Pan African University
Institute of Water
and Energy Sciences

PAN-AFRICAN UNIVERSITY

INSTITUTE FOR WATER AND ENERGY SCIENCES

(including CLIMATE CHANGE)

Master Dissertation

Submitted in partial fulfillment of the requirements for the Master degree in

Energy engineering

Presented by

Amira GHIED

TECHNO-ECONOMIC ANALYSIS OF HYBRID ENERGY SYSTEM FOR RURAL ELECTRIFICATION USING OPEN SOURCE ENERGY MODELING TOOL

Defended on 02 /09/2019 Before the Following Committee:

Chair	Abdellah KHALAF	Professor	CDER - Algiers
Supervisor	Olayinka OHUNAKIN	Professor	U.C.O -Nigeria
External Examiner	Daniel YAMENGEU	Professor	2iE- Burkina Faso
Internal Examiner	Chakib SELADJI	Professor	U.A.B-Tlemcen

DECLARATION

I, **GHIED AMIRA** declare that this Master Thesis was independently composed/authored by myself, using solely the referred sources and support.

I additionally assert that this Thesis has not been part of another examination process.

Signed____________________________________Date_______________

CERTIFICATION

This thesis has been submitted with my approval as the supervisor

Signed______________________________________ Date____________

ABSTRACT

The world energy demand continues to increase due to the rising population growth and industrialization. In Algeria, the conventional energy resources represent the backbone of the energy sector while the huge renewable energy potential is not exploited. The country presents an electrification rate of 100%. However, Algeria is not fully connected to the grid; people in villages that are far from the grids, are left to the use of diesel generators for electricity supply. Those generators pollute the environment and are costly. In addition, the grid-connected sites in the south are plagued with incessant power outages and poor performance of the grid during summertime. Microgrid system is found to be the best solution for rural electrification, since it can be on- or off grid-connected. This work aims to conduct the techno-economic feasibility of Hybrid Micro-Grid energy system (HMG) for a village in Adrar province in the south of Algeria. A microgrid tool based on Oemof was designed and several scenarios were examined based on the available resource. For each scenario, the power system was optimized to get the most cost-effective electricity output. The systems have been analyzed based on selected decision criteria such as Levelized cost of electricity, net present value, and renewable energy share. The wind_LPG system gives the optimum system for the selected location with an LCOE of 0.192USD/kWh and 82,71% share of wind energy, thereby presenting the best compromise between RE share and energy cost. Sensitivity analysis was also performed on all the scenarios to track the effect of variation of the decisive parameters on the optimum energy system. The selected hybrid microgrid will assist in providing reliable energy to the village and reduce the carbon emission by 73% compared to LPG fuel only system.

Keywords: Renewable Energy, rural electrification, Oemof model, LCOE, Hybrid Micro Grid.

RÉSUMÉ

La demande énergétique mondiale continue d'augmenter en raison de la croissance démographique et de l'industrialisation croissante. En Algérie, les ressources énergétiques conventionnelles représentent l'épine dorsale du secteur de l'énergie, alors que l'énorme potentiel en énergies renouvelables n'est pas exploité. Le pays présente un taux d'électrification de 100%. Cependant, la population n'est pas entièrement connectée au réseau .Pour s'alimenter en électricité, les habitants des villages éloignés des réseaux utilisent des générateurs Diesel. Ces générateurs très coûteux polluent aussi l'environnement. De plus, les sites du sud connectés au réseau souffrent de coupures de courant incessantes et de mauvaises performances du réseau en été. Pour cela, le système à micro réseau s'avère être la meilleure solution pour l'électrification rurale, car il peut être connecté ou indépendant du réseau. Ce travail a pour objectif de réaliser la faisabilité technico-économique du système d'énergie hybride à micro-réseau (HMG) pour un village de la province d'Adrar au sud de l'Algérie. Un outil de micro-réseau basé sur Oemof a été conçu et plusieurs scénarios ont été examinés en fonction des ressources disponibles. Pour chaque scénario, le système d'alimentation a été optimisé pour obtenir la production d'électricité la plus rentable. Les systèmes ont été analysés en fonction de critères de décision choisis tels que le coût actualisé de l'électricité, la valeur actuelle nette et la part de l'énergie renouvelable. Le système wind_LPG donne le système optimal pour l'emplacement sélectionné avec un LCOE de 0,192 $ / kWh et une part de 82,71% de l'énergie éolienne, présentant ainsi le meilleur compromis entre action RE et coût énergétique. Une analyse de sensibilité a également été réalisée sur tous les scénarios pour suivre l'effet de la variation des paramètres déterminants sur le système énergétique optimal. Le micro-réseau hybride sélectionné contribuera à fournir une énergie fiable au village et à réduire les émissions de carbone de 73% par rapport au système utilisant uniquement du GPL.

Mots clés : Énergie renouvelable, électrification rurale, modèle Oemof, LCOE, micro-réseau

ACKNOWLEDGEMENTS

I wholeheartedly thank the African Union Commission for providing me with such a priceless opportunity to pursue the incredible Master's degree in Energy Engineering at PAUWES (the Institute of Water and Energy Sciences), Algeria.

I am especially indebted to Professor Dr. Ohunakin Olayinka and Dr. Kathrina Cader who have provided me with academic time throughout the commencement of this thesis and their support all through the courses of the Master program.

I am especially thankful to the Reiner Lemoine Institute (RLI), Berlin. I also express my regards and appreciation to the Off-Grid team for giving me the opportunity to pursue my research stays in the institute and provide me with the necessary tools and knowledge.

Nobody has been more important to me in the pursuit of this degree than the members of my family. I would like to thank my parents, my respected father Mr. Mohammed Ghied and my mother M. Saida Merabet, whose love and guidance are with me in whatever I pursue. They are the ultimate role models. Additionally, I wish to thank my loving and supportive Brothers and sisters.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

CHAPTER ONE: INTRODUCTION

1.1. Introduction

An overview of the world electrification is conducted. The role of the hydrocarbons in the Algerian energy sector is highlighted and its impact on the economy is explained. Finally, the renewable energy potential in Algeria is discussed along with the Algerian renewable energy program.

1.2. Background Information

Worldwide, there are about 1,1 billion people lacking access to electricity today; this represents 14% of the global population. About 84% of the affected people live in rural areas.
Despite the increase of the world electrification rate, the ratio of the under-supplied people in rural areas remains almost the same due to the increasing population resulting in the rise of electricity demand. Grid extension is also found not to be feasible due to lack of finance and terrain[1]. Because of these, microgrid solution seems to be an attractive solution for rural electrification since the architecture of the systems makes it be self-sustainable, and provide clean electricity, with the option of it operating as a stand-alone system or connected to the main grid [2].

Algeria is the largest country in Africa by size and has the third-largest economy in the Middle East and North Africa (MENA) region. The hydrocarbons sector represents the backbone of the Algerian economy; their export represents more than 90% of the total exports and 20% of the gross domestic product (GDP). However, the dependence on crude oil for economic growth increases its vulnerability to crude oil price volatility[3]. Therefore, the Algerian government economic plan2016-2019 was to reduce the domestic energy consumption growth to 3% in 2030 by implementing the energy efficiency program and integrate renewables energies in the total energy production mix [3].

According to the world bank, Algeria has an electrification rate of 100% with a 98% production from non-renewable energy resources, and consumption of consummation of 58 153 Gwh in 2018[4]. With the high electrification rate, Algeria is not fully connected to the grid because of the large portion of land enclosed in the Sahara Desert (80%) and the low population density, thus making it not very feasible to connect all the inhabitant to the main grid. This situation has restricted most villages to use diesel generators as the major source to provide the energy needed for agriculture and electrification [5].

In addition to fossil energy sources, Algeria is endowed with vast renewable energy resources. For instance, the country enjoys from 1,700 to 2,263 kWh/m2/year of solar energy and a considerable wind speed in the western part of the south where average wind speeds range from 4 to 6 m/s, thereby, making the region very attractive for wind farms [6]; this potential is not yet explored.

In a bid to reduce the load on the fossil fuel utilization, and to provide the rural areas with clean and affordable energy, the governments launched the Renewable Energy and Energy Efficiency Program. With the mandate to install 22,000 MW by 2030, of which 10,000 MW is aimed to be exported to the European market and 12000 MW for the national market [7].

1.3. Problem Statement

Algeria has a 100% electrification rate with grid connection extending to the north, Adrar region, and with isolated grids in the south. However, villages, that are far from the grids, are left to the use of diesel generators for electricity supply. In most of these cases, the supply using such systems has drawbacks such as high costs of operation due to high fuel consumption, high costs of maintenance, emission of Green House Gases (GHGs and pollutants to the local atmosphere. Furthermore, for low load levels, 40–50% of the rated power of the diesel generator (DG), the diesel fuel is not completely burnt in the diesel engine thereby causing carbon build-up; in this case, the DG becomes inefficient leading to a rise in its maintenance costs [8].

The exploration of the vast renewable energies in Algeria will provide clean, affordable, reliable, and sustainable energy sources to the rural areas.

This work aims to study the techno-economic feasibility of hybrid micro-grid for rural electrification in Algeria and to choose the best combination of wind, solar, and Diesel or Liquified Petroleum Gas (LPG).

1.4. Research Questions

1) Can the microgrid (hybrid energy system), consisting of renewable energy resources and the available potential provide continuous and sustainable power to Brinkane village, in the Adrar region?

2) To what extent is the suggested hybrid energy systems able to be competitive with the isolated grid?

3) What contribution will the hybrid energy system bring to the economy and what are the likely environmental impacts?

1.5. Aim and Objectives

The aim of this work is to select the most cost-effective hybrid energy system for the rural area in Brinkane, Adrar based on the techno-economic analysis of several hybrid energy systems. The specific objectives are to:

1- estimate the load profile of Brinkane village using the load stochastic generator based in R software and the appropriate dimensions of the different hybrid systems that will guarantee the energy autonomy of Brinkane in Adrar province;

2- investigate the techno-economic possibilities of integrating a mini-grid within the community in Brinkane village, Adrar province with a measure of the impact of renewable energy potential on the system size;

3- measure the affordability of the system (specific energy price in €/kWh) with all alternatives and sensitivity analysis for customers;

4- investigate the environmental impact of renewable energy systems on the community.

1.6. Scope of the Study

Brinkane village situated in Adrar, was selected as a case study for this work due to the high wind speed and the considerable solar irradiation in the location. The community is selected due to power shortage and poor performance of the grid especially during summer season weak inaccessibility to the grid. The energy solutions are limited to off-grid renewable energies/fuel plants.

CHAPTER TWO: LITERATURE REVIEW

2.1. Introduction

An overview of the electricity access in Algeria is conducted along with the rural electrification plan of Algeria. The existing renewable energy potential is also presented. A comprehensive literature review is conducted on a hybrid mini-grid and its components, their working principle and existing technologies. The chapter is concluded with a review of energy modeling tools.

2.2Demography of Algeria

Algeria is located in the North African region of the continent. She has an area of 2,381,741km2 and a population of 42.3 million inhabitants (18 inhabitants/km2)[9]. Algeria has borders with Morocco, Mauritania, Sahara Desert, Mali, Tunisia, Libya, Niger Republic. (figure 2.1).

Figure 2.1 : Map of Algeria

2.3 Renewable Energy Potential in Algeria

2.3.1. Solar Energy Potential of Algeria

Algeria has the highest solar potential in the Mediterranean basin as shown in Figure 2.2, having about 169,440 TWh per year allocated to thermal solar applications, and 13.9 TWh/year for Photovoltaics[6].

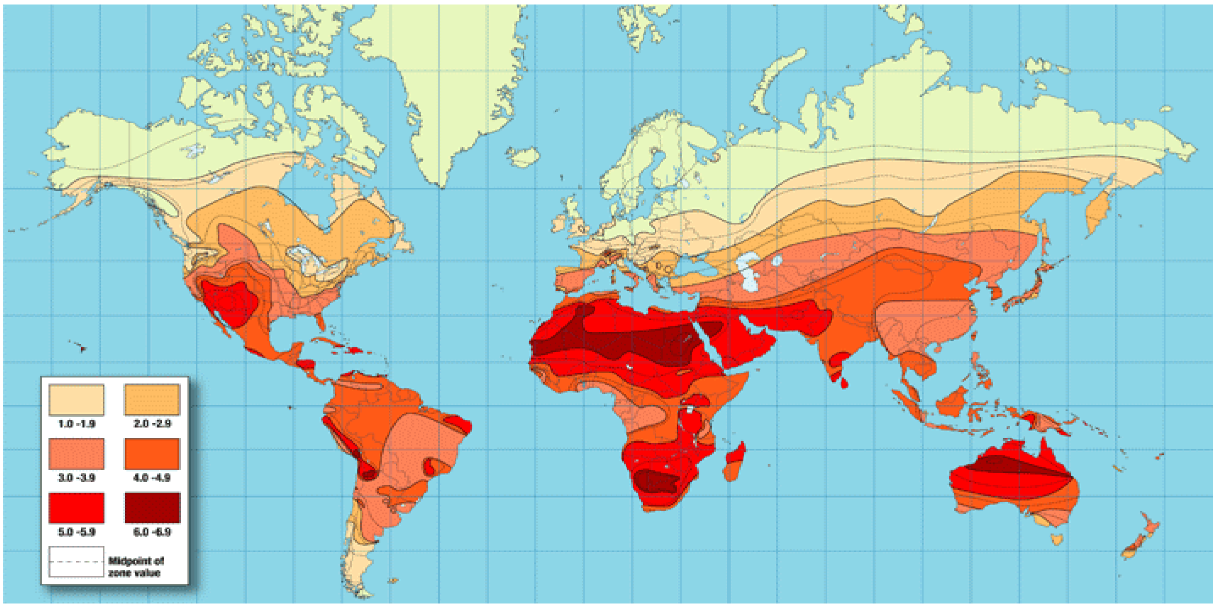


Figure 2.2 :Solar Insolation Map of the World [10]

The average sunshine duration across the country territory exceeds 2000 hours annually and reaches 3500 hours in the Sahara. It was reported in FCC PUBLIC the publisher pf professional literature, that the total exploitation of the solar potential of the Sahara desert cover of Algerian, can meet world energy need [11]. This summarized in table 2.1.

Table 2.1: Solar Potential of Algeria [12]

Region	**Coastal regions**	**Highlands**	**Sahara**
Surface %	4	10	86
Average sunshine duration (hours/year)	2650	3000	3500
Average energy (kWh/m²/year)	1700	1900	2650

2.3.2. Wind Energy Potential of Algeria

Algeria also has a considerable wind potential (figure 2.3). A total of 21 zones have been identified as areas with high wind potential having wind speed ranging from 5 to 9 m / s (at 150m altitude)like Tindouf, Bachar, and Adrar [7]. The wind maps also show that the highest wind speeds are distributed in the south while the north is generally less windy. It was also found that the south-western region has great potential with speeds exceeding 4m/s.

The south-western region is found to be close to the Atlantic Ocean(weather disturbance reaches the region with high intensity), and located in an area of high-pressure difference(wind in the latitude near 30°N)[13].

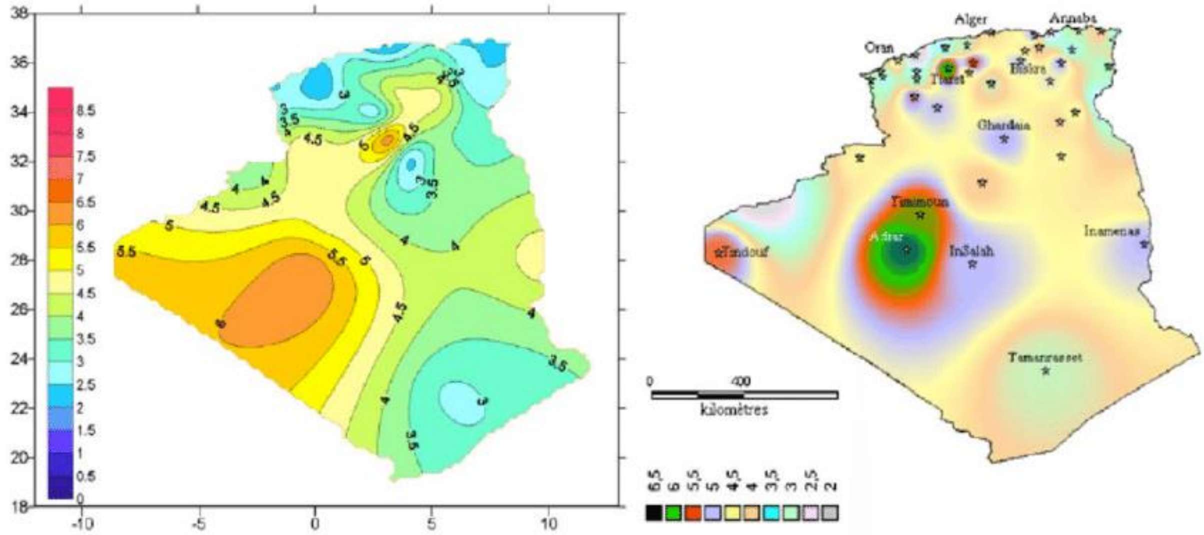


Figure 2.3: Wind Potential of Algeria [13]

2.3.3. Geothermal Energy Potential of Algeria

According to by the Centre of renewable energies development (CDER) Algeria possesses more than 200 geothermal sites. One-third of these locations have temperatures exceeds 45 ◦C, and the highest as 98 ◦C and 118 ◦C in Hamam El Maskhoutin and Biskra, respectively[5].

With the existing potentials, application of this resource is only found in leisure and therapeutic purpose by the locals [14].

2.3.4. Biomass Energy Potential of Algeria

Algeria has huge biomass potential with 3.7 Mtoe per year coming from forests and 1.33 Mtoe per year coming from agricultural and urban wastes, and with green waste per person represent 365 kg. Despite the important potential, exploitation is still minimal and need to be enhanced. For instance, a study showed that a discharge of Oued Smar will allow the production of 2 MW and can reach a peak of 6 MW [5].

2.3.5. Hydropower Energy Potential of Algeria

Algeria has an estimated from important water flows at 65 billion cubic meters, but not fully exploited due to restrained rainfall days, high evaporation and quick evacuation to the sea. Currently, 103 dam sites exist of which more than 50 dams are operational[5]. The largest 13 dams have a capacity of only about 269 MW and they are summarized in table 02 [5]. The hydroelectric production is the second-largest share of energy production from renewables, it is representing 1% of the total electricity production in Algeria with 265 GWh in 2003.

Table 2.2: Largest Hydropower Dams in Algeria [5]

Plant	Installed power (MW)
Darguina	71.5
Ighil Emda	24
Mansouria	100
Erraguene	16
Souk El Djemaa	8.085
Tizi Meden	4.458
Ghrib	7
Ighzernchebel	2.712
Gouriet	6.425
Bouhanifia	5.7
Oued Fodda	15.6
Beni Behdel	3.5
Tessala	4.228
Total	**269.208**

2.4Electricity Access Rate and Real Price in Algeria

Algeria had opted for the development of the energy sector, as part of the national development policy of electricity and gas infrastructure since independence in 1962. This policy aims to provide the population with electricity and natural gas as a top priority for improving the quality of life of the citizen and the economic situation of the country.

2.4.1 Electricity Network Algerian

The Algerian electricity network has a production installed capacity of 18,985 MW shared between the national grid (17,477MW), Adrar region grid(917MW), and isolated grids(786Mw)[7].

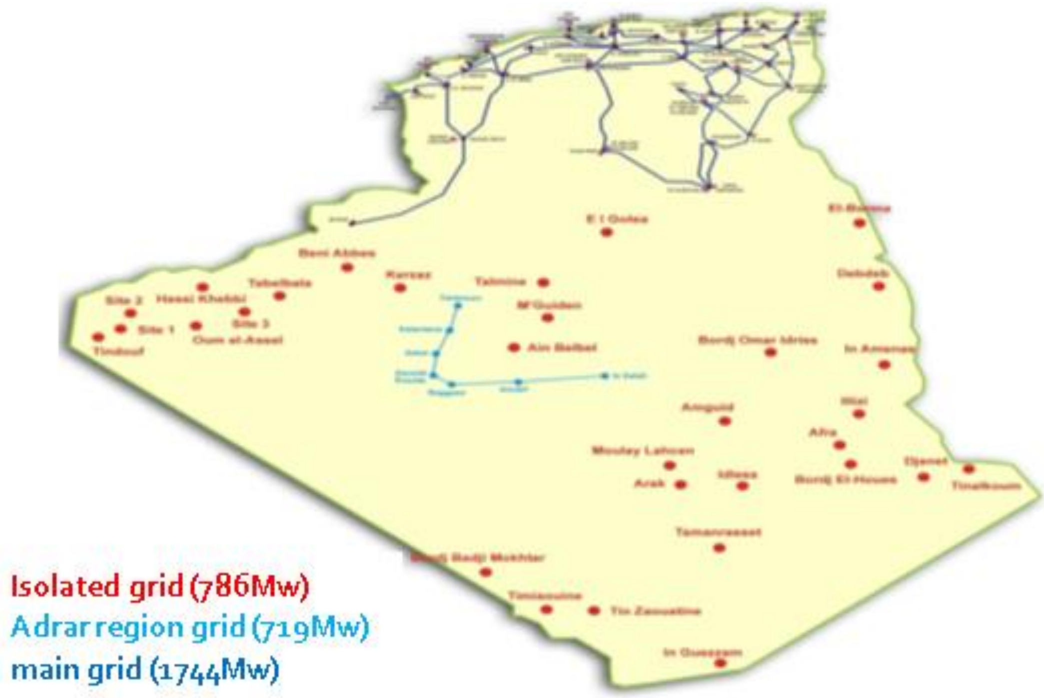


Figure 2.4: Electricity Network Map of Algerian [7]

As shown in Figure 2.4, it can be seen that the national grid network covers the north of the country and some regions of the south (Bechar, Hassi Messaoud, Hassi R'mel, Ghardaia). In this network, 40 power plants are interconnected through high voltage transmission lines (200 kV, 400 kV). The grid in Adrar region is supplied gas turbines to feed the regions of InSalah, Adrar, Timimoun via 220 kV transmission lines. The isolated grid networks are in 31 remote sites and powered by small diesel and gas turbines power plants.

2.4.2 National Production by Sector

A recent report by SONALGAZ and world bank statistics ascertained that Algeria has an electrification rate of 100% with a consumption rate of 58 153 Gwh in 2018[4]. compared to

2017. The electricity consumption grew by 4.9% to reach 13.9 Mtoe in 2018. This rise resulted from the increase in demand by SONALGAZ 's customers, whose total number of subscribers exceeded 9.6 million at the end of 2018, against 9.2 million at the end of 2017 (about 4.6% increase).

