²

System Parameter System type **Stand alone system**

Battery Model **12-CS-11PS**
Manufacturer Rolls
Battery Pack Characteristics Nb. of units 4 in series x 257 in parallel
Voltage 48 V Nominal Capacity 128500 Ah
Discharging min. SOC 20.0% Stored energy 4934.4 kWh
Temperature Fixed (20°C)

Controller Model Universal controller with MPPT converter
Technology MPPT converter Temp coeff. -5.0 mV/°C/Elem.
Converter Maxi and EURO efficiencies 97.0 / 95.0%

Battery Management control Threshold commands as SOC calculation
Charging SOC = 0.92 / 0.75 approx. 54.9 / 49.5 V
Discharging SOC = 0.20 / 0.45 approx. 45.8 / 48.3 V

PV Array loss factors
Array Soiling Losses Average loss Fraction 3.0 %

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%

Thermal Loss factor Uc (const) 29.0 W/m²K Uv (wind) 0.0 W/m²K / m/s

Wiring Ohmic Loss Global array res. 5.6 mΩ Loss Fraction 1.9 % at STC
Serie Diode Loss Voltage drop 0.7 V Loss Fraction 0.2 % at STC

Stand alone system: Simulation parameters

LID - Light Induced Degradation	Loss Fraction	2.0 %
Module Quality Loss	Loss Fraction	-0.4 %
Module mismatch losses	Loss Fraction	1.0 % at MPP
Strings Mismatch loss	Loss Fraction	0.10 %

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

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

Spectral correction FirstSolar model

Coefficient Set	C0	C1	C2	C3	C4	C5
	0	0	0	0	0	0

Stand alone system: Detailed User's needs

Project : **Indode Village-Community Stand Alone Solar PV Project**

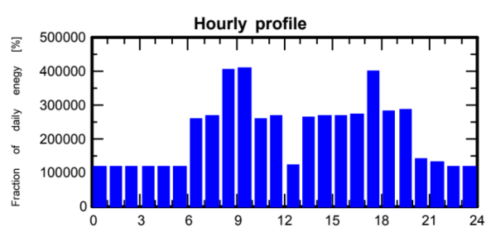
Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone system with batteries**		
PV Field Orientation	tilt	18°	azimuth	0°
PV modules	Model	Mono 400 Wp 72 cells	Pnom	400 Wp
PV Array	Nb. of modules	1812	Pnom total	**725 kWp**
Battery	Model	12-CS-11PS	Technology	Lead-acid, sealed, plates
Battery pack	Nb. of units	1028	Voltage / Capacity	**48 V / 128500 Ah**
User's needs	Daily household consumers	Constant over the year	Global	1915 MWh/year

Daily household consumers, Constant over the year, average = 5245 kWh/day

Annual values

	Number	Power	Use	Energy
Lamps (LED or fluo)	526	30W/lamp	4H/day	63120Wh/day
TV	150	75W/app	5H/day	56250Wh/day
Injera Baking Mitad	80	3500W/app	8H/day	2240000Wh/day
Fridge / Deep-freeze	53		24Wh/day	2798400Wh/day
Computers	64		7Wh/day	67200Wh/day
Mobile Charges	400	4W tot	4H/day	6400Wh/day
Radio	350	10W tot	4H/day	14000Wh/day
Total daily energy				5245370Wh/day



Stand alone system: Main results

Project : **Indode Village-Community Stand Alone Solar PV Project**

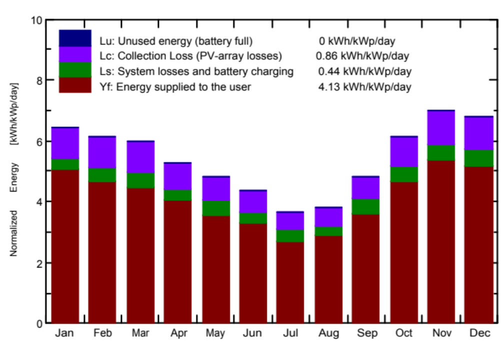
Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone system with batteries**		
PV Field Orientation	tilt	18°	azimuth	0°
PV modules	Model	Mono 400 Wp 72 cells	Pnom	400 Wp
PV Array	Nb. of modules	1812	Pnom total	**725 kWp**
Battery	Model	12-CS-11PS	Technology	Lead-acid, sealed, plates
Battery pack	Nb. of units	1028	Voltage / Capacity	**48 V / 128500 Ah**
User's needs	Daily household consumers	Constant over the year	Global	1915 MWh/year

