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Presented by

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MINI-GRID DESIGN FOR POWERING A RURAL COMMUNITY WATER SUPPLY AND TREATMENT UNIT

CASE STUDY: MURQAB BIN HAFAF, DJELFA, ALGERIA

Defended on 15/11/2021 before the following committee:

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2021

DECLARATION

I, Kahsu Gebrehans Gebreslassie, hereby declare that this thesis represents my personal work, realized to the best of my knowledge. In compliance with academic regulations and ethics, I further certify that all information, material, and results from other publications presented here have been fully cited and referenced.

Signed

__________________________ 07/12/2021

Kahsu Gebrehans Gebreslassie Date

CERTIFICATION

This is to certify that this thesis work entitled **"Mini-grid Design for powering a Rural Community Water Treatment and Supply: Case study in Algeria"** is a record of original work done by Kahsu Gebrehans Gebreslassie in partial fulfillment of the requirement for the award of a Master of Science Degree in Energy Engineering at the Pan African University Institute of Water and Energy Sciences, (including Climate Change), PAUWES, Algeria. He has taken into account all of the thesis supervisor's observations, suggestions, and comments.

Signed

A. Khellaf

………………………………………………

Professor Abdallah Khellaf — Date: December 7th, 2021

Centre de Développement des Energies Renouvelables (CDER),

Algiers, Algeria

DEDICATION

This master thesis is dedicated to Almighty God and my family.

ABSTRACT

A large portion of the African population, more particularly in the rural areas, remains without sustainable access to safe water. Even worse, there is increasing inequality between urban and rural communities' access to safe water. Rural areas, usually characterized by their remoteness, suffer from the lack of basic public services, such as sewage, access to electricity and access to sustainable safe water supplies and infrastructures. There is then the need for these areas to improve access to safer and sustainable water supplies. This helps to meet the Millennium Development Goal on drinking water and eliminate the exposition to waterborne diseases such as cholera, diarrhea, dysentery, hepatitis A and typhoid. Moreover, with running water, less time is spent and less risk is taken on fetching water of unreliable quality from a water source. This challenging in enhancement of the quality of life.

The lack of access to safe water requires a suitable and efficient water supply and treatment systems. Moreover, electricity is required to power these water systems. The link between water and energy, i.e., water-energy nexus, is well established. Energy is used in many aspects of water supply and infrastructures such as water and wastewater treatment, water supply, water transfer, etc. Usually, rural areas suffer unfortunately from access not only to safe water but also to adequate energy supply. The remoteness of the rural areas raises the challenge of extending the public services to these areas.

The study presents a mini-grid design for powering rural community water treatment and supply. The selected case study for this is Murqab Bin Hafaf Village, Djelfa, Algeria. After identifying of the basic problems from the village and collecting of water demand, the mini-grid power system was designed and optimally sized using water data and energy resources data. Three scenarios were analyzed i.e., on-grid, off-grid with generator and hydrogen-based off-grid. The on-grid system with the Levelized COE value of 0.02671 $/kWh is most cost-effective mini-grid design because excess electricity generated by the system is sold to the grid (resulting in more revenue from electricity). Off-grid with generator backup power has the higher COE value as compared to grid-connected with least value of 0.2863 $/kWh, and it comes with an emission penalty. Although the hydrogen-based off-grid solution is more expensive than others with COE of 0.3897 $/kWh, it produces no CO2. As a result, it is more environmentally friendly, and with the cost of hydrogen technology falling rapidly, it is undoubtedly the greatest future solution.

Keyword: Africa, rural areas, water treatment, water supply, Murqab Bin Hafaf, mini-grid, sizing, optimization, COE, NPC, hydrogen, off-grid, on-grid

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In this project, I have tried my best to achieve the final success. However, my work would not have been possible without the guidance of some individuals who directly or indirectly contributed their valuable assistance. Above all, I proudly thank the almightily God because he gave me the strength to complete my project.

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TABLE OF CONTENTS **PAGE**

DECLARATION ii

CERTIFICATION iii

DEDICATION iv

ABSTRACT v

ACKNOWLEDGMENT vi

TABLE OF FIGURES xi

TABLE OF TABLES xiv

ACRONYMS xv

CHAPTER ONE 1

1 INTRODUCTION 1

- 1.1 Background 1
- 1.2 Problem of statement 2
- 1.3 The objective of the project 3
  - 1.3.1 Main objective 3
  - 1.3.2 Specific objective 3
- 1.4 Research questions 3
- 1.5 Scope of the study 4
- 1.6 Study context 4
- 1.7 Obstacles 4
- 1.8 Relevance of the study 4
- 1.9 Thesis structure 5