According to table below(table03) based on the Ministry of Energy and Mines (MEM) report 2018, Table 2.3 shown that renewable energies represent 1.024% of electricity production obtained from the 2018 report of the Ministry of Energy and Mines [15].

Table 2.3 : Electricity National Production by Sector [16]

Source	**Value (KTep)**
Combined cycle	6764
Gas turbine	7608
Vapor turbine	2422
Diesel	75
Hydro energy	28
Solar and wind energy	160
Autonomous production	1302
Total	**18358**

2.4.3 Renewable Energy Policy in Algeria

The government of Algeria has been paving the way for renewable energy development since 1999, by enacting specific legislative framework and implement a financial scheme for the development of the renewable energy, through the establishment of the renewable energy legal framework.

The legislative framework and its development are summarized in Figure 2.5 and the details about the law can be accessed through the website of the Ministry of Energy and Mines.

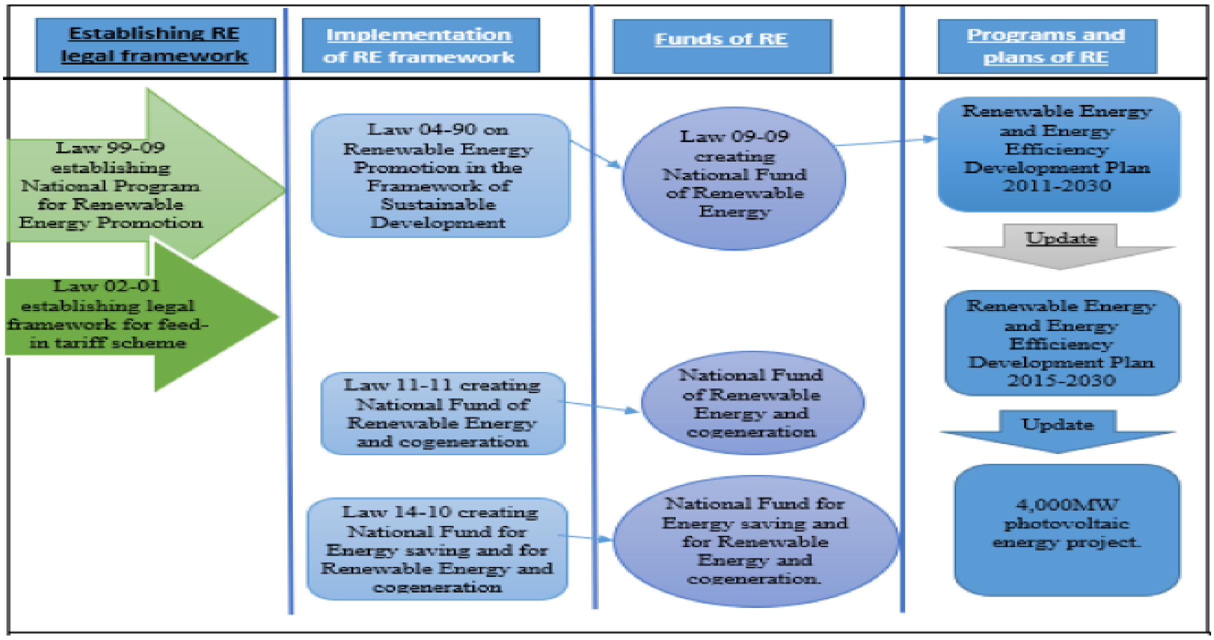


Figure 2.5 : Legal Framework of Renewable Energies in Algeria

In2015, the renewable energy program was updated, and the actual target was to achieve 22 GW by 2030. According to these projections, the total installed capacity based on PV would be to reach about 13.6 GW by 2030. The total wind-based power generation capacity would be about 5 GW. While that from Concentrated Solar Plant (CSP) technology was postponed to 2021 but was to reach 2 GW installed capacity by 2030. The total capacity from biomass would be about 1 GW by 2030[17].

Table 2.4 : Renewable Energy Plan for Algeria [17]

Source	1st phase 2015-2020 (MW)	2nd phase 2021-2030 (MW)	Total (MW)
Solar PV	3000	10575	13575
Wind	1010	4000	5010
CSP	-	2000	2000
Cogeneration	150	250	400
Biomass	360	640	1000
Geothermal	5	10	15
Total	**4525**	**17475**	**22000**

2.4.4 ral Electrification

Despite the high electrification rate, Algeria is not totally connected to the grid because of the high coverage of the Sahara Desert (80%) and the low population density in the region. In 2010, statistics showed 260000 villages which are not connected to the general electricity network[12]. Those villages use diesel generators as the source of power. These diesel generators are becoming costly, and they also pollute the environment.

In a bid to enhance rural electrification in Algeria and to implement the renewable energy plan, the National Gas and Electricity Society (Sonlgaz) launched a project called "Solar Villages" through which solar photovoltaic kits are being deployed all over isolated villages having a limited number of houses[18]. The project was implemented in two phases and covered a total of 34 villages [12]. Another project was also carried out for refugees at "Assekrem" in Tamanrasset; this project was a collaboration between the Renewable Energy Development Center (CDER), the "InstitutCatalàd'Energia" (ICAEN) and the region of Tamanrasset[5].

In addition, about 444 solar panels were distributed in 2014 in M'sila to supply isolated houses and provide them with clean and sustainable electricity. At El Bayadh, after first satisfying operation, a second project was launched in 2012 to supply 540 nomad families with photovoltaic kits.

Table 2.5: Distribution Per Province of PV Systems [12]

Province	Homes by unit	Power (kW) Energy	Energy (kWh)	Additional available energy (kWh)
Tamanrasset	555	277.5	1665	4026
Illizi	150	75	450	1100
Tindouf	156	78	468	1144
Adrar	45	22.5	135	330
Total	906	453	2718	6600

3 Real Electricity Price in Algeria

A statistics in 2017 showed that the electricity price in Algeria is 0.04 \$/kW, with a subsidy of 2.3 billion dollars to the electricity price [19] and with total unity consumed of 60.7 Twh [20]. Using the relation provided by the international energy agency (2.1):

$$\text{Subsidy} = (\text{Reference price} - \text{End-user price}) \times \text{Units consumed} \quad (2.1)$$

We find:

$$\text{Reference price} = [\text{Subsidy} / \text{Units consumed}]-+\text{End user price}$$

Therefore:

$$\text{Reference price} = (2.3*10^9/60.7*10^9)-0.04$$

Reference price=0.0778 \$/kWh

The real price of electricity without subsidy is 0.778 \$/kWh which represent 200% of the market price.

2.5 Case Study

Brinkane is a village in Tsabit district in Adrar province. It is located at 28,4007 ° north of latitude and -0,2377 ° west of longitude. Brinkane is 6.5km from Tsabit district and 80 km from Adrar.

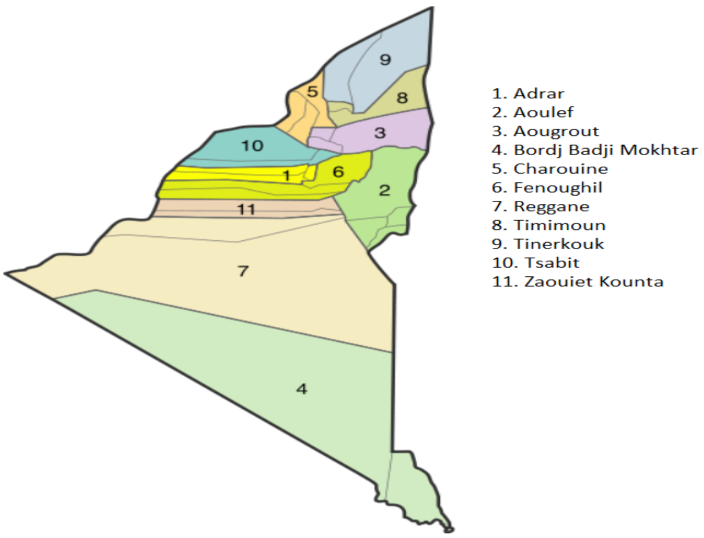


Figure 2.6 Map of Adrar [21]

With low population density, Brinkane is connected to electricity from the grid at Adrar region. This grid witnessed numerous blackouts and shortages especially during summer, because of the hot climate and the extensive use for air conditioning.

Adrar region is in the Saharan arid zone. The region is characterized by relatively flat terrain with the highest point reaching 421 meters which make it a good location for wind and PV installation. Hence, with the vast solar and wind potential of Brinkane, and the problem of electricity shortage and far distance from the grid, the location is found excellent for this study.

2.6Hybrid Microgrid

2.6.1. Definition of Hybrid Microgrid (HMG)

According to the U.S. Department of Energy, a 'microgrid' is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island model [22].

Three main possible configurations exist, but based on the application, the particular configuration will be selected for this [23].

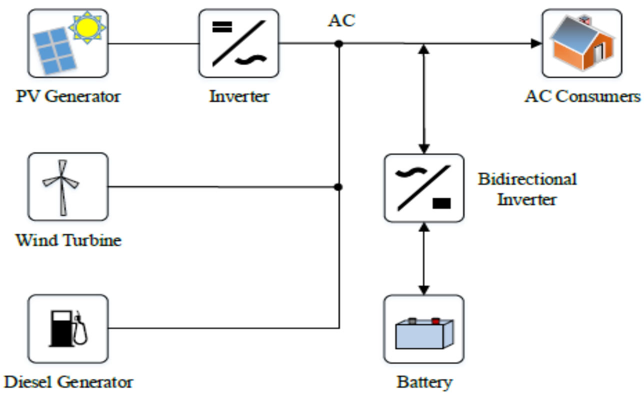


Figure 2.7: Schematic Interconnection of an AC-based HMG [24]

a) DC coupled systems

This consists of DC sources and DC loads in which the main advantage is there is no need to synchronize the system that can be used for DC micro-grid.

b) AC coupled systems

They are further categorized into two types namely:

i. power frequency AC coupled system:

Both the sources and loads are AC which results in ease of protecting the system.

ii. high-frequency AC coupled system:

This consists of AC sources operating at different frequencies and high-frequency loads which leads to the high efficiency of the system.

c) Hybrid coupled systems

Here, sources and loads can be AC as well as DC which provides the highest efficiency, and it is more flexible compared to the earlier configurations.

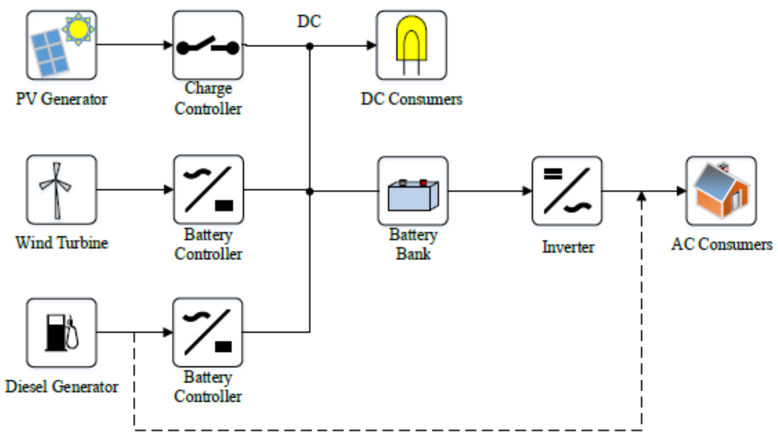


Figure 2.8: Schematic Interconnection of a Hybrid Coupled System [24]

The detailed explanations of the configurations in Figure 2.8 can be found in the reference a [25]. However, it should be noted that the hybrid coupled system is selected by Microgrid tool for the optimization of the system in this thesis.

2.6.2. Technological Components of a Microgrid

The basic working principles of HMG components are briefly described. Hence, the description is limited to a selection of the most important components that are used in this work, namely: Gensets, PV Systems, wind turbine, and energy storage systems.

2.6.2.1. Photovoltaic System

In a photovoltaic system (PV), the sunlight is converted into electricity without any heat engine to interfere. Photovoltaic devices can be constructed as stand-alone systems and give an output from microwatts to megawatts. They are used as a power source, in water pumping, remote buildings, solar home systems, communications, satellites, and space vehicles, reverse osmosis plants, and for even megawatt-scale power plants. With such a vast array of applications, the demand for photovoltaics is increasing every year[26].

Moreover, a solar PV system consists of various PV modules that are interconnected in a parallel and series circuit, being complemented by other components, such as inverters, Maximum Power Point Trackers (MPPT), and charge controllers.

a) Technologies PV Cells

A photovoltaic cell is an electronic device which directly converts sunlight into electricity [27]. There are two broad categories of technology used for PV cells, namely: (i)crystalline silicon which represents 80% of the cell production in the world, and (ii) thin film which is newer and growing in popularity. The laboratory existing technologies of PV systems are as shown in Figure 2.9.

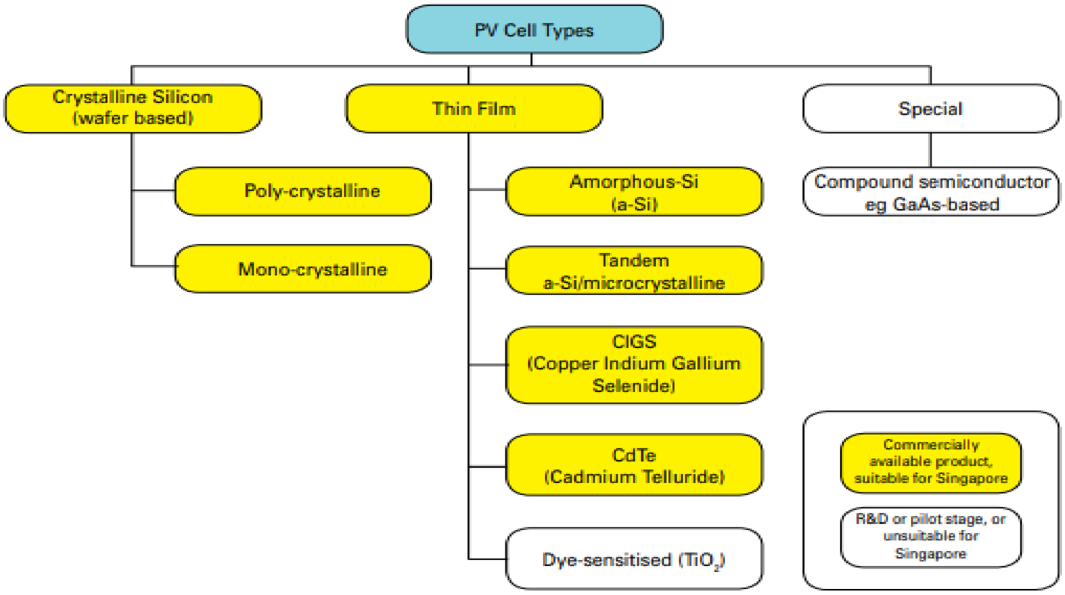
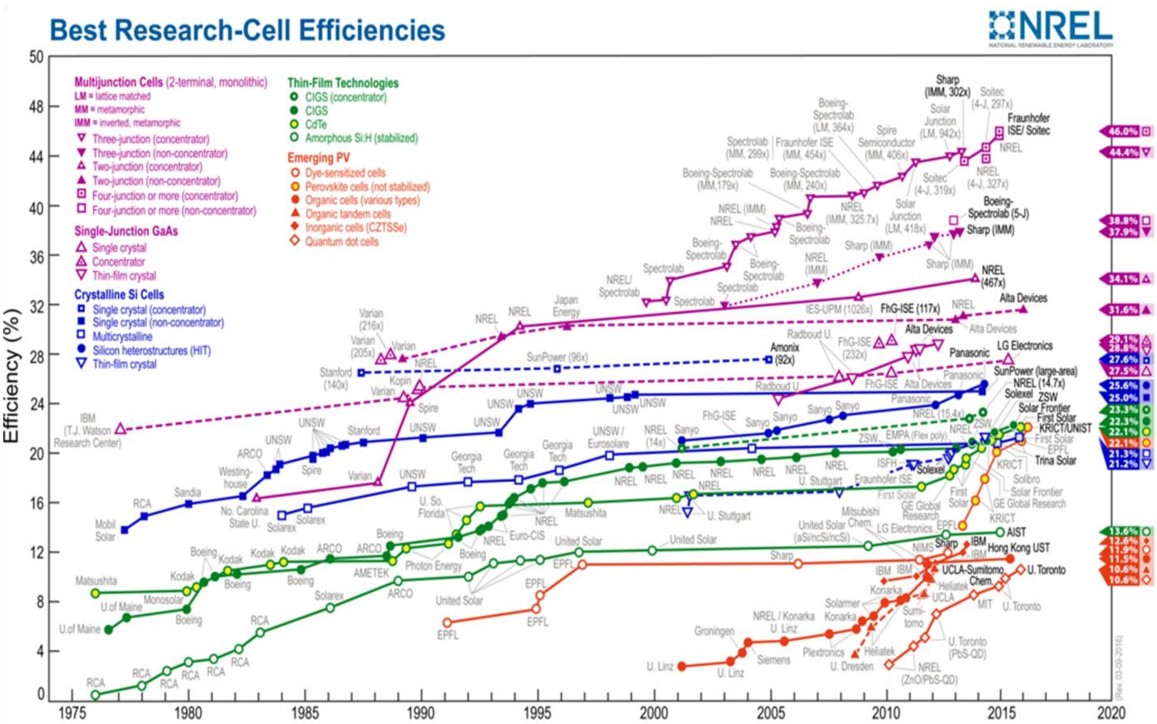


Figure 2.9: Existing Technologies in Photovoltaic [28]

The National Renewable Energy Laboratory (NREL) maintains a plot of compiled values of highest confirmed conversion efficiencies for research cells, from 1976 to the present, for a range of photovoltaic technologies.



Source: NREL

Figure 2.10: Efficiency Evolution of PV Cell Technologies [29]

This chart highlights cell efficiency results within different families of semiconductors: (1) multijunction cells, (2) single-junction gallium arsenide cells, (3) crystalline silicon cells, (4) thin-film technologies, and (5) emerging photovoltaics. As shown in Figure 2.10, the best efficiency of silicon cells obtained so far is 26.1%, while multi-junction solar cells have a much higher efficiency of 46% at laboratory level. Moreover, Cadmium Telluride (CdTe) and Perovskite PV cells have seen an increase in efficiency, reaching 22.1% and 22.7% respectively [29].

b) Electrical Characteristics of PV Cells

In a solar PV cell, the amount and intensity of solar insolation (solar irradiance) control the amount of output current (I) while the operating temperature of the solar cells affects the output voltage (V). Therefore, Solar cell I-V characteristic curves that summarize the relationship between the current and voltage and the PV array electrical characteristics further summarizes the relationship between the output current and voltage of the array based on the installation type.

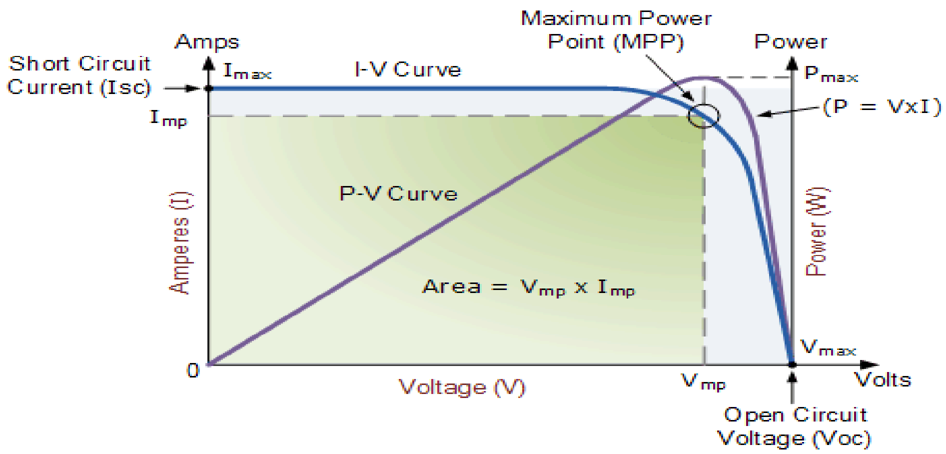


Figure 2.11: The I-V-Curve of a PV Module [30]

i. **V_{OC} (open-circuit voltage):** This is the maximum voltage that the panel provides when the terminal is not connected to any load (an open circuit condition)

ii. **I_{SC} (short-circuit current):** The maximum current provided by the PV array when the output connectors are shortened together (a short circuit condition).

iii. **MPP (maximum power point):** This relates to the point where the power supplied by the array that is connected to the load (batteries, inverters) is at its maximum value, where MPP = Imp x Vmp. It is measured in Watts (W) or peak Watts (Wp).

iv. **FF (fill factor)**: The fill factor is the relationship between the maximum power that the array can actually provide under normal operating conditions, FF= Voc x $I_{sc.}$ This value of fill factor gives an idea of the quality of the array; the closer the fill factor is to 1 (unity), the more power the array can provide. Typical values are between 0.7 and 0.8.

v. **%µ (percent efficiency)**: The efficiency of a photovoltaic array is the ratio between the maximum electrical power that the array can produce compared to the amount of solar irradiance hitting the array. The efficiency of a typical solar array is normally low at around 10-12%, depending on the type of cells (monocrystalline, polycrystalline, amorphous or thin-film) being used.

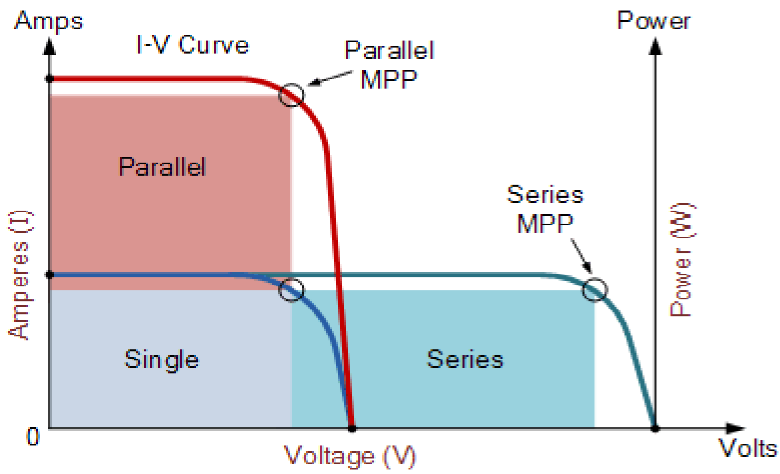


Figure 2.12 Solar panel IV curve [30]

Based on the installation of the solar PV array both high voltage or high current can be obtained. The curve on figure 2.12 illustrates the characteristics of a solar PV array output for both series and parallel installation.