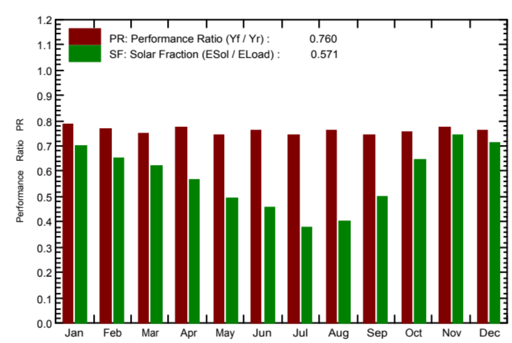
Main simulation results				
System Production	**Available Energy**	**1155614 kWh/year**	Specific prod.	1594 kWh/kWp/year
	Used Energy	1092721 kWh/year	Excess (unused)	51 kWh/year
	Performance Ratio PR	75.96 %	Solar Fraction SF	57.07 %
Loss of Load	Time Fraction	39.2 %	Missing Energy	821839 kWh/year
Battery aging (State of Wear)	Cycles SOW	94.8%	Static SOW	93.3%
	Battery lifetime	15.0 years		

Investment	Global	21'328'100.00 Bir	Specific	29.4 Bir/Wp
Yearly cost	Annuities	0.00 Bir/yr	Running Costs	3'341'916.19 Bir/yr
LCOE		**1.05 Bir/kWh**	Payback period	**9.3 years**

Normalized productions (per installed kWp): Nominal power 725 kWp



Performance Ratio PR and Solar Fraction SF



New simulation variant

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail kWh	EUnused kWh	E_Miss kWh	E_User kWh	E_Load kWh	SolFrac ratio
January	174.0	189.9	116936	0.00	49081	113525	162607	0.698
February	157.9	162.6	99291	0.00	51622	95249	146870	0.649
March	183.2	174.9	107244	0.00	62035	100571	162607	0.618
April	166.9	149.7	92525	5.64	68504	88857	157361	0.565
May	166.1	140.4	86829	0.00	82327	80279	162607	0.494
June	147.4	122.3	76157	11.49	85549	71813	157361	0.456
July	126.1	106.9	66716	5.56	101363	61243	162607	0.377
August	126.2	111.0	68856	2.63	97567	65039	162607	0.400
September	147.2	136.8	84837	5.71	79119	78242	157361	0.497
October	180.3	180.9	110932	2.87	58073	104534	162607	0.643
November	184.7	199.6	121922	14.30	40090	117271	157361	0.745
December	177.8	199.4	123368	2.89	46509	116097	162607	0.714
Year	1938.0	1874.5	1155614	51.08	821839	1092721	1914561	0.571

Legends:

GlobHor	Global horizontal 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 (battery full)	SolFrac	Solar fraction (EUsed / ELoad)

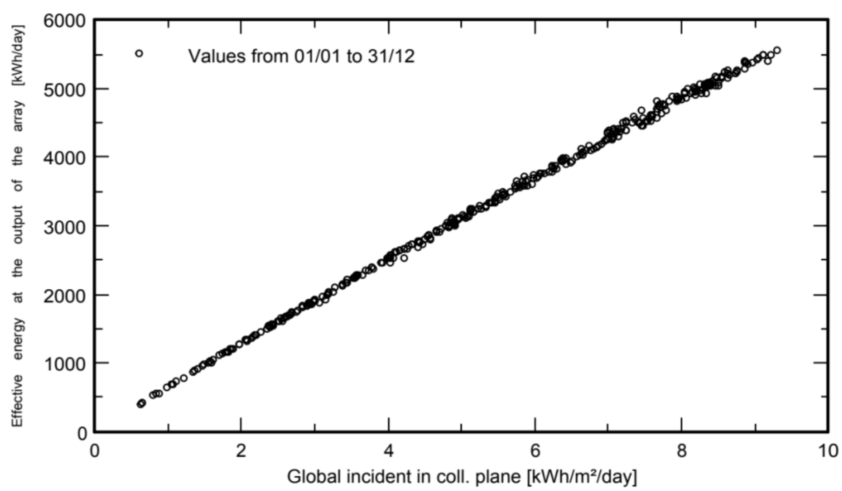
Stand alone system: Special graphs

Project : **Indode Village-Community Stand Alone Solar PV Project**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone system with batteries**		
PV Field Orientation	tilt	18°	azimuth	0°
PV modules	Model	Mono 400 Wp 72 cells	Pnom	400 Wp
PV Array	Nb. of modules	1812	Pnom total	**725 kWp**
Battery	Model	12-CS-11PS	Technology	Lead-acid, sealed, plates
Battery pack	Nb. of units	1028	Voltage / Capacity	**48 V / 128500 Ah**
User's needs	Daily household consumers	Constant over the year	Global	1915 MWh/year