CHAPTER TWO 7

2 LITERATURE REVIEW 7

- 2.1 Introduction 7
- 2.2 Status of access to water Africa rural communities 7
- 2.3 Water status in Africa 8

2.4 Water Scarcity in North Africa 10
2.5 Overview of the water situation in Algeria 11
2.6 Water resources potential in Africa 12
2.6.1 Groundwater potential in Africa 12
2.7 Africa Energy Resources Potential 12
2.7.1 Primary energy resources 13
2.8 Techniques and technologies used to provide rural community water supply and treatment 14
2.8.1 Water Pumping 14
2.8.2 Diesel pumping system 14
2.8.3 Solar Photovoltaic Water Pumping system 15
2.8.4 Wind turbine pumping system 17
2.8.5 Biomass water pumping system 18
2.8.6 Hybrid water pumping System 19
2.9 Water Treatment Techniques 20
2.10 Electrical Grid 22
2.11 Mini-grid 22
2.12 Mini-grid Components 22
2.12.2 Classification of Mini-grids 24
2.13 Smart Mini-grid 25
2.14 Mini-grid for Powering of Rural Community Water Supply and Treatment 26
CHAPTER 3 29
3 MATERIALS AND METHODS 29
3.1 Introduction 29
3.2 Case study 30
3.2.1 Issues existing in the village 30
3.3 Water resources in the region 31

3.4 Water Demand of the Village 32
3.5 Energy demand for the community 33
3.5.1 Water Treatment 34
3.6 Energy resources selection 35
3.6.1 Solar radiation potential of the region 36
3.6.2 The wind energy potential of the region 36
3.6.3 The temperature profile of the region 37
3.7 Sizing, Selection of Equipment, and Performance Evaluation and Simulation of the System 37
3.7.1 HOMER Software 37
3.7.2 Mathematical modeling 37
3.7.3 Pump selection 37
3.7.4 Solar PV 39
3.7.5 Wind turbine 40
3.8 Cost analysis 40
3.8.1 Cost of Energy 40
3.8.2 Net present cost 41
3.9 ICT and technologies in mini-grid systems 41
3.9.1 Sensor 41
3.9.2 Desktop 42
3.10 Design layout description 42
CHAPTER 4 43
4 RESULT AND DISCUSSION 43
4.1 Introduction 43
4.2 Survey assessment 43
4.3 HOMER analysis 45
4.3.1 Load profile 45

4.3.2 Component selection 46

4.3.3 Off-grid system analysis 47

4.3.4 On-grid system analysis 53

4.3.5 Hydrogen based off-grid system 59

4.3.6 Result summary 62

CHAPTER FIVE 64

5 CONCLUSION AND RECOMMENDATION 64

5.1 Conclusion 64

5.2 Recommendation 65

6 REFERENCES 66

7 APPENDIX 75

7.1 Appendix A: Water demand of the village 75

7.2 Appendix B: Energy demand 79

TABLE OF FIGURES

Figure 1:1 Thesis structure 6

Figure 2:1 Water availability in Africa 9

Figure 2:2 Proportion of population using safely managed to drink water services of the world, 2020 (%) 10

Figure 2:3 MENA region 11

Figure 2:4 Water pumping using diesel engine (concept take from [40]) 15

Figure 2:5 Photovoltaic water pumping system block diagram 16

Figure 2:6 Photovoltaic water pumping system with battery storage block diagram 16

Figure 2:7 Photovoltaic solar water pumping system (concept take from [40]) 16

Figure 2:8 Wind energy water pumping system layout 18

Figure 2:9 Biomass pumping system layout 19

Figure 2:10 Hybrid energy sources pumping system layout. 20

Figure 2:11 Desalination technology systems 20

Figure 2:12 Hybrid (solar and wind) reverse osmosis desalination system 21

Figure 2:13 Water treatment process 22

Figure 2:14 Hybrid mini-grid system 24

Figure 2:15 Schematic diagram of hybrid system 25

Figure 2:16 Smart mini-grid system 26

Figure 3:1 Methodology structure 29

Figure 3:2 Case study location 30

Figure 3:3 Collecting of water using tank and track in the village 31

Figure 3:4 System flow chart 34

Figure 3:5 Solar radiation potential of Djelfa region 36

Figure 3:6 wind speed potential of Djelfa region 36

Figure 3:7 Daily temperature profile of Djelfa 37

Figure 3:8 Cells collection forming PV arrays [101] 40

Figure 3:9 Layout mini grid design for rural community water supply and treatment (drawn by author using AutoCAD software) 42