2.6.2.2. Wind turbine

According to the World Wind Energy Association (WWA), the overall installed capacity worldwide reached 597 Gigawatt by the end of 2018[31]. The wind technology is improving and the capital cost is continuously decreasing, the installed capacity is predicted to exceed 760 GW by 2020 [32]. Figure 2.13 represent global cumulative wind power capacity from 1999 to 2020.

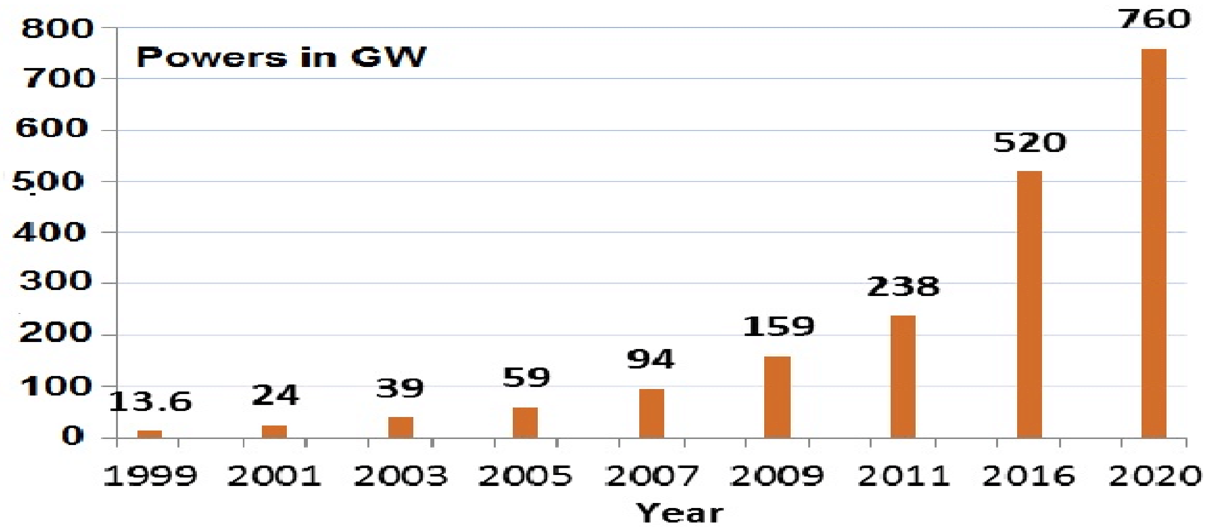


Figure 2.13 Global Cumulative Wind Power Capacity from 1999 to 2020 [32]

a) Wind Turbine Components

A wind turbine is a machine for converting the kinetic energy in wind into mechanical energy[33]. The machine that converts mechanical energy to electricity is called a wind generator. It consists principally of a rotor, an electric generator, and a gearbox. Figure 2.14 shows all the components of a horizontal axis wind turbine (HAWT)[34].

The energy conversion in current wind turbines is done in two processes, the rotor first extracts the kinetic energy of wind by means of friction between the air and its blades. With the help of a shaft, the rotor converts the kinetic energy into mechanical torque, the generator then converts the mechanical energy into electricity[35]. Although this working principle sounds rather straightforward, wind turbines are complex systems and require knowledge of aerodynamics, mechanical, civil, electrical and control engineering[33].

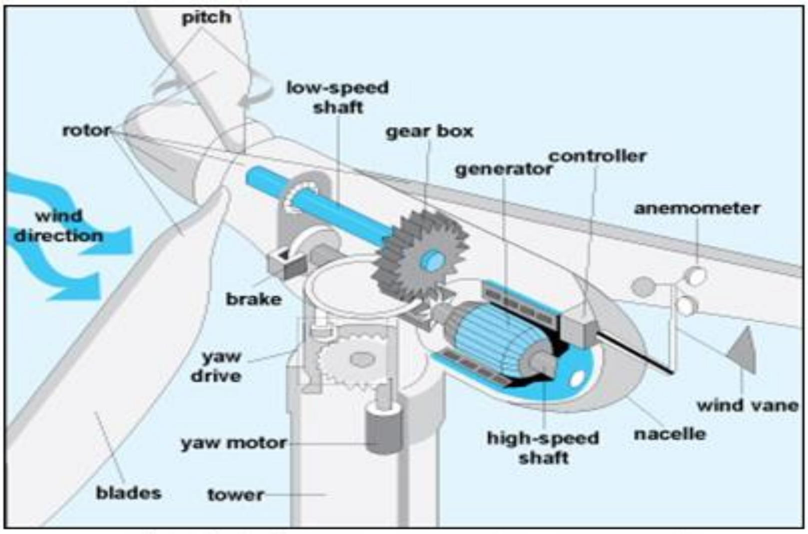


Figure 2.14: Wind Turbine Components [34]

b) Classification of Wind Turbine

Wind turbines are classified based on the axis, see Figure 2.15 [33]:

i) Horizontal axis

- Coaxial, multiaxial, multi-rotor horizontal axis turbines
- rotor horizontal axis turbines
- Counter-rotating horizontal axis turbines

ii) Vertical axis

- Darrieus wind turbine
- Giromill wind turbine or cycloturbines
- Sarvonious wind turbine
- Terra Moya Aqua wind turbine

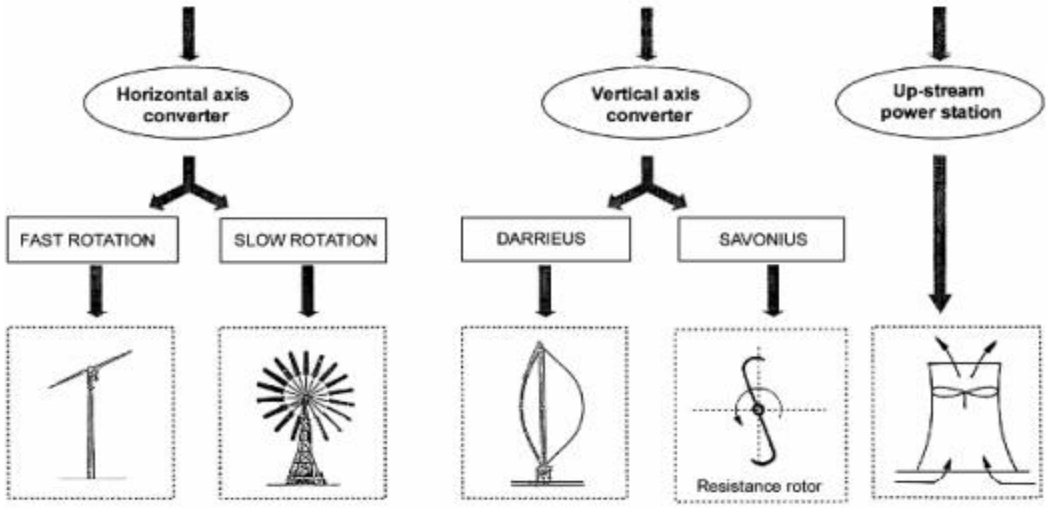


Figure 2.15: Types of Wind Turbines [35]

Besides wind turbine can also be classified based on location: Onshore, Offshore or Deepwater.

2.6.2.3. Energy Storage Systems

Energy storage systems are used to store energy converted from one form (mainly electrical energy) then convert it back into electrical energy when needed[36]. Different energy storage technologies have been developed by using various energy converting strategies. Those technologies can be categorized into[37]:

- Mechanical (pumped hydroelectric storage, compressed air energy storage and flywheels),
- Electrochemical (conventional rechargeable batteries and flow batteries),
- Electrical (capacitors, supercapacitors and superconducting magnetic energy storage),
- Thermochemical (solar fuels)
- Chemical (hydrogen storage with fuel cells) and
- Thermal energy storage (sensible heat storage and latent heat storage).

Each of the above approaches has advantages and disadvantages based on energy density, capacity, price and potential for scale-up e.g. batteries and supercapacitors, respectively, cover the mid-time range, minutes to hours and allow scale-up to MW-size [38]. Potential mechanical energy as pumped-hydro and compressed air energy storage may reach GW size [38].

However, the latter largely depends on the geographical conditions e.g. lakes in mountain areas or underground salt caverns. Chemical energy storage, as hydrogen, has the largest potential for large-scale energy storage, which is far out of the scale shown in Figure 2.16 This may be achieved simply by storage of compressed hydrogen gas in large stationary tanks or underground cavities, liquid hydrogen, or liquid hydrogen carrier e.g. ammonia and liquid organic hydrogen carriers [38].

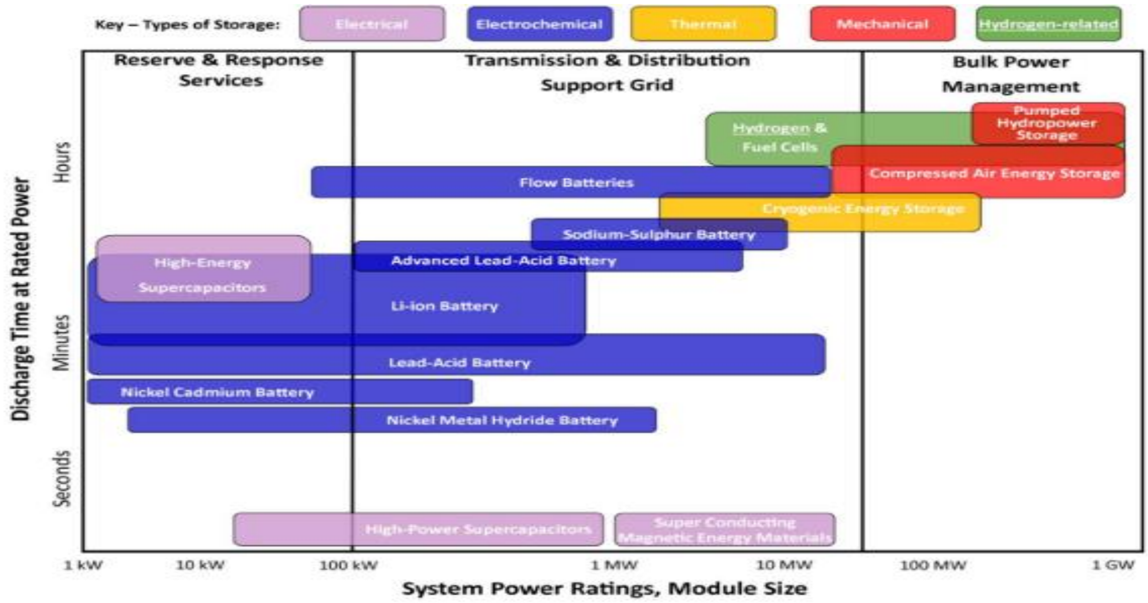


Figure 2.16: Comparison of Key-Type Energy Storage Technologies In Sense of Storage Capacity and Discharge Power Duration [38]

In a hybrid mini-grid system energy storage can be used to provide stabilization for both grid-connected and off-grid systems. Therefore, for the off-grid system's storage provides or absorbs power to balance supply and demand, to counteract the moment to moment fluctuations in customer loads and unpredictable fluctuations in a generation[39]. Also, grid-connected, energy storage systems can also provide ancillary services to improve power quality such as voltage and frequency regulation, harmonic filtering, and fault clearing (i.e. supply of short circuit current). This result in an increase in system efficiency and cost reduction[39].

2.6.2.4. Generator Set

A generator is a machine that transforms mechanical energy into electrical energy through the combustion of fuel [40]. The fuel can be diesel, gasoline, natural gas, propane, biodiesel, water, hydrogen or sewage gas. Some generators are a dual-fuel engine.

The liquefied petroleum gas (LPG) is the most attractive alternative fuel for both compression ignition (CI)and spark ignition (SI) engines. LPG fuel use in engine present[41]:

- cost-effectiveness;
- better mixing and combustion compared to other fuels;
- lower fuel consumption;
- and improved emission characteristics.

a) Dual Fuel Engine

Dual-fuel engines are engines that can run on diesel and gas simultaneously by using an electronic controller for fuel flow[42]. This allows the switch between diesel mode and gas mode as required. In diesel mode, an actuator mechanically operates the fuel pump's flow control lever, whereas, in gas mode, the timing for opening the gas valve is controlled electrically with the energizing duration of time for an electromagnetic solenoid[42].

The internal combustion engines can be classified into four-stroke and two-stroke engines respectively. For local power generation, four-stroke engines are mainly used[43]. The four-stroke cycle process is represented in Figure 2.17 as discussed below.

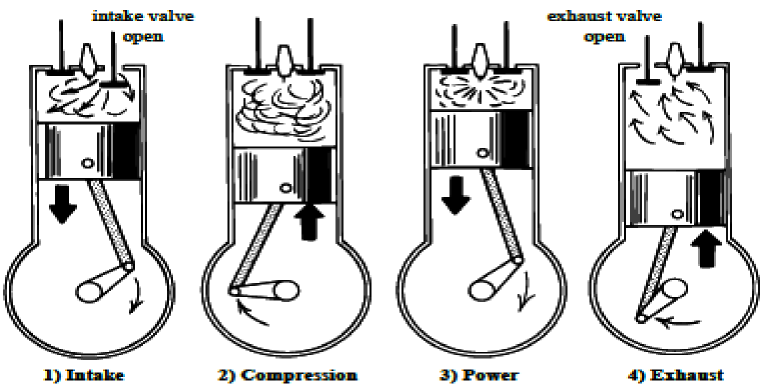


Figure 2.17: Four-Stroke Cycle of an Internal Combustion Engine [43]

i) **Intake Stroke:** Fresh air gets absorbed into the combustion chamber, as the cylinder moves downwards. The intake valve is open, while the exhaust valve is closed. The fuel injector sprays the fuel into the cylinder to achieve the perfect air-fuel ratio. The downward movement of the piston causes the air and fuel to be sucked into the cylinder[44].

ii) **Compression Stroke:** The piston moves upwards, as the air is compressed and heated (around 600°C). Both, the intake and exhaust valves are closed. The compression makes the air-fuel combination volatile for easier ignition[44].

iii) **Combustion/Power Stroke:** both the intake and exhaust valves are still closed. The spark plug produces a spark to ignite the compressed air-fuel mixture. The resulting energy of the combustion forcefully pushes the piston downward[44].

The rotational speed n causes the resulting volumetric expansion producing a force that pushes the piston downwards. A torque M(n) is induced, and when multiplied with the rotational frequency w = 2pn describes the mechanical power output Pm as expressed in Equation (2.2) [44].

$$Pm = M(n) \cdot w \qquad (2.2)$$

iv) **Exhaust Stroke:** The rotating direction of the crankshaft is reversed, as the piston reaches the bottom of the cylinder. The exhaust valve is open, while the intake valve is closed. Combustion residues are released out of the chamber. Finally, the cycle can be repeated [44].

2.7 Energy Modeling Tools

Driven by the technological improvements, falling costs, a proven track record, and growing recognition of the microgrid benefits [2], microgrids are progressively an option for electricity access in unelectrified areas in developing nations [45]. Hence, the increase of complexity of the microgrids caused by the intermittent nature of renewable generation as well as dynamic operating conditions of storage systems increased the need for microgrid simulation, sizing, and optimization tools [46].

Numerous tools emerged that can aid project planners in designing microgrids; they are based on a different programming language, and they can be either open-, closed- or closed-and-paid-code [47].

2.7.1. Closed Modelling Tools

Many closed-code commercial software tools are in the market; examples are like iHoga ®, PVSyst®, Polysun®, TRNSYS®. other software with their details can be found in the following references [47][48]. The most commonly, proprietary software is Homer®. Homer is closed-source and paid software developed by the National Renewable Energy Laboratory (NREL) for both on-grid and off-grid systems.

Homer® software allows:

- User-friendly GUI, quick guidance
- a huge number of advanced component models
- comparatively fast time intervals (8760-time increments in less than one minute).
- sensitivity variables.

The huge number of recently published studies that perform optimization and sizing with Homer® highlights its popularity amongst practitioners [46][47][48].

2.7.2. Open Modelling Tools

The high cost of license and inability to customize the internal code leads to the adoption of more open-source energy modeling tools such as Oemof, Calliope, OSeMOSYS, URBSS. Open source tools are therefore used [49]:

- To increase public transparency and public trust;
- for scientific reproducibility, and open development;
- for reduction of bottom-up planning barriers;
- to facilitate inclusive planning methods.

However, open-source modeling tools present some problems and barriers. First, most of the commercial and open-source codes available in the market are characterized by a limited number of components or offer limited complexity in the design of component models[50]. Further limitations are found in terms of user-friendliness or easy-to-use capabilities, such as an intuitive GUI as well as a complete, well-structured and accessible documentation[50]. Furthermore, a synonym of free-to-use so-called open-source models exist that are developed in programming languages, including the Generic Algebraic Modelling System (GAMS), or solved with proprietary solvers, that in both cases require license [50].

Therefore, in order to overcome these barriers, an Open Energy Modelling Initiative has been launched by a community [51]. This community can be regarded as a hub for sharing open data and code, in which the term open means to be published under an open-source or copyleft license. The community aim is to improve the quality of energy models by increasing scientific standards, reduce the double-work in recurring processes, and collaborative model development. Therefore, those frameworks can be used for the development of various applications in the field of energy system modelling [51].

CHAPTER THREE: METHODOLOGY

3.1 Introduction

The different software tools used for the assessment and optimization were described. The weather profile will be examined, and the load will be estimated. Then the techno-economic parameters will be determined.

Finally, the environmental impact of hybrid energy systems will be studied.

3.2 Software Tools

Three (3) software tools were used to first carry out the assessment of the renewable energy potential of the case study, another tool was used to simulate the load profile of the case study and the last to simulate and optimize the different scenarios and to obtain a techno-economic and environmental study of the systems.

3.2.1 RENEWABLES NINJA

The weather data of the selected case study are hard to obtain. besides, the optimization tool selected uses the time-series power output of both wind and PV. Because of these, an open-source web tool called Renewables ninja was selected to conduct the study.

Renewables ninja allows an hourly simulation of the power output from wind and solar power plants located anywhere in the world. The tool was developed by researchers from Imperial College London and ETH Zurich with the aim of improving the prediction of renewable output for both academic and industrial purposes.[52]

The tool can be found in the link: https://www.renewables.ninja/

3.2.2 R Tool for stochastic load generator

This study uses a simulation tool developed in the open-source programming language R, working with a multitude of input data specified in an Excel datasheet. The simulation generates the daily load profile of a household. The tool estimates a time series with half an hour step, covering a whole day.
The code is attached in the annex A.1.

The tool needs input parameters to create an output load profile of the selected case as described below in details.

a) Input Parameters

For a single household, the different types of appliances per household with their quantity are to be determined. Also, the power ratings of the appliances including AC and DC have to be recorded. Furthermore, for each appliance, we define the number of occurrences an appliance can have for one day (t1, t2, ..., tn) and the range of duration those occurrences can have (T1, T2, ...Tn). Finally, an availability window (W) that determines the hours of the day when the appliance could be used should be defined[53].

Figure 3.1 shows the input parameters needed for one single appliance.

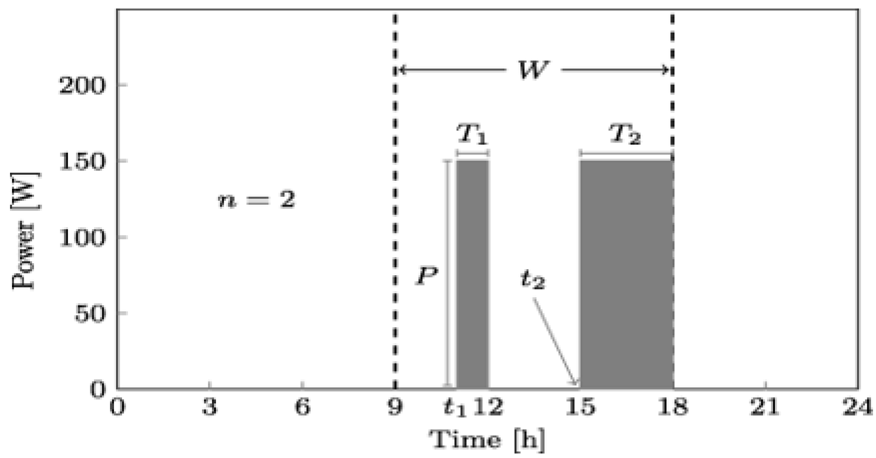


Figure 3.18: Illustration of Load Usage Window (W) and Load Occurrence during the Day [53]

Once all the inputs are defined, the load modeler will randomly determine for each application the number of occurrences, duration of occurrences and their starting time. Once this has been done for every occurrence, an appliance load profile for 24 hours with a time step of an hour is generated. This is conducted for every appliance and appliance type. The flowchart shown in Figure 3.2 conveys the methodology employed for one appliance. The load profile for a household would, therefore, be the sum of the process shown below for each appliance.

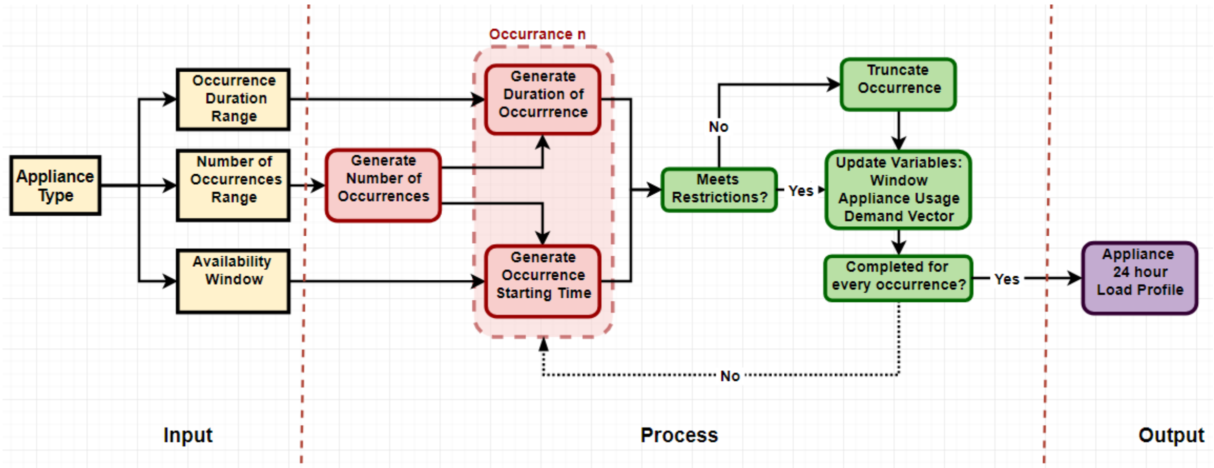


Figure 3.19: Load Modeler Flow Chart for One Appliance.

b) Output Chart

The load profile for a household would be the sum of the process shown above for each appliance. The result of this sum is a daily load profile (figure 3.3). To achieve a yearly load profile, this process is repeated for each day in the year, thus resulting in a load curve where every day is different, with the intent of simulating real-life variability.