Daily Input/Output diagram



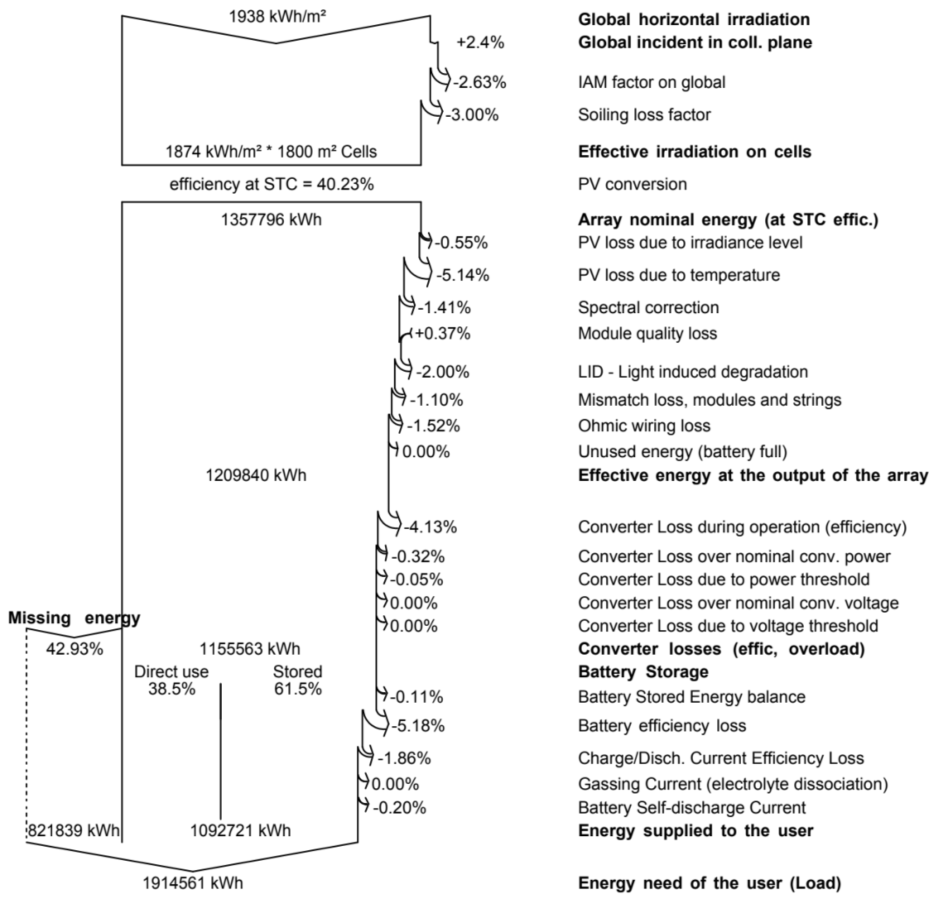
Stand alone system: Loss diagram

Project : **Indode Village-Community Stand Alone Solar PV Project**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone system with batteries**		
PV Field Orientation	tilt	18°	azimuth	0°
PV modules	Model	Mono 400 Wp 72 cells	Pnom	400 Wp
PV Array	Nb. of modules	1812	Pnom total	**725 kWp**
Battery	Model	12-CS-11PS	Technology	Lead-acid, sealed, plates
Battery pack	Nb. of units	1028	Voltage / Capacity	**48 V / 128500 Ah**
User's needs	Daily household consumers	Constant over the year	Global	1915 MWh/year

Loss diagram over the whole year



Stand alone system: Cost of the system

Project : **Indode Village-Community Stand Alone Solar PV Project**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone system with batteries**		
PV Field Orientation	tilt	18°	azimuth	0°
PV modules	Model	Mono 400 Wp 72 cells	Pnom	400 Wp
PV Array	Nb. of modules	1812	Pnom total	**725 kWp**
Battery	Model	12-CS-11PS	Technology	Lead-acid, sealed, plates
Battery pack	Nb. of units	1028	Voltage / Capacity	**48 V / 128500 Ah**
User's needs	Daily household consumers	Constant over the year	Global	1915 MWh/year