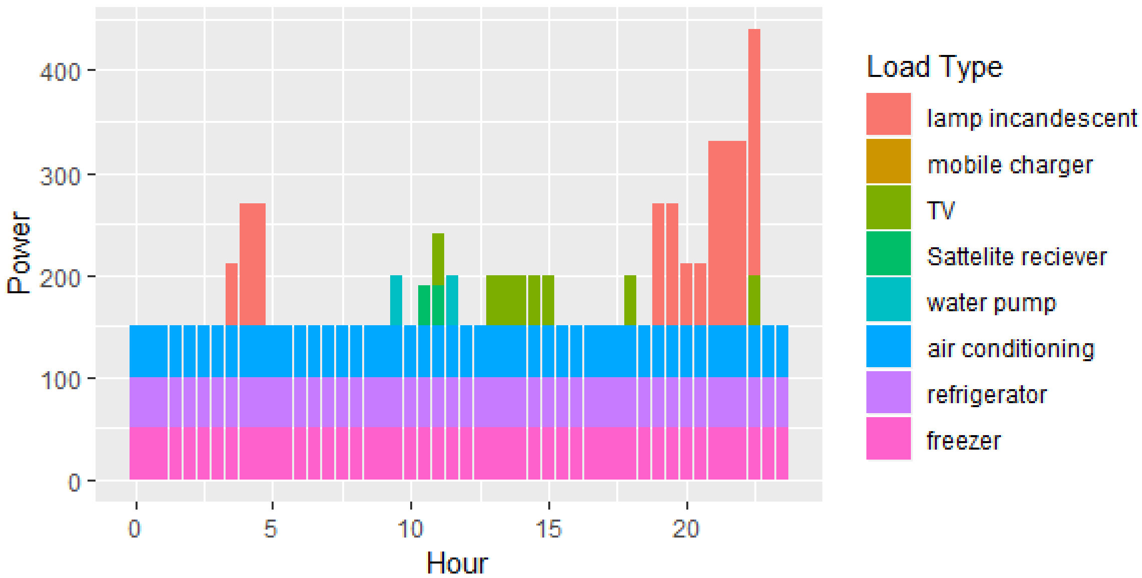


Figure 3.20: Daily Load Profile for a Basic Household in Brinkane

3.2.3 Micro-Grid Tool Based on Open Energy Modeling Framework (Oemof)

The Micro-Grid tool is developed on Open Energy Modelling Framework (Oemof), to model, optimize and study the sensitivity parameters of both off-grid and grid-connected hybrid energy systems. For better understanding, a simple introduction to Oemof and an explanation of how the different component models are connected to the energy system model are explained.

3.2.3.1. Open Energy Modeling Framework (Oemof)

The Oemof provides a free, open-source and clearly documented toolbox to analyze energy supply systems. It is a generic framework that can be applied for various purposes in the field of energy system modeling. This signifies that Oemof is not limited to a specific mathematical approach or to restrictions of spatial or temporal resolutions [54].

The tool can be accessed at:

https://github.com/smartie2076/simulator_gridconnected_micro_grid/releases/tag/V3.0_bata

The Oemof is developed in the object-oriented programming language Python and designed as a framework with a modular structure containing several packages which communicate through well-defined interfaces [55].

An energy system in Oemof is portrayed as a network consisting of **nodes** that are connected with **flows**. In which nodes are divided into buses and components, where components are meant to represent both producers and consumers of energy system while buses are connected to components and represent how the components are connected together. On the other hand, inputs and outputs are represented by flows.[56]

There are three types of components: Sources, Sinks, and Transformers, and objects of the Generic Storage-class. These are classified according to the number of attributes and the types of flows that connect the different components. They are represented in Figure 3.4:

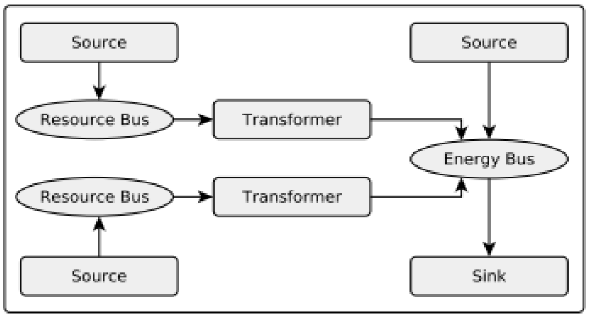


Figure 3.21: Schematic Illustration of an Energy System Represented as an Oemof Network [56]

- **Transformers** and **Generic Storages** have both inflows and outflows. For example, a battery can be charged form the electricity bus in the morning and used as a source at night.
- **Sinks** only have inflows but no outflows. Sinks can represent consumers of the energy system e.g. electrical appliances, loads, etc.
- **Sources** have outflows but no inflows. Sources can be used to model energy producers e.g. RE power generators, natural resources, etc.

With the scope of this work, the description of the framework should be limited to its basic principle. The detailed mathematical approach of Oemof can be found in [57].

3.2.3.2. Micro-Grid Tool

A microgrid optimization tool utilizing the Oemof, based on python3 is used. Due to its interface and coding structure, the developed tool can not only be applied to optimize microgrid systems but various on- or off-grid electricity solutions. It performs a dispatch optimization of the optimized system and evaluates its performance and costs.

3.2.3.3. Energy system in Microgrid

The energy system in Microgrid is modeled by busses (AC and DC) connected to components by flow to activate and deactivate a flow, allows the simulation and modeling of several energy systems (on-grid or off-grid systems). A visualization of the tool's structure can be found in Figure 3.5.

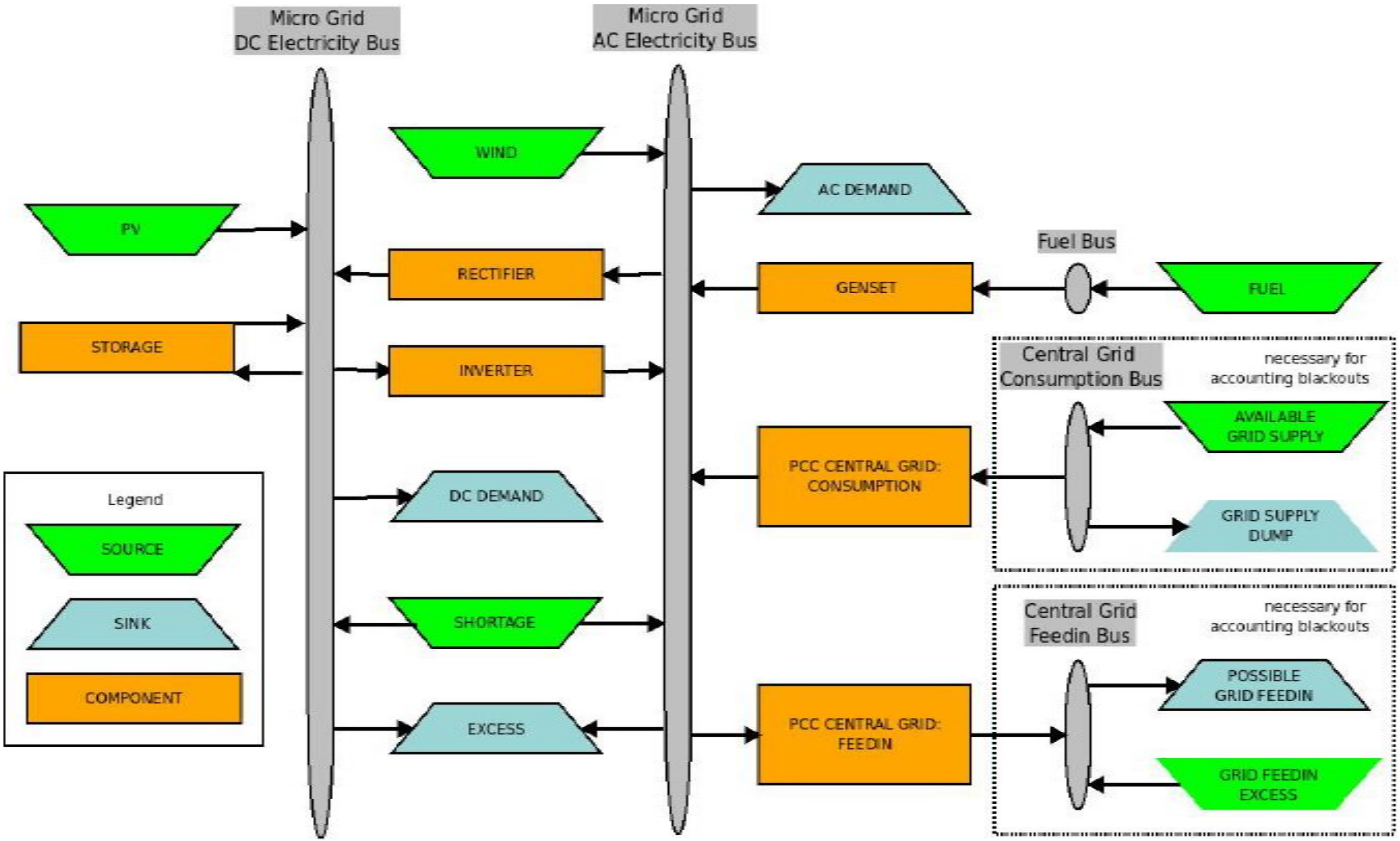


Figure 3.22: Energy System Modelled with Simulation Tool [46]

3.2.3.4. Tool Structure and Implemented Features

a) Scenario Definition

For a single energy system, it can be represented by a combination of components including : AC and /or DC demand, Genset, PV panels, wind plant, storage, inverter, rectifier, and connection to a national grid. Multiple scenarios and locations can be defined and optimized by the tool.

b) User-friendly Interface

All the input parameters, case definition, and scenarios can be defined within a single excel file. The other excel file referred time series contains the hourly load, solar generation and wind generation. It can be connected to one or multiple project locations. However, to execute the code it is necessary to install python packages and execute the tool via terminal (e.g. miniconda)

c) Multitude of Input Parameters, and Sensitivity Analysis

The Microgrid tool allows the optimization of several energy systems with different techno-economic parameters. Also, it allows a sensitivity analysis of many parameters in order to evaluate the overall system (e.g. fuel price, maximum shortage, etc. …)

d) Multiple Project Sites

For one simulation multiple locations can be defined and optimized. Each location is defined with a specific time series excel template that contains: the AC and/or DC demand, renewable generation and grid-availability.

e) Restarting Simulations

The Oemof results can be saved and reused to restart a simulation which can save computing time, especially during multi-parameters sensitivity analysis.

f) Automatically Generated Graphs

After the simulation and optimization of the energy system, the results will be automatically saved in a file named "Results".This file contains graphs of energy flows, the dispatch of the optimized components and grid availability of the system. They can be saved as a .png or .csv format.

g) Additional Constraints

To ensure technological reliability of the system, a static stability constraint can be enabled. A minimal renewable share can also be defined.

3.3 Simulation Data

3.3.1 Data of Brinkane weather

For the fix mode, the PV modules should be sloped with 30° toward the geographical south and 0° with azimuth angle for the fixed mode, However the PV modules are pivoted with an angle of 15°/h from the east to the west during all the day in the tracking mode, and adjusted automatically at optimal angle at each time according to the sun's movement [58].

Data of solar irradiation, wind speed and temperature of Brinkane were extracted from the web tool Renewables Ninja (see appendix Figure A.2). The typical year is 2014 and it covers an average of 30 years. The relevant extracted data are represented in Figures 3.6, 3.7, 3.8, and 3.9 bellows:

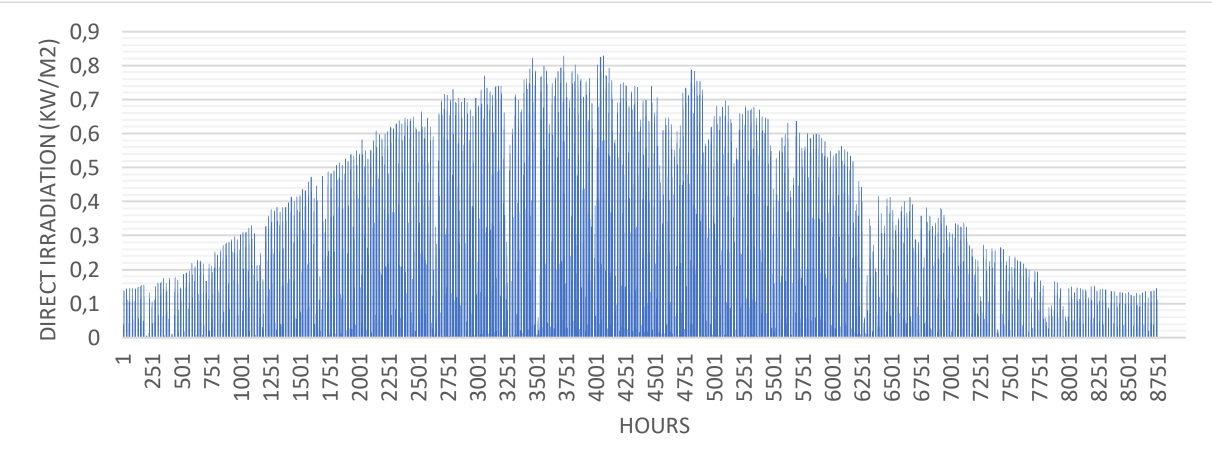


Figure 3.23 Hourly Direct Irradiation for One Year in Brinkane District

Figure 6 represents the hourly direct irradiation for the typical year 2014 in Brinkane District where it shows very high direct irradiation content, especially in winter and autumn with a maximum value of 1.03KW/m^2, this tends to decrease during the hot seasons (spring and summer). The calculation error is 10%.

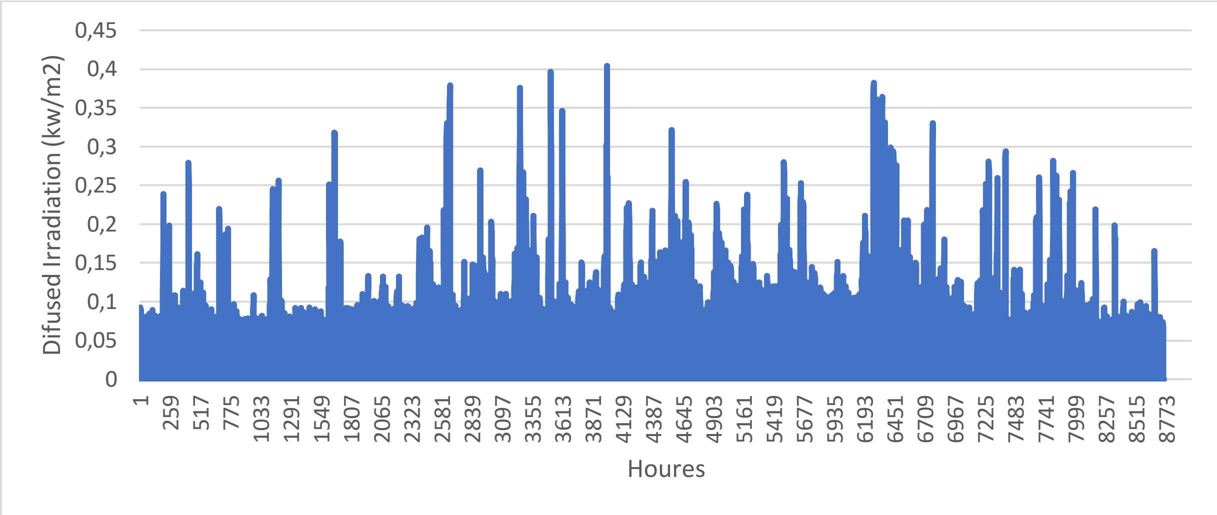


Figure 3.24: Hourly diffused irradiation in Brinkane District.

Unlike the direct irradiation, the diffuse irradiation (DI) reaches its peak during hot seasons (i.e. Spring and summer), and it rarely surpasses 300 w/m². The calculation error was defined by the web tool to be 10%.

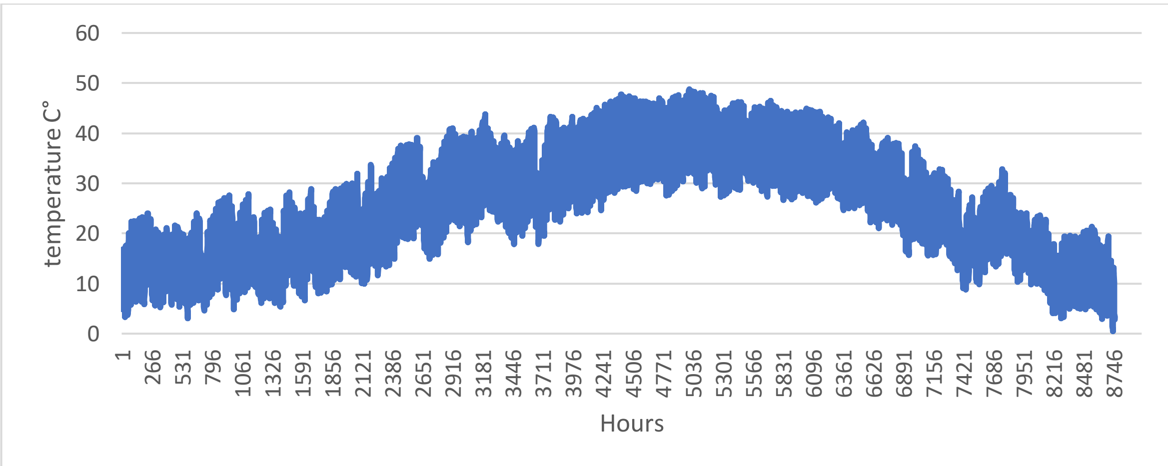


Figure 3.25: Hourly Temperature for one year in Brinkane District

The temperature trend shows a noticeable increase in hot seasons, to get to its maximum in the summer season, this will slightly decrease the efficiency of the PV generator and which is not the case for the other seasons which are much cooler and more favorable.

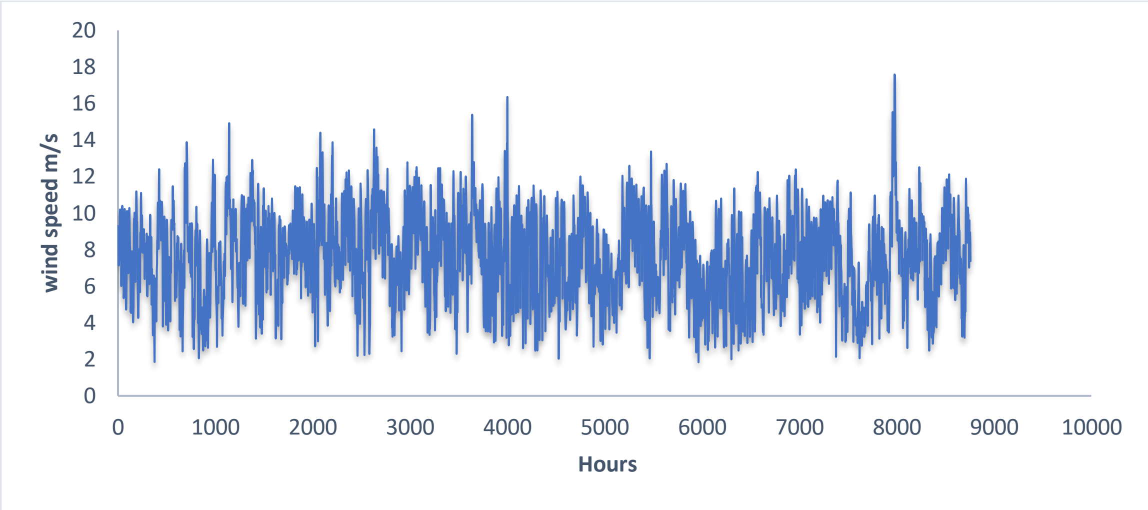


Figure 3.26: Wind Speed of Brinkane District

The plot of wind speed shows an average speed of around 6 m/s at 80m height. The maximum speed is around 17 m/s which very suitable for wind energy systems.

3.3.2 Load Profile of Brinkane, Tsabit, Adrar District

On-site electrical demand profiles are also needed to discover whether the energy produced is meeting the load demand [59].

Due to this, a general interview has been conducted in the Brinkane village to estimate the demand profile and to assess the need per house. With this interview, we found it needful to divide the household into two based on appliances owned and energy consumption rate. Law and high energy consumption were taken as the two types of householders in Brinkane. The total number of appliances in the residential sector together with their respective power ratings resulted in the total connected load of **82,6 kW** in moderate and cold weather (winter) and a total connected load of **89,6 kW** in hot weather (summer).

Details about the type of appliances of the two categories can be found in Tables 3.1 and 3.2.

Table 3.6: High Electricity Consumption Appliances in Household in Brinkane

Appliances	Unit/ household	Power (w)	Total units	Total power [KW]
Lamp incandescent	5	40	100	4
Mobile phone	4	5	80	0.4
Air conditioning	2	50	40	2
TV	1	40	20	0.8
Satellite receiver	1	30	20	0.6
Refrigerator	1	50	20	1
Freezer	1	50	20	1
Water pump	1	500	20	10
Washing machine	1	500	20	10
Computer	1	70	20	1.4
Total	---	---	---	**31.2**

Table 3.7: Low Electricity Consumption Appliances in Household in Brinkane

Appliances	Unit/ household	Power (w)	Total units	Total power [KW]
Lamp incandescent	5	40	300	12
Mobile phone	4	5	240	1.2
Air conditioning	2	50	100	5
TV	1	40	60	2.4
Satellite receiver	1	30	60	1.8
Refrigerator	1	50	60	3
Freezer	1	50	60	3
Water pump	1	500	60	30
Total	---	---	---	**58.4**

3.3.3 Generation of Daily Load profile

3.3.3.1 Data input

To generate the daily and yearly load profile the input data needed for the modeler such running hours, the number of occurrences, duration, and availability window will be defined.

The appliances in different households and their running hours were also estimated. We assume that the fridge, freezer and the air conditioning are working 24 h/ day (assume that the compressor works with an average value). This is reflected in the daily load profile which is displayed in Figures 10 and 11. We also found out that the households use the incandescent lamp that consumes a lot of energy when compared to the LED lamps.

The estimation of the availability windows was based on interviews conducted with the local people, the people. For instance, in Brinkane village and Tsabit District, people wake up early in the morning, and go out for daily activities at 6:00 am; also, they sleep relatively earlier in the night, at around 23:00 pm. The generated load profile reflects two-time spans and seasons (winter and summer). The only difference is in the usage of air-conditioning 24 hours/day for 5 months and during the hot weather that starts in May. This reflected in Figure 3.12.

The data needed are captured from interviews with the local households and appliances' power rating from [60], [53] as illustrated in Tables3. 3 and 3.4.

Table 3.8: Input Data for low Household Consumption

Load type	appliance	Min occurrence	Max occurrence	Min duration (30min)	Max duration (30min)	Max usage	Power (w)
Lamp incandescent	5	0	6	1	8	10	40
Mobile phone	4	1	8	1	2	4	5
Air conditioning	2	100	150	1	2	120	50
TV	1	1	4	1	12	24	40
Satellite receiver	1	1	4	1	12	24	30
Refrigerator	1	100	150	1	1	120	50
freezer	1	100	150	1	1	120	50
Water pump	1	0	1	1	4	4	500

Table 3.9: Input Data for High Household Consumption

Load type	appliance	Min occurrence	Max occurrence	Min duration (30min)	Max duration (30min)	Max usage	Power (w)
Lamp incandescent	5	0	6	1	8	10	40
Mobile phone	4	1	8	1	2	4	5
Air conditioning	2	100	150	1	2	120	50
TV	1	1	4	1	12	24	40
Satellite receiver	1	1	4	1	12	24	30
Refrigerator	1	100	150	1	1	120	50
freezer	1	100	150	1	1	120	50
Water pump	1	0	1	1	4	4	500
computer	1	1	2	1	4	4	70
Washing machine	1	0	1	2	4	6	500

3.3.3.2 Daily load profiles During Summer Season

After running the modeler with the input data, the daily summer load profile for the community (Figure 2.10) gives total energy of 1 477,565KW in a random day:

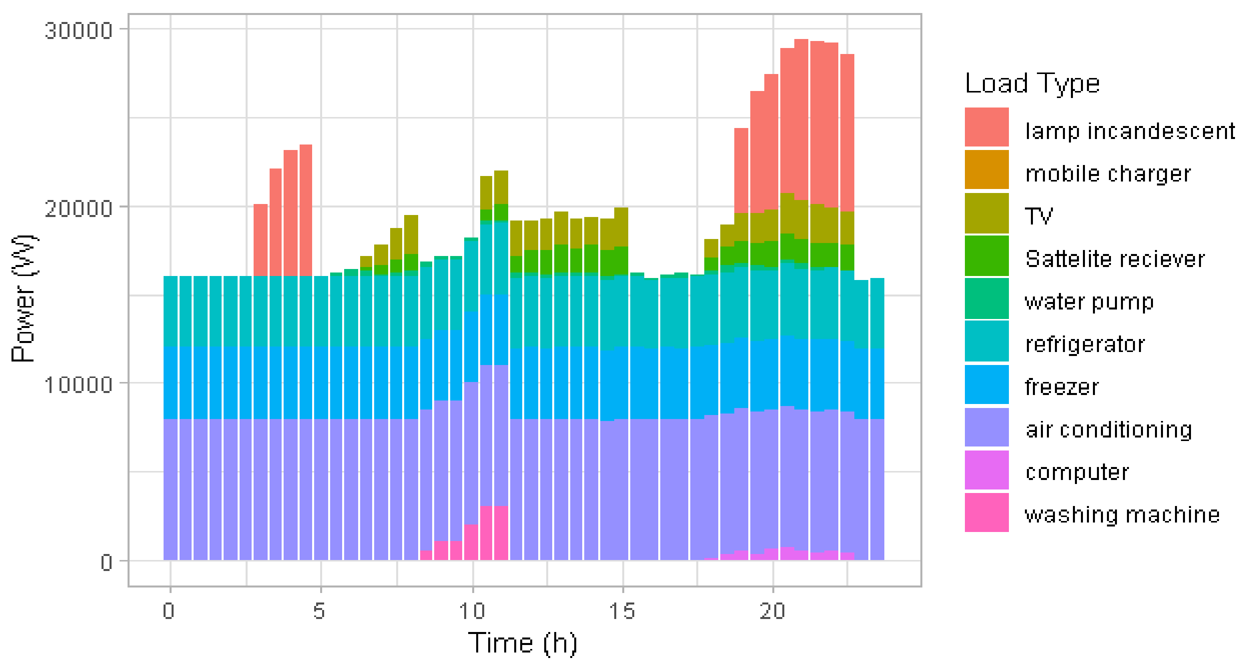


Figure 2.27: Daily Load Profile of The Community of Brinkane in Summer Time

3.3.3.3 Daily Load Profiles During Winter Season

Figure 2.11 shows the daily winter load profile for the community with a total energy value of 284.445 kW in a random day. This was obtained after running the modeler with input data.

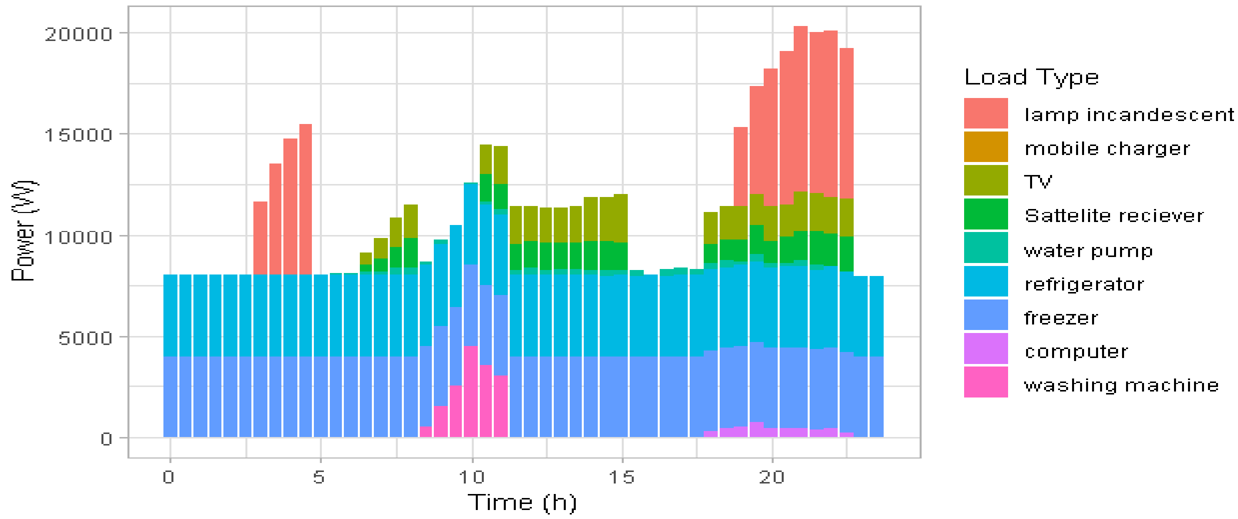


Figure 3.28: Daily Load Profile of The Community of Brinkane In Wintertime

3.3.3.4 Generation of the Yearly load profile

To get the yearly demand profile a simulation was carried for 365 days to cover the whole year. We assumed the summer season to be 5months (150days) and 7 months for the winter season (215days). This shown in Figure 3.12.

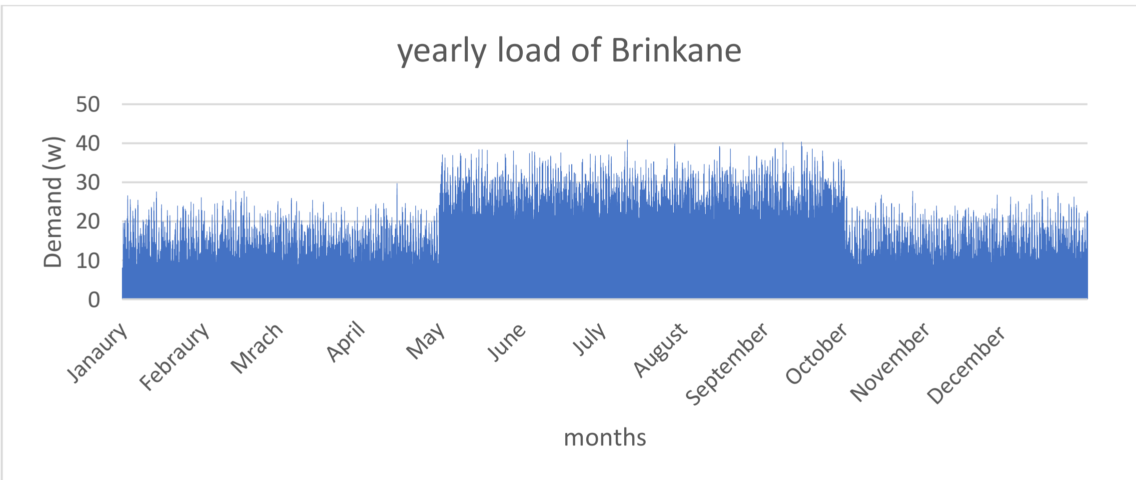


Figure 3.29: Yearly load Profile of Brinkane

The energy demand will ultimately be affected by the seasons and related conditions. In this work, the use of air-conditioning comes into play and triggers the peak demand in the summertime. The maximum peak load is **40.8 KW** in the summer season and mainly caused by cooling appliances. The peak loads in spring, autumn and winter were determined to be **29,8 kW.**

3.4 System Size and Optimization

Due to the interface and coding structure of Oemof, the developed tool can not only be applied to optimize microgrid systems but various on- or off-grid electricity solutions. It performs a dispatch optimization of the optimized system and evaluates its performance and costs.

3.4.1. Energy system and components

The energy system is composed of components connected to the DC and AC buses. The input parameters for the techno-economic assessments are defined below:

a) PV Plant

This is modeled based on a feed-in time series in kWh/kWp $_{\text{installed}}$. The installed capacity can be optimized. The system efficiency is taken to decrease by 10% due to shading dust and others. Moreover, the PV cost variable per kW and PV patch can be added. In this work where the patch is neglected.

b) Wind Plant

This is modeled based on a feed-in time series kWh/kW $_{installed}$. The installed capacity (kW) can be optimized. The output was taken from the renewable ninja webtool, using a hub high of 80m and a decrease of efficiency by 10%. In a similar approach with solar panel, the wind patch and the variable cost are neglected.

c) Battery Storage

This is modeled with a constant throughput-efficiency, charge C-rate of 80% and discharge C-rate of 100%, as well as minimal and maximal state of charge SOC. Also, the variable cost for the battery is taken into consideration for the battery.

The tool allows both capacities installed (kWh) and power output (kW) optimization.

d) Generator Set

This is modeled with a constant efficiency of 33%. With both minimum and maximum loading, generator type is determined by the combustion/calorific value of the fuel used. The installed capacity (kW) can be optimized and both variable cost and batch can be inserted.

e) Inverter and Rectifier

This is modeled with defined conversion efficiencies.

f) Distribution grid

In a microgrid, the cost of distribution grid is one of the hardest and important tasks especially in low population density or difficult terrain, [61] The cost of each connection was taken to be 400 USD with other additional fixed project development costs of 20.000USD with a lifetime of 40 years.

3.4.2 Techno-Economic Input Parameters of Hybrid Energy Systems

In general, the cost of any system is composed of capital costs, replacement costs, variable cost, and operating and maintenance costs.

a) Capital Investment Cost (CAPEX)

This is the total cost of purchasing, transportation, packaging, and installation of the system. It is a fixed cost can be calculated using expression in (3.1):

$$Capital\ cost = (1+K).N.C \qquad (3.1)$$

Where:

- C is the cost of a single component.

- K is the cost related to transportation, engineering, installation, etc.

- N is the number of components.

b) Replacement and Operating and Maintenance Cost (O&M)

This is a variable cost including the expenses of maintenance and operation of the system. They are expressed as a percentage of the initial capital cost. The replacement costs are the expenses needed to change components as these have different lifetimes and some of them requires to be replaced a number of times during the lifespan of the project [62].

c) Levelized Cost of Electricity (LCOE)

The Levelized Cost of electricity is the cost of generating one energy unite during the lifetime of the system. As given in Equation (3.2), the LCOE is calculated by dividing the annualized cost of electricity-producing by the total electrical energy produced [8].

$$LCOE = TAC/(E_{prim,AC}+E_{prim,DC}) \qquad (3.2)$$

Where:

-$E_{prim,AC}$ is the AC primary served load,

- $E_{prim,DC}$ is the DC primary served load, and

-TAC is the total annualized cost of electricity.

d) Net Present Value (NPV)

The NPV includes all benefits and costs of a project converted into present value equivalents. The total of these values gives the overall worth of the project.

The NPV is calculated by using expression (3.3), it is calculated by subtracting the cash outflows from the actual values of cash inflows over a period of time [8].

$$NPV = \sum_{t=1}^{n} \frac{R_t - C_t}{(1+i)^t} - I_0 \qquad (3.3)$$

Where:

R_t is the revenue in year t, C_t represents the costs in year t, i is the discount rate, I_0 is the initial Investment.

Table 5 summarizes the techno-economic inputs of the hybrid energy system inputted into the microgrid tool. Detailed input parameters can be found attached in Annex A.3 as well as the simulation result parameters.

Table 3.10: Techno-Economic Input Parameters of Hybrid Energy Systems

Asset	Parameter	Unit	Value
PV	CAPEX	USD/kWp	1500
	OPEX	USD/kWp/a	15
	Life time	a	20
Wind turbine	CAPEX	USD/kWh	1477
	OPEX	USD/kWp/a	14
	Lifetime	a	20
Battery	CAPEX (capacity)	USD/kWh	250
	CAPEX (power)	USD/kW	500
	OPEX	USD/kWp/a	6.75
	Lifetime	a	13.5

	Maximum c-rate	KW/kWh	100
	Maximum SOC	%	100
	Maximum depth of discharge	%	50
	Charging efficiency	%	97
	Discharging efficiency	%	97
Diesel Genset	CAPEX	USD/kWh	320
	OPEX	USD/kWh	40
	Lifetime	a	10
	Efficiency	%	33
Invertor	CAPEX	USD/kWh	174
	OPEX	USD/kWh	7
	Lifetime	a	15
	Efficiency	%	95
rectifier	CAPEX	USD/kWh	150
	OPEX	USD/kWh	6
	Lifetime	a	15
	Efficiency	%	80
Distribution grid	CAPEX	USD/consumer	400
	OPEX	USD	1% of
	lifetime	a	40
Project development	CAPEX	USD	20000
	Project lifetime	a	20
Other	Diesel fuel price (t=0)	USD/l	0.19
	LPG fuel price (t=0)	USD/l	0.08
	Annual diesel fuel price change	% p.a	5
	Electricity price of the national grid	USD/KWh	0.778
	Stability limit	%	20
	WACC	%	16

3.4.1. Fuel Carbon Pricing

Carbon pricing is defined as putting a value or price on carbon emissions with the goal to decarbonize the global economic activity and change the behavior of consumers, businesses, and investors. In general, carbon pricing helps to protect the environment, drive investments in clean technologies, and raise revenue. This encourages investors and companies for the creation of innovations.

Currently, 20 percent of global GHGs emission is covered by carbon pricing. For instance, 70 jurisdictions (46 national and 24 sub-national) have implemented, or are scheduled to implement, carbon pricing initiatives but Algeria is not a member yet [63]. According to the world bank, half of the current carbon emission is priced at less than 10$ per ton co_2. However, this value should be at $40-80 per ton by 2020 and $50-100 per ton by 2030.[63]

As the optimization tool does not allow the calculation of the carbon emission of the system. The carbon taxing and pricing of the fuel will be included in both diesel and LPG price to find the most environmentally friendly system.

3.4.2.1 Diesel Fuel Pricing

One litre of diesel weighs 835 grammes. Diesel consists of 86,2% of carbon or 720 grammes of carbon per litre of diesel. To combust this carbon to CO_2, 1920 grammes of oxygen is needed. The sum is then 720 + 1920 = 2640 grammes of CO_2/liter diesel [64].

With a penalty of 10 USD per ton co_2 E

- Pricing of diesel = +0.0291 USD/l

3.4.2.2 LPG Fuel Pricing

One litre of LPG weighs 550 grammes. LPG consists of 82,5% of carbon or 454 grammes of carbon per liter of LPG. To combust this carbon to CO2, 1211 grammes of oxygen is needed. The sum is then 454 + 1211 = 1665 grammes of CO_2/liter of LPG [64].

With a penalty of 10USD per ton co_2 E

- Price of LPG= +0.0183USD/l

CHAPTER FOUR: RESULT AND DISCUSSION

4.1. Introduction

The different results obtained from the optimizations of the different scenarios are presented and gave the selection of the most optimum hybrid energy system. Thereafter, a sensitivity analysis for the different scenarios is conducted alongside the environmental analysis of the project.

4.2. The Optimization using Oemof Model

In this work, six (6) scenarios were considered and subjected to the microgrid tool while optimization is done to select the most cost-effective hybrid energy system for the selected location. The hybrid systems were developed with both diesel and LPG fuels to select the best fuel option for the hybrid microgrid (HMG) system. Results are illustrated in Tables 4.1.

The scenarios considered in this work are:

1- off-grid PV_wind_LPG and battery storage.

2- off-grid wind_LPG.

3- off-grid PV_wind and battery storage.

4- off-grid wind _LPG and battery storage.

5- off-grid PV_LPG and battery storage.

6- off-grid LPG only

7- off-grid Diesel only.

System optimization was performed keeping the constraint values constant to all system configurations. The minimum share of renewable was taken as “0” and the stability criteria was selected to be 20%. The best energy system will be selected with high net present value (NPV), less Levelized cost of electricity (LCOE), and high renewable energy share.

For each scenario, many economical and technical parameters can be delivered by the microgrid tool (summarized in Table 4.2); the energy flow of each component of the HMGs, as well as the preliminary consumption and production graphs, can be generated also. Furthermore, the full result parameters and the preliminary consumption and production of the HMG systems is given in annex A.4.

Table 4. 1 : General Optimization Results Based on Oemof Model

S/N	Scenarios	LCOE [$/kWh]	Annuity [USD]	NPV [USD]	RE share [%]	Excess [kW]
1	Off grid_PV_wind_LPG_storage	0.19172	29586.864	251889.6	82.55	60148.69
2	Off grid_wind_LPG	0.19251	29708.19	252922.6	82.713	66241.52
3	Off grid_PV_wind_storage	0.6913	106682.17	908245.5	100	800687.2
4	Off grid_wind_LPG_storage	0.19172	29586.86	251889.	82.55	60111.6
5	off grid PV_LPG_storage	0.1639	25302.52	215414.7	21.07	579.7572
6	Off grid_LPG only	0.1663	25672.04	218560.	0	0
7	Off-grid Diesel only	0.19774	30514.64	259788.	0	0

4.2.1 Comparison Between the 6th and 7th Scenarios (LPG and Diesel Only System)

Analysis of the economic outputs of the 06th and 07th scenarios proved that LPG as fuel is a better option than diesel fuel in the hybrid system in Algeria. This is because the LPG is cheaper (0.08 USD/l) and readily available than diesel fuel (0.19 USD/l). Also, in Table 4.1, the net present value (NPV) of the system using LPG only, is 16% less than the that with diesel fuel only. We also found that the Levelized cost of electricity (LCOE) produced using diesel is 16% higher than the that with LPG fuel.

4.2.2 Optimization Comparison for Economically Optimum Power System

The results of the techno-economic optimization revealed the potential for hybridization. For the 1st, 2nd, and 4th scenarios, the LCOE is competitive with an average of 0.19USD/kWh; the renewable share is also found to be close except from the 5th scenario having 21% share of renewables. This can be justified by the low price of LPG fuel when compared to that of PV and storage. Storage in PV_storage system will increase the initial investment cost; hence, it will be much more economical to run the system on LPG only that PV_storage.

The 3rd scenario was found to have the highest LCOE with 0.6913 USD/kWh; this may be due to the high investment cost of PV, and storage. Also, the high excess of energy between summer load and winter load (air-conditioning), increased the complexity of the sizing and result a considerable energy excess.

For the 1st and 4th scenarios the output parameters are equal, and the share of PV is zero “0” in the 1st scenario. In this case, the PV was not selected by the optimization tool because of the:

- high investment cost of the PV compared to fuel price.
- considerable wind power output compared to solar generation in the location selected.

The 2nd scenario has a low price of electricity after the 4th scenario. The highest share of renewables 82.713%; and the highest NPV (252922.6 USD). However, energy excess was determined to be high compared to the 4th scenario, this is due to:

- the big gap between summer load and winter load (air-conditioning).
- The use of storage in the 4th scenario decreases the energy excess by 10%.

Therefore, the 2nd scenario was selected as the optimum system based on affordable LCOE and high NPV and a considerable value of RE share of 82.71%. Also, the system is found to be less complex compared to the 4th scenario because there is no need for the inclusion of storage in the system design.

Table 4. 2: The Techno-Economic Results Based on Oemof Model

Energy systems	Off grid_PV_wind_LPG_storage	Off grid_wind_LPG	Off grid_PV_wind_storage	Off grid_wind_LPG_storage	off grid PV_LPG_storage	LPG only
capacity_pv_kWp	0	0	29.24241	0	16.8421	0
capacity_wind_kW	85.29911	87.79254	445.6067	85.29911	0	0
capacity_genset_kW	30.72681	37.31994	0	30.72681	36.97956	40.8
capacity_storage_kWh	14.05248	0	186.5156	14.05248	8.04304	0
consumption_fuel_annual_l	109571.4	111496.5	0	109571.4	355831.8	444255.2
annuity_pv	0	0	4165.863	0	2399.32	0
annuity_wind	15992.55	16460.04	83545.86	15992.55	0	0
annuity_rectifier_ac_dc	61.05899	0	125.5465	61.05899	0	0
annuity_inverter_dc_ac	201.2448	0	914.7161	204.2448	329.5019	0
annuity_genset	5908.458	6820.083	0	5908.458	10806.19	12775.02
annuity_storage	1029.9	0	13669.65	1029.9	589.4706	0
annuity_distribution_grid	1911.354	1911.354	1911.354	1911.354	1911.354	1911.354
expenditures_fuel_annual	2130.107	2167.531	0	2130.107	6917.498	8636.48
costs_pv	0	0	35466.34	0	20426.76	0
costs_storage	8768.177	0	116377.4	8768.177	5018.495	0
costs_rectifier_ac_dc	519.8296	0	1068.848	519.8296	0	0
costs_inverter_dc_ac	1738.851	0	7787.493	1738.581	2805.236	0
costs_wind	136153.6	140133.6	711573	136153.6	0	0
costs_genset	50302.04	58063.21	0	50302.04	91999.2	108760.9

4.3.Preliminary Consumption and Production of the Selected HMG System

Based on the RE share, low LCOE, and higher NPV, the 2nd scenario (Wind_ LPG system) was selected as an optimum HMG for the selected location. The preliminary consumption and production of the selected HMG System are presented in Figure 4.1. The dispatch of each of the installed generation and storage components are visualized in line with load profile. The location-specific load profile, characterized by a summer peak demand of 40.8 kW, and winter peak demand of 29.8kW results in an optimal wind_LPG system capacity of 87.79 kW of wind and annual consumption of 111496.5 l/a of LPG fuel. It is able to cover the whole demand of the location. During the year about 82.71 % renewable supply is defined, and stability of supply is ensured through the utilization of LPG generator. The generator is used in occasions where the wind generator is not producing enough (due to reduced wind speed), to cover all demand. The HMG has an NPV of 2529226 USD and an LCOE of 0.1925 USD/kWh.