Installation costs

PV modules			
Mono 400 Wp 72 cells	1812 units	3'800.00 Bir/unit	6'885'600.00 Bir
Supports for modules	1812 units	500.00 Bir/unit	906'000.00 Bir
Batteries	1028 units	12'500.00 Bir/unit	12'850'000.00 Bir
Controllers			25'000.00 Bir
Inverters	63 units	10'500.00 Bir/unit	661'500.00 Bir
		Total	**21'328'100.00 Bir**
		Depreciable asset	21'328'100.00 Bir

Operating costs

Maintenance		
Salaries		36'000.00 Bir/year
Provision for battery replacement		1'070'833.33 Bir/year
Administrative, accounting		36'000.00 Bir/year
	Total (OPEX)	**1'142'833.33 Bir/year**
	Including inflation (8.00%)	**3'341'916.19 Bir/year**

System summary

Total installation cost	**21'328'100.00 Bir**
Operating costs (incl. inflation 8.00%/year)	**3'341'916.19 Bir/year**
Used solar energy	**1093 MWh/year**
Excess energy (battery full)	**0.1 MWh/year**
Used energy cost	**1.991 Bir/kWh**

Stand alone system: Financial analysis

Project : **Indode Village-Community Stand Alone Solar PV Project**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone system with batteries**		
PV Field Orientation	tilt	18°	azimuth	0°
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Battery pack	Nb. of units	1028	Voltage / Capacity	**48 V / 128500 Ah**
User's needs	Daily household consumers	Constant over the year	Global	1915 MWh/year

Financial parameters

Simulation period

Project lifetime 25 years Start year 2021

Production variation Aging tool results

Income variation over time

Inflation	8.00	%/year
Production variation	Aging tool results	%/year
Discount rate	12.00	

Self-consumption

Consumption tariff	2.20	Bir/kWh
Tariff evolution	+15.0	%/year

Return on investment

Payback period	**9.3**	**years**
Net present value (NPV)	**84'730'997.18**	**Bir**
Return on investment (ROI)	**397.3**	**%**

Stand alone system: Financial analysis

Project : **Indode Village-Community Stand Alone Solar PV Project**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone system with batteries**		
PV Field Orientation	tilt	18°	azimuth	0°
PV modules	Model	Mono 400 Wp 72 cells	Pnom	400 Wp
PV Array	Nb. of modules	1812	Pnom total	**725 kWp**
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User's needs	Daily household consumers	Constant over the year	Global	1915 MWh/year

Detailed economic results (Bir)

	Run. costs	Self-cons. saving	Cumul. profit	% amorti.
2021	1'142'833	2'403'984	1'261'151	5.9%
2022	1'234'260	2'764'582	2'791'473	13.1%
2023	1'333'001	3'125'180	4'583'652	21.5%
2024	1'439'641	3'485'777	6'629'788	31.1%
2025	1'554'812	3'846'375	8'921'351	41.8%
2026	1'679'197	4'206'973	11'449'126	53.7%
2027	1'813'533	4'567'570	14'203'164	66.6%
2028	1'958'615	4'928'168	17'172'716	80.5%
2029	2'115'305	5'288'765	20'346'177	95.4%
2030	2'284'529	5'649'363	23'711'011	111.2%
2031	2'467'291	6'009'961	27'253'680	127.8%
2032	2'664'675	6'370'558	30'959'564	145.2%
2033	2'877'849	6'731'156	34'812'871	163.2%
2034	3'108'077	7'091'754	38'796'548	181.9%
2035	3'356'723	7'452'351	42'892'177	201.1%
2036	3'625'261	7'812'949	47'079'865	220.7%
2037	3'915'281	8'173'547	51'338'131	240.7%
2038	4'228'504	8'534'144	55'643'771	260.9%
2039	4'566'784	8'894'742	59'971'729	281.2%
2040	4'932'127	9'255'340	64'294'941	301.5%
2041	5'326'697	9'615'937	68'584'181	321.6%
2042	5'752'833	9'976'535	72'807'883	341.4%
2043	6'213'060	10'337'133	76'931'956	360.7%
2044	6'710'104	10'697'730	80'919'582	379.4%
2045	7'246'913	11'058'328	84'730'997	397.3%
Total	**83'547'905**	**168'278'902**	**84'730'997**	**397.3%**

Stand alone system: Financial analysis

Project : **Indode Village-Community Stand Alone Solar PV Project**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone system with batteries**		
PV Field Orientation	tilt	18°	azimuth	0°
PV modules	Model	Mono 400 Wp 72 cells	Pnom	400 Wp
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