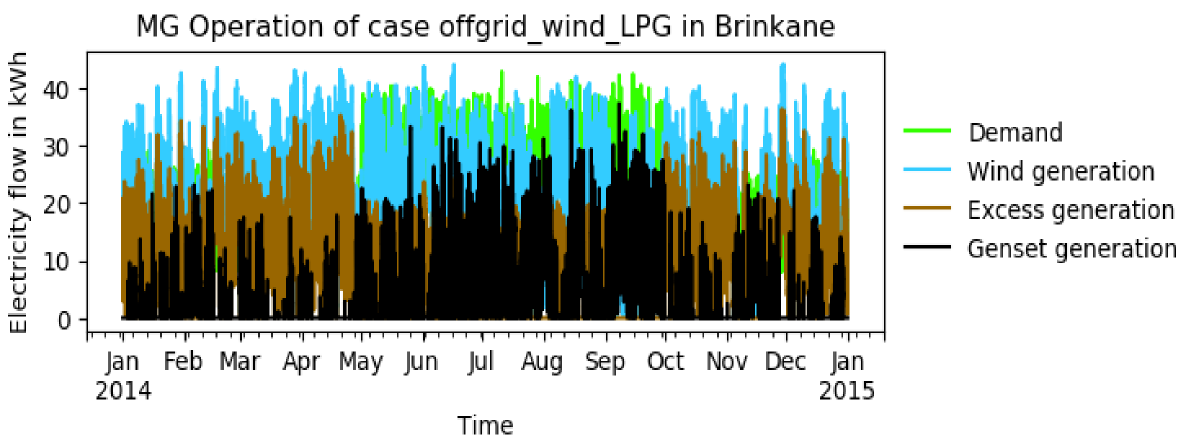


Figure 4. 1: Energy Flows of the selected HMG

The use of air-conditioning in the summer season creates a big gap between the summer load and winter load, resulting in considerable excess energy during winter. The energy excesses can be seen clearly in Figure 4.2, and which represents the energy flow of HMG components in the first week of January 2014. The Genset is used as a backup to cover the demand mainly in the summer season where the energy demand increases due to the utilization of air-conditioning systems.

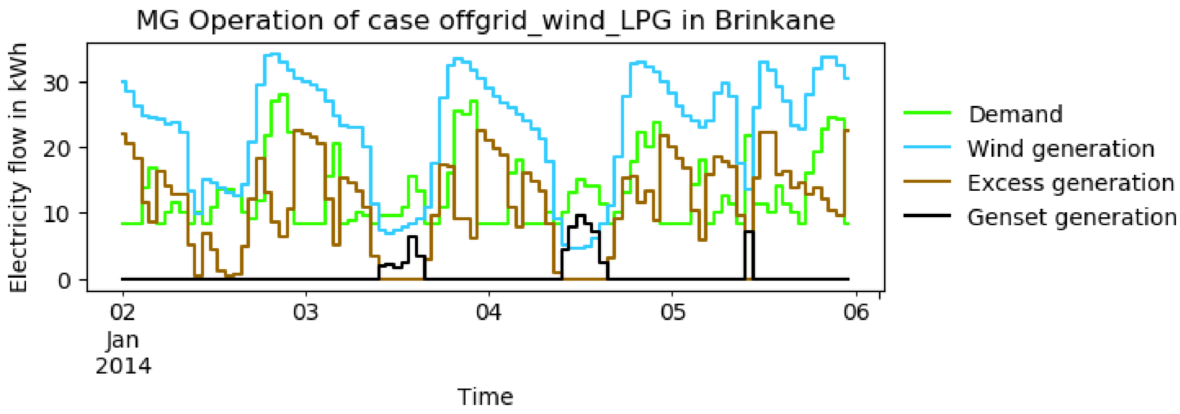


Figure 4. 2: Energy Flows of the HMG during the First Week of January

During winter, the demand curve has peak demand in the morning, mid-day and at night. Power from the wind is used to meet demand with excess during the day. At mid-day (from 11 am to 14 pm) there will be a reduction in wind power due to rise in temperature (it should be known that air density drops with the rising in temperature thereby bringing about a reduction in the wind power density); therefore, the Genset work to cover the load during this period.

4.4. Sensitivity analysis

Sensitivity is a proportion of how the ideal and optimum combination of the system components changes based on any parametric varieties in the lifetime of the system. Optimum hybrid system design relies on the various input parameters to be inserted into the modeler tool. At the point when these set of inputs change, it is necessary to track the change in the system as well. In this work, simulation of four (4) separate sensitivity cases were conducted using variables like fuel price, battery price, PV cost, and WACC.

All the scenarios were selected to study the robustness of the above results and assess the sensitivity of the results to key input parameters. In this study, the HMG was compared to fuel only system since fuel price is a decisive factor that determines the economic feasibility of the optimum performance of HMG. Fuel price is also considered because it is not stable and may increase or decrease in the future. Because of this, a study is needed to picture the influence of the fuel price in the selection of the optimum HMG.

4.4.1 Sensitivity Analysis for LPG Fuel Prices

Table 4.3 summarizes the results of the sensitivity analysis on fuel cost for 0.04 USD/l (-50%), 0.12USD/litre (+50%),0.16 USD/litre (+100%), 0.2USD/litre (+150%) and 0.08 USD/litre.

It was observed that the drop-in fuel cost (-50%) decreases the overall cost of electricity generation (LCOE). This can be explained by the drop in the investment cost due to the low price of fuel.

Table 4. 3 : Sensitivity Analysis for LPG Fuel Prices

Sensitivities	**Diesel fuel price [USD/l]**	**LCOE [USD/kwh]**	**NPV [USD]**	**RE share [%]**
	1- PV_wind_LPG and battery storage			
-50%		0.17359	26788.74	77.708
Current fuel price		0.19172	251889.6	82.55
+50%		0.20856	274014.2	85.949
+100%		0.22449	294933.9	88.484
+150%		0.23896	313945.2	90.268
	2- Wind_LPG			
-50%		0.17401	228613	78.15
Current fuel price		0.19251	252922.6	82.713
+50%		0.20867	274147.8	85.637
+100%		0.22446	294897.7	87.943
+150%		0.23863	313517	89.571
	3- PV_wind and battery storage			
-50%		0.6913	908245.5	100
Current fuel price		0.6913	908245.5	100
+50%		0.6913	908245.5	100
+100%		0.6913	908245.5	100
+150%		0.6913	908245.5	100
	4- wind _LPG and battery storage			

-50%	0.174	228613	78.15
Current fuel price	0.192	252922.6	82.713
+50	0.208	274147.8	85.637
+100	0.224	294897.7	87.943
+150	0.238	313517	89.571
	5- PV_LPG and battery storage		
-50%	0.13837	181796.99	0
Current fuel price	0.16396	215414.7	21.079
+50%	0.18595	244297.7	24.824
+100%	0.20716	272165.1	29.479
+150%	0.22738	298730.7	36.396

Apart from this, the RE share was also found to decrease with an average of 6% for the 1st, 2nd, and 4thscenarios, while the RE share for the 5th scenario was found to be zero due to the low cost of fuel and the high investment cost of PV and batteries. Furthermore, increasing the value of fuel by +50%, +100, and +100%, resulted in the rise of the LCOE and RE share brought about by the rise in the investment cost and other costs like maintenance, etc. The optimization tool is thus found to be designing the HMGs for fuel savings during the day, and the use of batteries to provide system stability rather than using fuel.

4.4.2 Sensitivity Analysis for WAAC

The weighted average cost of capital (WAAC) is also a decisive parameter in the effective cost of the renewable energy projects [65]. The high investment cost of renewable technologies and low operational cost due to the low fuel expenditure may be responsible for this. Therefore, financing cost influences the economic performance of renewable technologies more than conventional technologies with low investment cost and high fuel expenditure.

Table 4. 4: Sensitivity Analysis for WAAC

Sensitivities	WAAC [%]	LCOE [USD/kwh]	NPV [USD]	RE share [%]
		1- PV_Wind_LPG and battery storage		
-50%		0.15741	302727	87.795
Current value		0.19172	251889.6	82.55
+50%		0.22937	221559.8	77.833
		2- wind_LPG		
-50%		0.15723	302385.5	87.322
Current value		0.19251	252922.6	82.713
+50%		0.22937	222349.1	78.343
		3- PV_wind and battery storage		
-50%		0.49564	953191	100
Current value		0.6913	908245.5	100
+50%		0.91436	883222.1	100
		5- wind _LPG and battery storage		
-50%		0.15741	302727	87.795
Current value		0.19172	251889.6	82.55
+50		0.22937	221559.8	77.833
		6- PV_LPG and battery storage		
+50%		0.14399	276920	26.187
Current value		0.16396	215414.7	21.079
+50%		0.18322	176984.6	0

Table 4.4 reveals that lower value of WAAC (-50%) results in a considerable increase in RE share by an average of 6%, and a decrease in the LCOE by an average of 4%. Considering the initial value of the WAAC at +50%, we found that the RE share tends to decrease while LCOE increases. In the PV_LPG and battery storage scenario, the RE share drops to zero because of the high investment cost resulting from the high value of WAAC; this makes fuel an optimum solution when compared to PV and battery storage.

4.4.3 Sensitivity Analysis for PV Investment Cost

According to the word bank, the investment cost of PV is continuously decreasing since the last decade and projected to further decrease. It is thus worthy to test the impact of the PV investment cost on the optimization results and the selection of the optimum HMG for the Brinkane site.

Table 4. 5: Sensitivity Analysis for PV Investment Cost

Sensitivities	**PV cost [USD/kw]**	**LCOE [USD/kwh]**	**NPV [USD]**	**RE share [%]**
		1- PV_wind_LPG and battery storage		
-50%		0.18799	246988	83.834
Current price		0.19172	251889.6	82.55
+50%		0.91251	252922.6	82.713
		2- Wind_ LPG		
-50%		0.15628	252922.6	82.713
Current price		252922.6	252922.6	82.713
+50%		252922.6	252922.6	82.713
		3- PV_wind and battery storage		
+50%		0.67027	880614.7	100
Current price		0.6913	908245.5	100
+50%		0.70121	911266.3	100
		4- wind _LPG and battery storage		
+50%		0.19172	251889.6	82.55
Current price		0.19172	251889.6	82.55
+50		0.19172	251889.6	82.55
		5- PV_LPG and battery storage		
-50%		0.15628	205325.8	30.6
Current price		0.16396	215414.7	21.079
+50%		0.16636	218560.6	0

The sensitivity analysis provided in Table 4.5 reveals that changes in the PV investment cost have an impact on LCOE, RE share, and other parameters. For instance, lower PV cost (-50%) results in a decrease by 5% in the LCOE and an increase by 10% in the RE share. On the other hand, with higher PV cost (+50%) result in an increase in the LCOE, and a decrease in the PV share in the 1st scenario (i.e. PV_wind_LPG and battery storage). Worthy of note is the fact that higher PV investment costs (+50%) substantially lowers the potential for hybridization. This can be seen in the first scenario (PV_LPG and battery storage) where the RE share decreases from 21% to 0%. This resulted in a decrease in the LCOE.

4.4.4 Sensitivity Analysis for Battery Investment Cost

Similar to PV investments cost, the battery investment cost is projected to decrease [66]. This will make renewable technologies competitive with conventional ones. The effect of lower and higher battery investment cost is similar to that of PV cost investment on the optimization results.

Table 4. 6: Sensitivity Analysis for Battery Investment Cost

Sensitivities	**Battery cost**			
	[USD/kw]	**LCOE**	**NPV**	**RE share**
		[USD/kwh]	**[USD]**	**[%]**
	1- PV_wind_LPG and battery storage			
-50%		0.19178	251965.5	83.122
Current price		0.19172	29586.86	82.55
+50%		0.19236	29685.45	82.022
	2- Wind_LPG			
-50%		0.19251	252922.6	82.713
Current price		0.19251	252922.6	82.713
+50%		0.19251	252922.6	82.713
	3- PV_wind and battery storage			
+50%		0.66997	880219	100
Current price		0.6913	908245.5	100
+50%		0.71477	939077.9	100
	4- wind _LPG and battery storage			
+50%		0.19178	251965.5	83.122

Current price	0.19172	251889.6	82.55
+50	0.19236	252759	82.022
5- PV_LPG and battery storage			
-50%	0.16309	214275.6	21.102
Current price	0.16396	215414.7	21.079
+50%	0.16441	216008	16.658

The results of the simulation in Table 4.6 reveals a low effect of the battery on the hybridization. Lower battery cost increases the PV/ battery ratio and increases the RE share as well as a slow decrease in LCOE. With higher battery cost (+50%) less PV and battery capacity are installed thereby resulting in a lower RE share and higher LCOE.

4.5. Environmental Impact and Carbon Pricing

When designing a renewable power project, it is crucial to measure the environmental benefits, and how to reduce the Greenhouse Gases (GHG) emissions. As explained in Chapter 3, carbon taxing is one of the policies used worldwide to price carbon emission in order to reduce carbon emission activities and encourage creation and innovation. Although there is no carbon taxing in Algeria, it is very necessary to design a system by taking into consideration the emissions costs.

A comparison between the two cases i.e. with and without considering carbon pricing is established and Table 4.7 summaries the techno-economic parameters resulting from both optimizations.

4.2.1 Without Carbon Taxing

The selected scenario (2nd scenario) reduced 75% of the carbon emission compared to the LPG only system.

4.2.2 With Carbon Pricing

The introduction of carbon taxing increased fuel cost. This resulted in an increase in RE share of approximately 2% and an increase of approximately 1% in the LCOE. Besides, the carbon emission decreased by more than 76% for the 1st, 2nd, and 3rd scenarios when compared to HMG with LPG only (6th scenario).

Table 4. 7: Results of Oemof Optimization Before and After Carbon Pricing

Scenarios	LCOE [USD/kwh]	RE share [%]	Annual fuel consumption [l]	Carbon emission [kg]
		Without Carbon Pricing		
Off grid_PV_wind_LPG_storage	0.20012	84.415	102320.5	270 126 120
Off grid_wind_LPG	0.20051	84.308	105386.4	278 220 096
Off grid_PV_wind_storage	0.6913	100	0	0
Off grid_wind_LPG_storage	0.20012	84.415	102320.5	270 126 120
off grid PV_LPG_storage	0.17411	22.994	348918.2	921 144 048
Off grid_LPG only	0.17916	0	444255.2	1172 833 728
		With Carbon Pricing		
Off grid_PV_wind_LPG_storage	0.19172	82.55	109571.4	289268496
Off grid_wind_LPG	0.19251	82.713	111496.5	294 350 760
Off grid_PV_wind_storage	0.6913	100	0	0
Off grid_wind_LPG_storage	0.19172	82.55	109571.4	289 268 496
Off grid PV_LPG_storage	0.16396	21.079	355831.8	939 395 952
Off grid_LPG only	0.1663	0	444255.2	1 172 833 728

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1.Conclusion

In this work, a techno-economic analysis on hybrid microgrids as a solution for rural electrification in Brinkane, Adrar District was conducted. The location for the HMG was chosen according to the availability of wind and solar energy potential, loads of the location were estimated and several scenarios were considered for the optimization tool. The following were concluded:

1. The optimization showed that using wind_PV_battery storage will allow a 100% share of renewables with a very high cost of electricity 0.6931USD/kwh. However, wind_LPG storage and wind_PV_LPG_storage had the same values due to the high investment cost of PV and the abundant wind energy compared to solar energy. Therefore, wind_LPG system was chosen as the most optimum system for the location as it is less complex and have a higher NPV value of 252922USD and RE share of 82.713%. The use of this system will also reduce carbon emission by 75% compared to LPG only system.
2. Sensitivity analysis was applied to all the scenarios to track the effect of the decision parameters on the choice of optimum system. The WAAC, battery cost investment, PV cost investment, and fuel price were used to evaluate the systems and track the variation. With the increase of WAAC, initial value the RE share tends to increase and LCOE decrease whereas, for fuel price, the increase resulted in an increase of RE share as well as LCOE. However, the decrease in both PV and battery initial cost increase the RE share.

3. The introduction of carbon pricing resulted in an increase of approximately 1% in the LCOE and an increase in RE share of approximately 2%. Besides, the carbon emission decreased by more than 76% for the 1st, 2nd, and 3rd scenarios when compared to HMG with LPG only (6th scenario).

5.2.Recommendations

The energy demand is rapidly increasing with time in Algeria. The government launched a program to integrate more renewable resources in the energy mix, to decrease the heavy reliance on conventional fuel, and to target the rural areas where grid extension is impossible. However, the program seems unambitious, insufficient, and less goal-oriented since the implementation is going slowly, and people still use diesel-based generators for electrification. Hence, the solution for off-grid will be the deployment of renewable energies and hybrid systems in order to increase the rate of energy access to rural areas. The following were recommendations for future work:

1. Establishment of meteorological centers that possess on-site solar data and wind profiles for accurate and countable systems design.
2. Compare findings of this work with that of grid-connected Hybrid Energy System and include externalities.
3. Compare findings on load estimation and environmental analysis in this work, with others done using other existing optimization tool for more robust findings on system sizing over the selected district.

References

[1] IEA, "International Energy Agency - Energy Access Outlook 2017: From poverty to prosperity," *Energy Procedia*, vol. 94, no. March, p. 144, 2017.

[2] A. Hirsch, Y. Parag, and J. Guerrero, "Microgrids: A review of technologies, key drivers, and outstanding issues," *Renew. Sustain. Energy Rev.*, vol. 90, no. March, pp. 402–411, 2018.

[3] U. S. E. I. Administration, "Country Analysis Executive Summary : Norway," no. June 2018, pp. 1–6, 2020.

[4] "Access to electricity (% of population) | Data." [Online]. Available: https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=DZ. [Accessed: 06-Jul-2019].

[5] A. B. Stambouli, "Promotion of renewable energies in Algeria: Strategies and perspectives," *Renew. Sustain. Energy Rev.*, vol. 15, no. 2, pp. 1169–1181, 2011.

[6] A. Midoun, M. Tioursi, A. Khellaf, and H. Ilikti, "Contribution à l ' Étude des Systèmes Hybrides Photovoltaïque / Pile à Combustible," 2010.

[7] B. C. Pr, "Filiale du Groupe SONELGAZ Rencontre Nationale avec MICLAT Samedi 2 Juin 2018," 2018.

[8] H. Rezzouk and A. Mellit, "Feasibility study and sensitivity analysis of a stand-alone photovoltaic-diesel-battery hybrid energy system in the north of Algeria," *Renew.*

Sustain. Energy Rev., vol. 43, pp. 1134–1150, 2015.

[9] "Algeria Population (2019) - Worldometers." [Online]. Available: https://www.worldometers.info/world-population/algeria-population/. [Accessed: 12-Jul-2019].

[10] Z. Abada and M. Bouharkat, "Study of management strategy of energy resources in Algeria," *Energy Reports*, vol. 4, no. 2018, pp. 1–7, 2018.

[11] "How Much Room Do We Need To Supply The Entire World With Solar Electricity? - Odborné časopisy." [Online]. Available: http://www.odbornecasopisy.cz/en/post/how-much-room-do-we-need-to-supply-the-entire-world-with-solar-electricity--898. [Accessed: 05-Jul-2019].

[12] Z. Bouzid, N. Ghellai, and T. Mezghiche, "Overview of Solar Potential , State of the Art and Future of Photovoltaic Installations in Algeria," *Int. J. Renew. Energy Res.*, vol. 5, no. 2, pp. 427–434, 2015.

[13] Laidi, "Study of a Solar PV-Wind-Battery Hybrid Power System for a Remotely Located Region in the Southern Algerian Sahara: Case of Refrigeration," *J. Technol. Innov. Renew. Energy*, no. 213, pp. 30–38, 2012.

[14] L. Hadji, "How is 100% Renewable Energy Possible for Algeria by 2030?," no. 619, 2016.

[15] "Ministry of Energy and Mining - Algeria." [Online]. Available: https://www.hotelsinvictoria.net/mem-algeriaorg/. [Accessed: 04-Aug-2019].

[16] "Electricité et Gaz I. Electricité I.1 Introduction."

[17] S. O. Amrouche *et al.*, "Distributed photovoltaic systems in Algeria and control of DC-DC converters for grid integration - an overview," *Energy Procedia*, vol. 136, pp. 356–361, Oct. 2017.

[18] "Sonelgaz." [Online]. Available: https://www.sonelgaz.dz/. [Accessed: 06-Jul-2019].

[19] "Algeria electricity prices, June 2018 | GlobalPetrolPrices.com." [Online]. Available: https://www.globalpetrolprices.com/Algeria/electricity_prices/. [Accessed: 04-Jun-2019].

[20] "International Energy Agency." [Online]. Available: https://www.iea.org/. [Accessed:

04-Jun-2019].

[21] "Daïras de la wilaya d'Adrar — Wikipédia." [Online]. Available: https://fr.wikipedia.org/wiki/Daïras_de_la_wilaya_d%27Adrar. [Accessed: 14-Jul-2019].

[22] D. T. Ton and M. A. Smith, "The U.S. Department of Energy's Microgrid Initiative," *Electr. J.*, vol. 25, no. 8, pp. 84–94, 2012.

[23] K. Shivarama Krishna and K. Sathish Kumar, "A review on hybrid renewable energy systems," *Renew. Sustain. Energy Rev.*, vol. 52, pp. 907–916, 2015.

[24] Alexander Schies, "No Title," in *TECHNOLOGICAL AND ECONOMIC ASSESSMENT OF PV-DIESEL HYBRID SOLUTIONS VERSUS OTHER TECHNOLOGIES*, 2013.

[25] N. Manhas and G. D. Yadav, "A Review on Configurations , Control , and Future of Hybrid Renewable Energy Systems for Electric Power Generation," pp. 1018–1025, 2016.

[26] X. Zhang, X. Zhao, S. Smith, J. Xu, and X. Yu, "Review of R&D progress and practical application of the solar photovoltaic/thermal (PV/T) technologies," *Renew. Sustain. Energy Rev.*, vol. 16, no. 1, pp. 599–617, 2012.

[27] A. Mohammad Bagher, "Types of Solar Cells and Application," *Am. J. Opt. Photonics*, vol. 3, no. 5, p. 94, 2016.

[28] E. M. Authority, "Handbook for Solar Photovoltaic (PV) Systems Contents," 2011.

[29] "PERC cell explained." [Online]. Available: https://www.aleo-solar.com/perc-cell-technology-explained/. [Accessed: 10-Jul-2019].

[30] "Solar Cell I-V Characteristic and Solar I-V Curves." [Online]. Available: http://www.alternative-energy-tutorials.com/energy-articles/solar-cell-i-v-characteristic.html. [Accessed: 10-Jul-2019].

[31] "World Wind Energy Association – Statistics." [Online]. Available: https://wwindea.org/information-2/information/. [Accessed: 26-Jul-2019].

[32] B. Das Vairagi, A. Tandon, and R. S. Dewra, “Performance Analysis of DFIG Based Standalone 2 . 2 kW Laboratory Prototype Wind Turbine Emulator,” no. June, 2017.

[33] Q. H. Nagpurwala, “Wind Turbines.”

[34] M. Khudri Johari, M. Azim A Jalil, and M. Faizal Mohd Shariff, “Comparison of horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT),” *Int. J. Eng. Technol.*, vol. 7, no. 4.13, p. 74, 2018.

[35] H. Wagner, “Introduction to wind energy systems,” vol. 01011, 2013.

[36] N. Altin, “Energy storage systems and power system stability,” *2016 Int. Smart Grid Work. Certif. Program, ISGWCP 2016*, no. March 2016, 2016.

[37] X. Luo, J. Wang, M. Dooner, and J. Clarke, “Overview of current development in electrical energy storage technologies and the application potential in power system operation,” *Appl. Energy*, vol. 137, pp. 511–536, 2015.

[38] K. T. Møller, T. R. Jensen, E. Akiba, and H. wen Li, “Hydrogen - A sustainable energy carrier,” *Prog. Nat. Sci. Mater. Int.*, vol. 27, no. 1, pp. 34–40, 2017.

[39] R. Iea-pvps, “The Role of Energy Storage for Mini-Grid Stabilization The role of energy storage for mini-grid stabilization,” 2011.

[40] “Engine Powered Generators | Components and Types of Generators | PowerZone.” [Online]. Available: https://www.powerzone.com/resources/glossary/enginepoweredgenerators. [Accessed: 27-Jul-2019].

[41] R. Dhakar, A. Tripathi, and J. Raj, “Use of Lpg in Internal Combustion Engines-a State of Art Review,” vol. 3, no. 8, pp. 58–66, 2016.

[42] B. Ashok, S. Denis Ashok, and C. Ramesh Kumar, “LPG diesel dual fuel engine - A critical review,” *Alexandria Eng. J.*, vol. 54, no. 2, pp. 105–126, 2015.

[43] S. Berendes, “Modelling Hybrid Mini-Grids with Open Source Software,” 2018.

[44] “Cycles of a Four Cycle Engine - How Does a 4 Stroke Engine Cycle Work?” [Online]. Available: https://www.buyautoparts.com/howto/the-cycles-of-a-four-cycle-engine.htm. [Accessed: 27-Jul-2019].

[45] O. M. Longe, N. D. Rao, F. Omowole, A. S. Oluwalami, and O. T. Oni, “A Case Study on Off-grid Microgrid for Universal Electricity Access in the Eastern Cape of South Africa,” *Int. J. or Energy Eng.*, vol. 7, no. 2, pp. 55–63, 2017.

[46] S. Berendes, P. Bertheau, and P. Blechinger, “Sizing and Optimization of Hybrid Mini-Grids with micrOgridS-an Open-Source Modelling Tool,” *3rd Int. Hybrid Power Syst. Work.*, no. May, 2018.

[47] S. Sinha and S. S. Chandel, “Review of software tools for hybrid renewable energy systems,” *Renew. Sustain. Energy Rev.*, vol. 32, pp. 192–205, 2014.

[48] H. K. Ringkjøb, P. M. Haugan, and I. M. Solbrekke, “A review of modelling tools for energy and electricity systems with large shares of variable renewables,” *Renew. Sustain. Energy Rev.*, vol. 96, no. April 2017, pp. 440–459, 2018.

[49] R. Morrison, “Energy system modeling : Public transparency , scienti fi c reproducibility , and open development,” *Energy Strateg. Rev.*, vol. 20, pp. 49–63, 2018.

[50] C. Pietro Elia, Z. Yang, L. Anders, L. Hailong, and Y. Jinyue, “An Open-source Platform for Simulation and Optimization of Clean Energy Technologies,” *Energy Procedia*, vol. 105, pp. 946–952, 2017.

[51] “Overview of models - wiki.openmod-initiative.org.” [Online]. Available: https://wiki.openmod-initiative.org/wiki/Overview_of_models#Overview_of_models_by_open-source_license.2C_data_availability_etc. [Accessed: 04-Jul-2019].

[52] “Renewables.ninja.” [Online]. Available: https://www.renewables.ninja/. [Accessed: 04-Jun-2019].

[53] M. Zeman, P. Bauer, Z. Qin, N. Narayan, J. Popovic-Gerber, and J.-C. Diehl, “Stochastic load profile construction for the multi-tier framework for household electricity access using off-grid DC appliances,” *Energy Effic.*, no. Iea 2017, 2018.

[54] S. Hilpert, C. Kaldemeyer, U. Krien, S. Günther, C. Wingenbach, and G. Plessmann,

"The Open Energy Modelling Framework (oemof) - A novel approach in energy system modelling," *Doi.Org*, vol. 49, no. June, pp. 1–24, 2017.

[55] oemof developer group, "oemof - open energy modelling framework (v0.2.2)," Jun. 2018.

[56] S. Hilpert *et al.*, "Addressing energy system modelling challenges : The contribution of the Open Energy Modelling Framework (oemof)," *Preprints*, no. February, pp. 1–26, 2017.

[57] S. Wingenbach, C., Hilpert, S., & Günther, "The core concept of the open energy modelling framework (oemof)," *.), Environ. informatics stability, Contin. Innov. Curr. trends Futur. Perspect. based 30 years Hist.*, no. Aachen, pp. 361–66, 2016.

[58] M. Rebhi, M. Sellam, A. Belghachi, and B. Kadri, "Conception and Realization of Sun Tracking System in the South-West of Algeria," *Appl. Phys. Res.*, vol. 2, no. 1, pp. 533–542, 2014.

[59] G. G. Pillai, G. A. Putrus, and N. M. Pearsall, "Generation of synthetic benchmark electrical load profiles using publicly available load and weather data," *Int. J. Electr. Power Energy Syst.*, vol. 61, pp. 1–10, Oct. 2014.

[60] "Power Consumption of Typical Household Appliances." [Online]. Available: https://www.daftlogic.com/information-appliance-power-consumption.htm. [Accessed: 15-Jul-2019].

[61] B. Cory, "Pricing in electricity transmission and distribution," no. April, pp. 19–25, 2002.

[62] M. Kolhe, S. Kolhe, and J. C. Joshi, "Economic viability of stand-alone solar photovoltaic system in comparison with diesel-powered system for India," *Energy Econ.*, vol. 24, no. 2, pp. 155–165, 2002.

[63] "Carbon Pricing." [Online]. Available: https://www.worldbank.org/en/results/2017/12/01/carbon-pricing. [Accessed: 23-Jun-2019].

[64] "Ecoscore." [Online]. Available: http://ecoscore.be/en/info/ecoscore/co2. [Accessed: 27-Jun-2019].

[65] J. Ondraczek, N. Komendantova, and A. Patt, “WACC the dog: The effect of financing costs on the levelized cost of solar PV power,” *Renew. Energy*, vol. 75, pp. 888–898, 2015.

[66] O. Schmidt, A. Hawkes, A. Gambhir, and I. Staffell, “The future cost of electrical energy storage based on experience rates,” *Nat. Energy*, vol. 2, no. 8, 2017.

Appendix

A 1. The R code of the stochastic load modeler

```
.libPaths()

# install.packages("datapasta")

# Stochastic load model -------------------------------------------------------

library(here)

library(tidyverse)

library(datapasta)

library(lubridate)

library(readxl)

## Define Function. specify type of customer 'basic' or 'rich'

generate_load <- function(ctyp){

# Section 1

# Step 1.1: Data Import
```

```
if (ctyp == 'basic' ){
 load <- load_basic <- read_xlsx(here::here("data","appliances.xlsx"),
                       sheet = "household_basic_AC")}
if (ctyp == 'rich' ){
 load <- load_rich <- read_xlsx(here::here("data","appliances.xlsx"),
                      sheet = "household_rich_AC")}
# Step 1.2: Number of Occurrences
load_n <- setNames(data.frame(matrix(ncol = 5, nrow = 0)),
           c("loadid","loadtype","nj","djmin","djmax"))
for (a in seq_along(load[['j']])){
 b<- load[['q']][a]
 njmin<-load[['nj_min']][a]
 njmax<-load[['nj_max']][a]
 djmin<-load[['d_min']][a]
 djmax<-load[['d_max']][a]
 loadnum<-1
 for (c in 1:b){
  #Generation of random number betweeen njmin and njmax
  if (load[['j']][a] == 'water.pump') {
   n_random<- rbinom(1, 1, 1)
  }else if (load[['j']][a] == 'fridge'){
   n_random <- njmin
  }else{
```

```
    n_random <- sample(njmin:njmax, 1, replace = FALSE, prob = NULL)}
   #Table created to include nj as column for each appliance type and number
   row <- data.frame(loadid = paste(load[['j']][a],loadnum,sep="_"), loadtype = load[['j']][a],
                nj = n_random, djmin = djmin, djmax = djmax, stringsAsFactors = FALSE)
   load_n <- rbind(load_n, row)
   loadnum <- loadnum + 1
  }
 # rm(row, n_random,a,b,c, njmin,njmax,djmin,djmax,loadnum) # remove non necessary
vars
}
## Section 2
## Step 2.1: Occurrences Durations
##Table to save Occurrence Durations
#creating table load_d with 4 columns and names
load_d <- setNames(data.frame(matrix(ncol = 4, nrow = 0)),
             c("loadtype","loadid","loadoccid", "dij"))
# Step 1.2:
#import window table
if (ctyp == 'basic' ){
  window <- window_basic <-
   read_xlsx(here::here("data","appliances.xlsx"), sheet = "basic_windowAC")
}
if (ctyp == 'rich' ){
  window <- window_rich <-
```

```
    read_xlsx(here::here("data","appliances.xlsx"), sheet = "rich_windowAC")
}
##Generation of duration times dij
#creating table load_d with 4 columns and names
load_d <- setNames(data.frame(matrix(ncol = 4, nrow = 0)),
                   c("loadtype","loadid","loadoccid", "dij"))
for (d in seq_along(load_n[['loadid']])) {
  #Assignate Number of Occurrences from load_n table
  #Establish min and max durations
  djmin<-load_n[['djmin']][d]
  djmax<-load_n[['djmax']][d]
  nj<-load_n[['nj']][d]
  loadtype <- load_n[['loadtype']][d]
  #counter to give an id to all occurrances
  occurance <- 1
  while (occurance<=nj) {
    ##Generation of random duration betweeen dmin and dmax
    if (load_n[['loadtype']][d]=='fridge'){
      d_random <- djmin
    }else{
    d_random <- sample(djmin:djmax, 1, replace = FALSE, prob = NULL)
    }
    ##Table including duration as column for each ocurrence of each appliance
```

```
    row <- data.frame(loadtype = loadtype, loadid = load_n[['loadid']][d],
             loadoccid = paste(load_n[['loadid']][d], occurance,sep="_"),
             dij = d_random, stringsAsFactors = FALSE)
    load_d <-rbind(load_d, row)
    occurance <- occurance + 1
  }
  # rm(row, d_random,d,e,djmin,djmax,nj,loadtype,occurance)
}
# Step 2.2: Occurence Time Creation
load_w <- data.frame(matrix(ncol = 0, nrow = 48))
#Process input tables of windows into vectors for each load appliance
for (f in seq_along(load_n[['loadid']])) {
  loadwindow <- window %>% filter(j == load_n[['loadtype']][f]) %>%
    select(w0:w47) %>% as.numeric()
  load_w[[f]] <- loadwindow
  rm(f,loadwindow)
}
colnames(load_w) <- load_n$loadid
load_on <- data.frame(matrix(ncol = 0, nrow = 48))
for (g in seq_along(load_n[['loadid']])){
  windowocc <- load_w[[g]]
  occ1 <- load_d %>% filter(loadid == load_n[['loadid']][g])
  loadocc<-occ1[['loadoccid']]
```

```
 loadhours <- 0 #counter to keep track of hours a load is used
 for (h in seq_along(loadocc)) {
  dij <- load_d %>% filter(loadoccid == loadocc[[h]]) %>% select(dij) %>% pull()
  avbl <- which(windowocc == 1) #Assignates a time start within available window
  if (length(avbl) == 0) break
  t <- sample(avbl, 1, replace = TRUE, prob = NULL)
  d <- 1
  #Used to define the maximum hours a load can be used
  loadtype <- occ1[['loadtype']][h]
  dmax <- load %>% filter(j==loadtype) %>% select(d_tot) %>% pull()
  while (t <= 48 && d <= dij && loadhours<dmax) {
   #Makes sure the time slot is available
   while (windowocc[[t]] == 1) {
    windowocc[[t]] <- 2
    loadhours <- loadhours+1
   }
   d <- d + 1
   t <- t + 1
  }
 }
 load_on[[g]]<-windowocc
 #rm(avbl,d,dij,dmax,g,h,loadhours,loadocc,loadtype,t,windowocc,OCC1)
}
```

```
colnames(load_on) <- load_n$loadid

load_on[load_on == "1"] <- 0

load_on[load_on == "2"] <- 1

for (i in colnames(load_on)) {

  loadtype <- sub('_.*', '', i)

  typefilt<-load %>% filter(j == loadtype)

  power<-typefilt[['power']]

  load_on[[i]] <- load_on[[i]] * power

}

load_plot <- load_on %>% gather(loadid,power) %>% mutate(hour =
rep(0:47,length(colnames(load_on))))

load_plot <- load_plot %>%  mutate (hour = hour / 2)

total_energy <- load_plot %>% summarise(sum = sum(power))

# Mutate load_plot to gather loadtype from load_id

load_plot <- load_plot %>% rowwise %>% mutate(loadtype = sub('_.*', '', loadid))

#str(load_plot)

#glimpse(load_plot)

#mutate load_plot to convert strings into factors

load_plot <- load_plot %>%

  mutate(loadtype = factor(loadtype,

                    levels = load$j))

#Define parameters for hourly power plot stratified by loadtype

load_plot %>%

  ggplot(aes(hour,power, fill = loadtype)) +
```

```
 geom_col(position = "stack")
 #+scale_y_log10()
# write.csv(load_plot,'load.csv', row.names = FALSE)
return (load_plot)
}
# Adding Customers Function----------------------------------------------------
add_customers <- function(nbasic, nrich){
 # create empty dfs with same format as load_plo
 profile_basic  <- setNames(data.frame(matrix(ncol = 5, nrow = 0)),
                    c("loadid","power","hour", "loadtype","customer_id"))
 profile_rich  <- setNames(data.frame(matrix(ncol = 5, nrow = 0)),
                    c("loadid","power","hour", "loadtype","customer_id"))
 i <- 1
 j <- 1
 # add loads for every customer
 while (i <= nbasic){
  load_plot_basic <- generate_load('basic')
  load_plot_basic <- load_plot_basic %>% mutate("customer_id" = paste('basic',i,sep="_"))
  profile_basic <- data.frame( rbind (profile_basic, load_plot_basic ))
  i <- i + 1
 }
 # create load for every rich customer
 while (j <= nrich){
```

```
   load_plot_rich <- generate_load('rich')
   load_plot_rich <- load_plot_rich %>% mutate("customer_id" = paste('rich',j,sep="_"))
   profile_rich <- data.frame(rbind( profile_rich, load_plot_rich ))
   j <- j + 1
  }
  profile <- data.frame(rbind(profile_basic, profile_rich))
  return (profile)
  # create plot for all customers in one day
  profile %>%
   ggplot ( aes(hour, power, fill = loadtype )) +
   geom_col(position = "stack")
}
#Adding Days and Customers Raw  Function---------------------------------------
add_days_community <- function(days, nbasic, nrich){
  customers_days_raw  <- setNames(data.frame(matrix(ncol = 6, nrow = 0)),
               c("loadid", "power", "hour","loadtype", "customer_id","day"))
  for (d in 1:days){
   customers <- add_customers(nbasic,nrich)
   customers <- customers %>% mutate(hour = hour +(24*(d-1)))
   customers <- customers %>% mutate(day = d)
   customers_days_raw<- data.frame(rbind(customers_days_raw, customers))
  }
  customers_days_raw <- customers_days_raw %>%
```

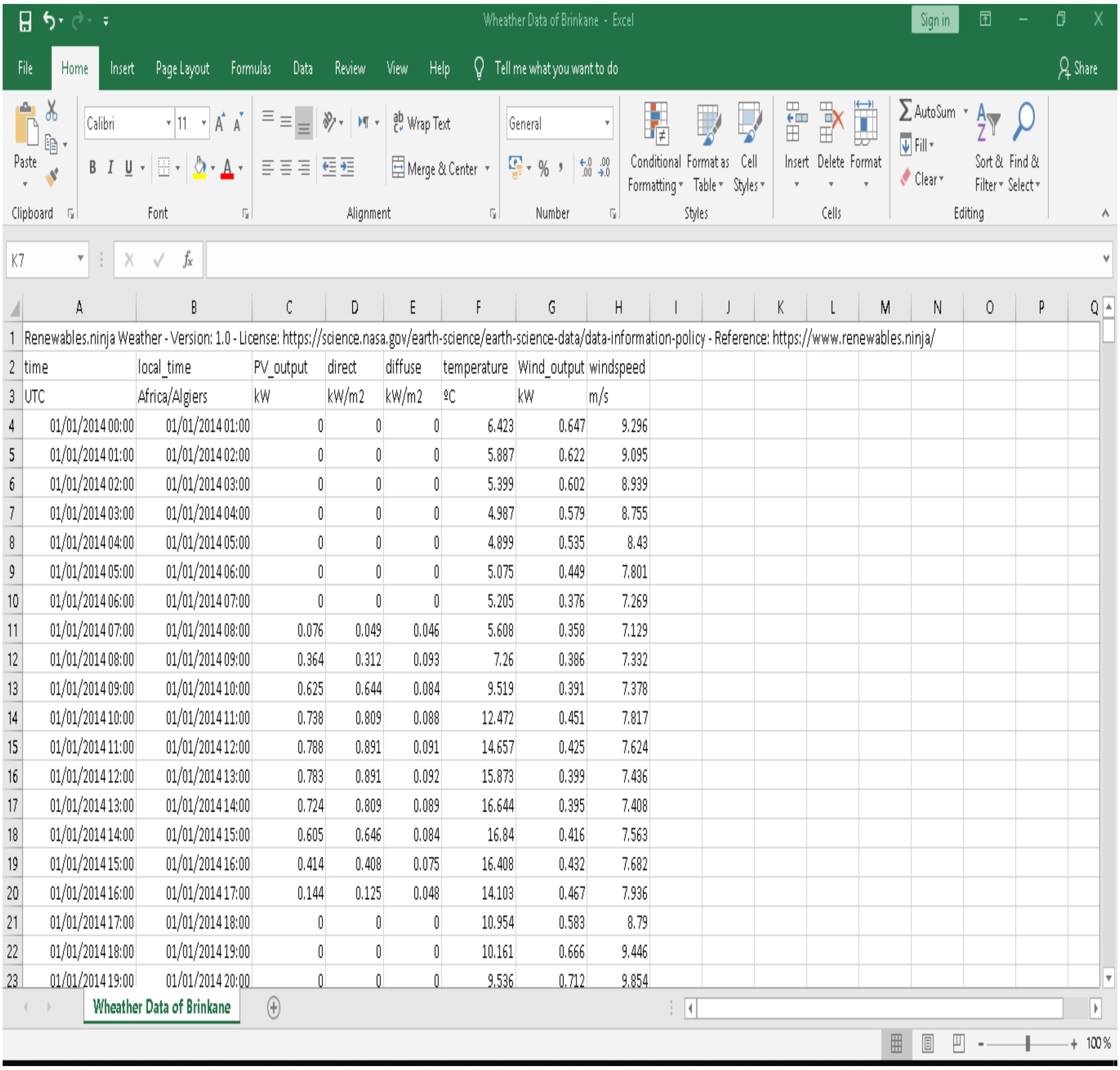
```
    mutate(customer_type = sub('_.*', '', customer_id))
  # define factors for community load type
  return (customers_days_raw)
}
# Create Year Vector from Raw customers and days ------------------------------
compile_days <- function (days,nbasic,nrich){
  raw_customers <- add_days_community(days,nbasic,nrich)
  raw_customers_h <- raw_customers %>% mutate(hour = floor(hour))
  total_power <- raw_customers_h %>% select (hour, power) %>%
    group_by(hour) %>%
    summarise(power=sum(power)/2)
  return (total_power)
}
# yearly_basic <- compile_days(5,1,1)
# yearly_basic %>%
#   ggplot(aes(hour,power)) +
#   geom_col()
# # Yearly Profile for 1 basic customer
# yearly_basic <- add_days_community(10,1,0)
# yearly_basic <- yearly_basic %>%
#   mutate( totalpower <- as.numeric(as.character(totalpower)))
# yearly_basic %>%
#   ggplot(aes(hour,totalpower)) +
```

```
#   geom_col()

# ## Add days to a customer ----------------------------------------------------

 add_days_customer <- function(days){

prof_sum<-c()

for (c in 1:days){

  load_plot <- generate_load('basic')

total_power <- group_by(load_plot,hour) %>%

    summarise(totalpower=sum(power))

total_power <- total_power %>% mutate(hour = floor(hour))

  total_power <- total_power %>%

   group_by(hour) %>%

    summarise(totalpower=sum(totalpower)/2)

  prof_sum <- append(prof_sum,total_power[[2]])

 }}

 prof_sum<-as.numeric(as.character(prof_sum))

hour<-(1:(days*24))

 year_profile<-data.frame(as.table(setNames(hour, prof_sum)))

colnames(year_profile) <- c('power','hour')

 return (year_profile)

year_profile %>% ggplot(aes(hour,as.numeric(as.character(power)))) + geom_col()

# Visualisation ---------------------------------------------------------------

# Use this section to enter inputs

# input for single day single customer function
```

```
type <- 'basic'

# input for other functions

nbasic <-0

nrich <-1

days <-1

# Run this section to include inputs above

# one day, one customer

gen <- generate_load(type)

# add customers to one day

customers <- add_customers(nbasic,nrich)

# add days and customers

community_customers <- add_days_community (days,nbasic,nrich)

# compile for CSV creation

customer_time_df <- compile_days (days, nbasic, nrich)

write.csv(customer_time_df,'ac_year_tier2_fbase.csv', row.names = FALSE)

customer_time_df %>% ggplot(aes(hour,as.numeric(power)))+

  geom_col()

#visualize total energy in wh/day

total_energy <- (customer_time_df %>% summarise(sum = sum(power)))/days

 # Different graphs

gen %>%  ggplot(aes(hour,power, fill = loadtype)) +

  geom_col(position = "stack") +

  labs( x= "Hour", y="Power", fill= "Load Type")
```

```
#load type
community_customers %>%  ggplot(aes(hour,power, fill = loadtype)) +
  geom_col(position = "stack") +
  #geom_vline(xintercept = 24, colour = "red", linetype = 2, size = 1) +
  #geom_vline(xintercept = 48, colour = "red", linetype = 2, size = 1) +
  labs ( x = 'Time (h)', y ='Power (W)' , fill = 'Load Type')+
  theme_light()
#ggsave("AC_T4.png", device = "png", width = 5, height = 5*0.618, units = "in")
#customer type
community_customers %>% ggplot(aes(hour,power, fill = customer_type)) +
  geom_col(position = "stack")
# day
community_customers %>% ggplot(aes(hour,power, fill = as.factor(day))) +
  geom_col(position = "stack")+
  scale_fill_discrete(drop = FALSE)
```

A. 2 Weather Data and Estimated Power Output of Brinkane



	A	B	C	D	E	F	G	H
1	Renewables.ninja Weather - Version: 1.0 - License: https://science.nasa.gov/earth-science/earth-science-data/data-information-policy - Reference: https://www.renewables.ninja/							
2	time	local_time	PV_output	direct	diffuse	temperature	Wind_output	windspeed
3	UTC	Africa/Algiers	kW	kW/m2	kW/m2	ºC	kW	m/s
4	01/01/2014 00:00	01/01/2014 01:00	0	0	0	6.423	0.647	9.296
5	01/01/2014 01:00	01/01/2014 02:00	0	0	0	5.887	0.622	9.095
6	01/01/2014 02:00	01/01/2014 03:00	0	0	0	5.399	0.602	8.939
7	01/01/2014 03:00	01/01/2014 04:00	0	0	0	4.987	0.579	8.755
8	01/01/2014 04:00	01/01/2014 05:00	0	0	0	4.899	0.535	8.43
9	01/01/2014 05:00	01/01/2014 06:00	0	0	0	5.075	0.449	7.801
10	01/01/2014 06:00	01/01/2014 07:00	0	0	0	5.205	0.376	7.269
11	01/01/2014 07:00	01/01/2014 08:00	0.076	0.049	0.046	5.608	0.358	7.129
12	01/01/2014 08:00	01/01/2014 09:00	0.364	0.312	0.093	7.26	0.386	7.332
13	01/01/2014 09:00	01/01/2014 10:00	0.625	0.644	0.084	9.519	0.391	7.378
14	01/01/2014 10:00	01/01/2014 11:00	0.738	0.809	0.088	12.472	0.451	7.817
15	01/01/2014 11:00	01/01/2014 12:00	0.788	0.891	0.091	14.657	0.425	7.624
16	01/01/2014 12:00	01/01/2014 13:00	0.783	0.891	0.092	15.873	0.399	7.436
17	01/01/2014 13:00	01/01/2014 14:00	0.724	0.809	0.089	16.644	0.395	7.408
18	01/01/2014 14:00	01/01/2014 15:00	0.605	0.646	0.084	16.84	0.416	7.563
19	01/01/2014 15:00	01/01/2014 16:00	0.414	0.408	0.075	16.408	0.432	7.682
20	01/01/2014 16:00	01/01/2014 17:00	0.144	0.125	0.048	14.103	0.467	7.936
21	01/01/2014 17:00	01/01/2014 18:00	0	0	0	10.954	0.583	8.79
22	01/01/2014 18:00	01/01/2014 19:00	0	0	0	10.161	0.666	9.446
23	01/01/2014 19:00	01/01/2014 20:00	0	0	0	9.536	0.712	9.854

A 3.1 Detailed Input Parameters

case_name	offgrid_shs	offgrid PV_LPG_batt	offgrid_wind_LPG_batt	offgrid_LPG only	offgrid_PV_wind_batt	offgrid_PV_wind_LPG_batt	offgrid_wind_LPG
perform_simulation	False	True	True	True	True	True	True
based_on_case	False	False	False	False	False	False	False
capacity_pv_kWp	oem	oem	None	None	oem	oem	None
capacity_wind_kW	None	None	oem	None	oem	oem	oem
capacity_storage_kWh	oem	oem	oem	None	oem	oem	None
force_charge_from_maingrid	False	False	False	False	False	False	False
discharge_only_when_blackout	False	False	False	False	False	False	False
capacity_rectifier_ac_dc_kW	oem	oem	oem	oem	oem	oem	oem
capacity_inverter_dc_ac_kW	oem	oem	oem	oem	oem	oem	oem
enable_inverter_only_at_backout	False	False	False	False	False	False	False
capacity_genset_kW	None	oem	oem	oem	None	oem	oem
genset_with_minimal_loading	False	oem	oem	oem	None	oem	oem
number_of_equal_generators	1	1	1	1	1	1	1
capacity_pcc_consumption_kW	None	None	None	None	None	None	None
capacity_pcc_feedin_kW	None	oem	oem	None	None	oem	oem
allow_shortage	False	False	False	False	False	False	False

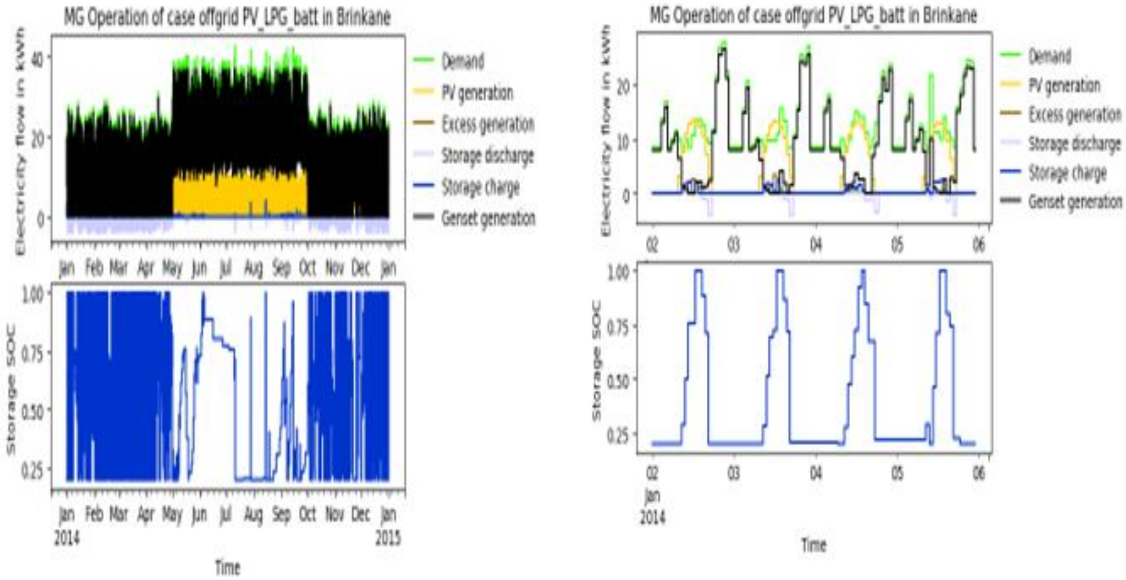
max_shortage	default	default	default	default	default	default	default
stability_constraint	False	share_hybrid	share_hybrid	share_hybrid	share_hybrid	share_hybrid	False
renewable_constraint	False	False	False	False	False	False	False
evaluation_perspective	AC_system	AC_system	AC_system	AC_system	AC_system	AC_system	AC_system

A 3.2 Input Constants of the Tool

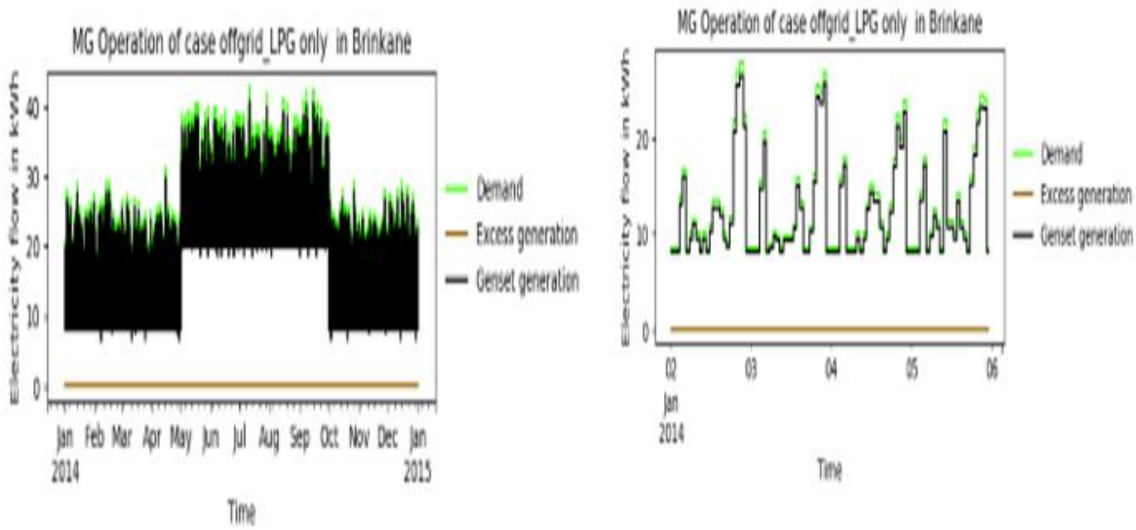
Parameter	Value	Unit
blackout_duration	0	hrs
blackout_duration_std_deviation	0	fraction
blackout_frequency	0	/mth
blackout_frequency_std_deviation	0	fraction
combustion_value_fuel	6.44	kWh/l
demand_ac_scaling_factor	1	factor
demand_dc_scaling_factor	1	factor
distribution_grid_cost_investment	32000	currency
distribution_grid_cost_opex	32	/a
distribution_grid_lifetime	40	a
genset_batch	0	kW
genset_cost_investment	820	/kW
genset_cost_opex	0	/kW/a
genset_cost_var	0.05	/kWh
genset_efficiency	0.33	factor
genset_lifetime	10	a
genset_max_loading	1	fraction
genset_min_loading	0.1	fraction
genset_oversize_factor	1.2	factor
inverter_dc_ac_batch	0	kW
inverter_dc_ac_cost_investment	174	/kW
inverter_dc_ac_cost_opex	7	/kW/a

inverter_dc_ac_cost_var	0	/kWh
inverter_dc_ac_efficiency	0.95	fraction
inverter_dc_ac_lifetime	15	a
maingrid_distance	0	km
maingrid_electricity_price	0.0787	/kWh
maingrid_extension_cost_investment	0	/km
maingrid_extension_cost_opex	0	/km/a
maingrid_extension_lifetime	40	/km/a
maingrid_feedin_tariff	0	/kWh
maingrid_renewable_share	0	fraction
min_renewable_share	0	fraction
pcoupling_batch	1	kW
pcoupling_cost_investment	200	/kW
pcoupling_cost_opex	0	/kW/a
pcoupling_cost_var	0	/kWh
pcoupling_efficiency	1	fraction
pcoupling_lifetime	20	a
pcoupling_oversize_factor	1.5	factor
fuel_price	0.08	/l
fuel_price_change_annual	0.05	p.a.
project_cost_investment	20000	currency
project_cost_opex	0	/a
project_lifetime	20	a
pv_batch	0	kWp
pv_cost_investment	1250	/kWp
pv_cost_opex	25	/kWp/a
pv_cost_var	0	/kWh
pv_lifetime	25	a
rectifier_ac_dc_batch	0	kW
rectifier_ac_dc_cost_investment	150	/kW
rectifier_ac_dc_cost_opex	6	/kW/a
rectifier_ac_dc_cost_var	0	/kWh
rectifier_ac_dc_efficiency	0.95	fraction

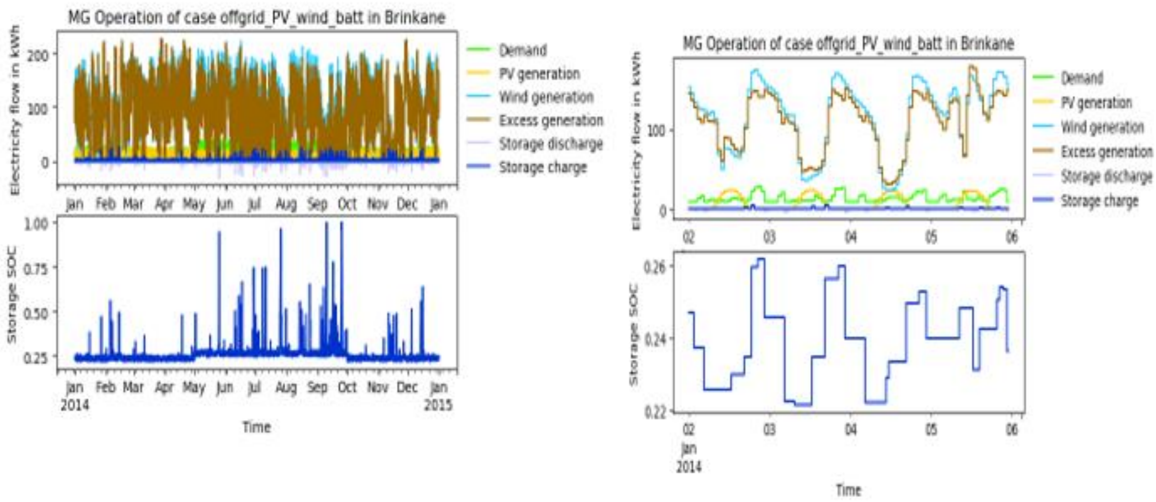
rectifier_ac_dc_lifetime	15	a
shortage_max_allowed	0	fraction
shortage_max_timestep	0	fraction
shortage_penalty_costs	0	/kWh
stability_limit	0.2	fraction
storage_batch_capacity	1	kWh
storage_batch_power	1	kWh
storage_capacity_cost_investment	250	/kWh
storage_capacity_cost_opex	6.75	/kWh/a
storage_capacity_lifetime	13.5	a
storage_cost_var	0	a
storage_Crate_charge	1	fraction
storage_Crate_discharge	0.50	fraction
storage_efficiency_charge	0.97	fraction
storage_efficiency_discharge	0.97	fraction
storage_loss_timestep	0	fraction
storage_power_cost_investment	500	/kW
storage_power_cost_opex	0	/kW/a
storage_power_lifetime	13.5	a
storage_soc_initial	None	None or factor
storage_soc_max	1	fraction
storage_soc_min	0.2	fraction
tax	0	fraction
wacc	0.1	fraction
white_noise_demand	0	fraction
white_noise_pv	0	fraction
white_noise_wind	0	fraction
wind_batch	0	kW
wind_cost_investment	1477	/kW
wind_cost_opex	14	/kW/a
wind_cost_var	0	/kWh
wind_lifetime	20	a



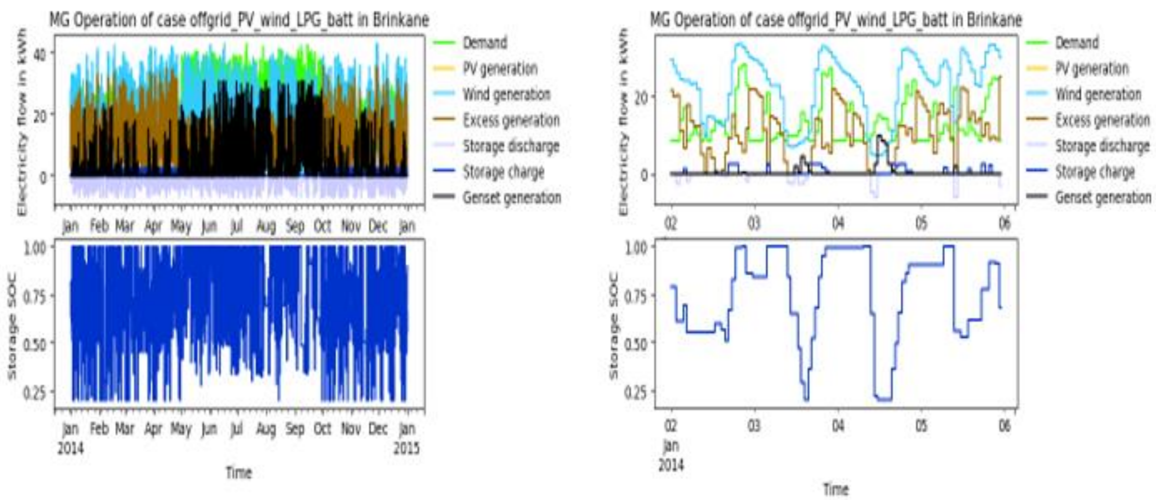
A.4. 1: Preliminary Consumption and Production of PV_LPG and Storage



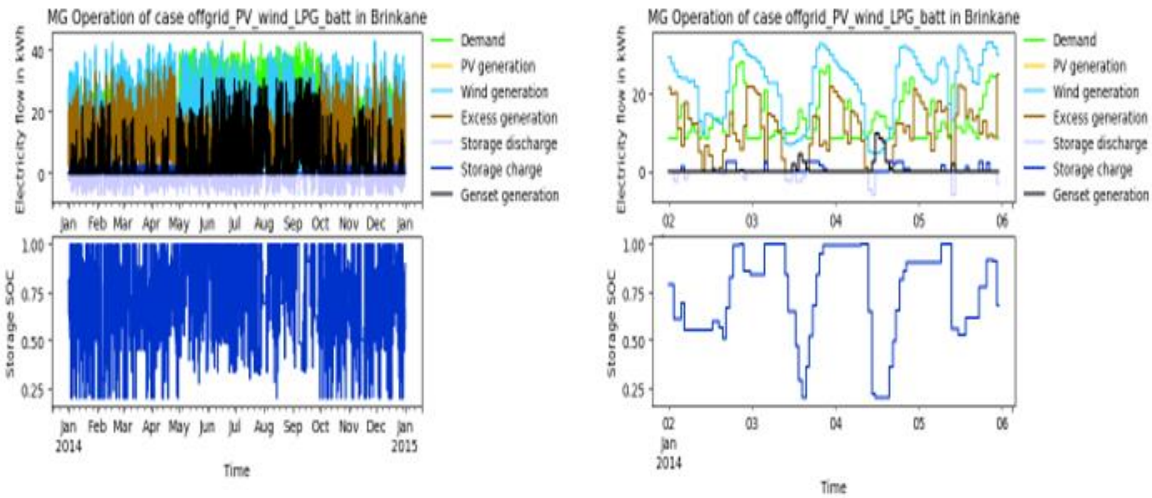
A.4. 2 : Preliminary Consumption and Production of LPG only



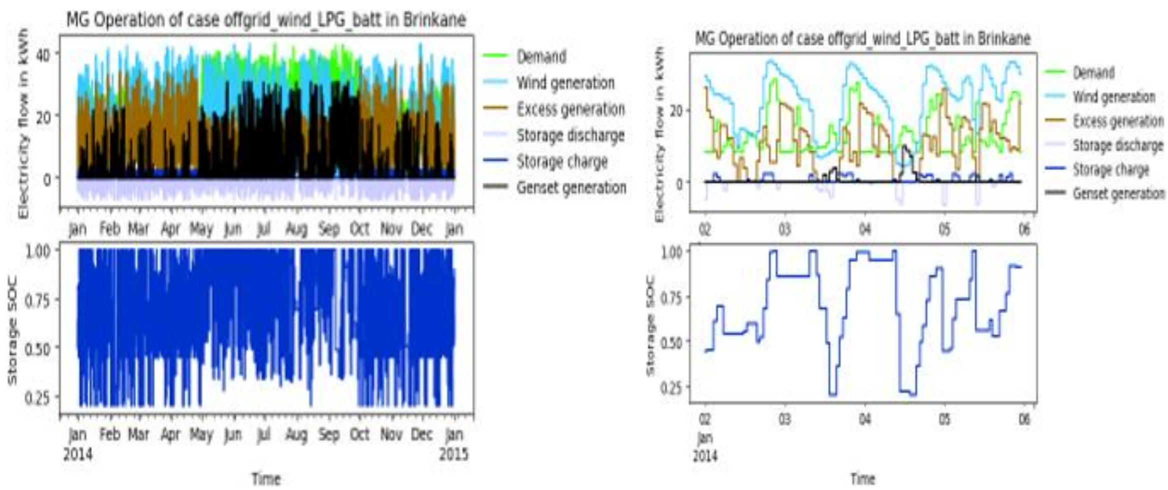
A.4. 3: Preliminary Consumption and Production of PV_Wind and Battery Storage



A.4. 4 : Preliminary Consumption and Production of PV_Wind _LPG



A.4. 5 : **Preliminary Consumption and Production of PV_Wind_LPG and Storage**



A.4. 6 : **Preliminary Consumption and Production of Wind_LPG_battery Storage**

Description of research grant use:

S/No.	Item	Unit	Quantity	Rate (Unit price)	Amount*
	(A) Travel + Visa Costs				
1	Flight from Tlemcen to Germany	$	1	434	434+120EUR
2	Visa to Germany	$	1	60	83+30*
3	Travel insurance	$	1	90	90
	Sub Total	$			**757**
	(B) Materials and supplies				
1	Internet in Algeria	$	3	21	63
2	Internet in Berlin	$	3	34	102
	Sub Total	$			**165**
	(C) Special activities				####
1	Printing of the thesis	$	5	13	73
	Sub total				**73**
TOTAL					
	Grand Total				**1055 $**

The research internship was conducted in the Reiner Lemoine institute in Germany.

The flight ticket was purchased based on the visa period, and due to the delay entry, another change in the return flight ticket was done as well as the visa extension application.