Figure 4:1 Daily load profile 45

Figure 4:2 Seasonal load profile 45

Figure 4:3 Yearly load profile 46

Figure 4.4 Off-grid schematic for powering of water treatment and supply 47

Figure 4:5 Cost summery of PV/Wind turbine/generator/battery/converter system 48

Figure 4:6 Cash flow of PV/wind/generator/battery/converter system 48

Figure 4:7 Monthly electricity production of PV/generator/battery/converter system 49

Figure 4:8 Cost summery PV/generator/Battery/converter system 49

Figure 4:9 Cash flow PV/generator/battery/converter system 50

Figure 4:10 Monthly electric production of PV/generator/battery/converter system 50

Figure 4:11 Cost summery of PV/wind /battery/converter system water treatment and supply unit 51

Figure 4:12 Coat cash flow PV/wind/battery/converter system 51

Figure 4:13 Monthly electric production of PV/wind/battery/converter system 52

Figure 4:14 Sensitivity analysis 52

Figure 4:15 Grid connected schematic water treatment and supply system 54

Figure 4:16 Cost summery of PV/Wind/Grid water treatment and supply system 54

Figure 4:17 Cost Cash flow of PV/Wind/Grid/Battery/Converter water treatment and supply system 55

Figure 4:18 Monthly electric production of PV/Wind/Grid/Battery/Converter water treatment and supply system 55

Figure 4:19 Cost summery of PV/Grid/Converter water treatment and supply system 56

Figure 4:20 PV/Grid/Converter with converter cash flow 56

Figure 4:21 Monthly electric production of PV/Grid/Converter with converter water treatment and supply system 57

Figure 4:22 Cost summery of Wind/Grid water treatment and supply system 57

Figure 4:23 Cash flow of wind/grid water treatment and supply system.................................. 58

Figure 4:24 Monthly electric production of Wind/Grid water treatment and supply system 58

Figure 4:25 Sensitivity analysis of on-grid system 59

Figure 4:26 Schematic of off-grid system with electrolyzer and fuel cell 61

Figure 4:27 Cost summary of mini-grid with electrolyzer and fuel cell.................................... 61

Figure 4:28 Cost cash flow mini-grid with electrolyzer and fuel cell.. 62

Figure 4:29 Monthly electric production of the mini-grid with electrolyzer and fuel cell 62

TABLE OF TABLES

Table 3:1 Total water demand of the village in (m^3/ day.month) 33

Table 3:2 Pump selection 38

Table 3:3 Pump working hours 39

Table 4:1 survey assessment from the community 43

Table 4:2 Component selection 46

Table 4:3 Result summery 62

Table 7:1 Water demand for household 75

Table 7:2 Water demand for animal farm 76

Table 7:3 Water demand for irrigation 76

Table 7:4 Water demand for school 77

Table 7:5 Water demand for clinic 77

Table 7:6 Seasonal water demand 78

Table 7:7 Energy demand for pumping water 79

Table 7:8 Energy demand for electronics and light 80

Table 7:9 Hourly arranged energy demand for spring season 81

Table 7:10 Hourly arranged energy demand for summer season 82

Table 7:11 Hourly arranged energy demand for Autumn season 83

Table 7:12 Hourly arranged energy demand for winter season 84

ACRONYMS

AC	Alternative current
COE	Cost of Energy
CO2	Carbon dioxide
DC	Direct current
HOMER	Hybrid optimization model for electric renewable
kW	Kilowatt
kWh	kilowatt-hour
h	hour
ICT	Information and Communication Technologies
LCOE	Levelized cost of energy
NPC	Net present cost
MENA	Middle East and North Africa
PV	Photovoltaic
SDGs	sustainable development goals
UN	United nations
SSA	Sub Saharan Africa
yr	year

CHAPTER ONE

1 INTRODUCTION

1.1 Background

A large number of the African population, particularly in rural regions, lacks long-term access to safe drinking water. Worse, the gap between urban and rural residents in terms of access to safe water is widening. Rural areas, which are typically characterized by their isolation, lack basic public services such as sewerage, power, and access to sustainable, safe water sources and infrastructures. The need for these places to enhance access to safer and more sustainable water resources arises as a result (Kim et al. 2016).

Universal access to safe and clean drinking water is a basic need and a human right. In 2000, the number of people who have adequate drinking water was around 2 billion and in 2020 5.8 billion people was having access to safely managed services and around 2 billion with basic services. Despite that, about 771 million of the world's population lives without access to safe drinking water. From the total population, 282 million of it using improved sources with a collection time of more than 30 minutes. In addition, 367 million people use not treated water, and 122 million people use water direct from unprotected surface water such as lakes and rivers (UNICEF 2021a).

The relevance of this study of mini-grid design for powering of water treatment and supply in providing access water for drinking, irrigation, and increasing quality of life is reflected in the global commitments of the Sustainable Development Goals. This research work's main objective is to investigate how efficiently to design and implement such energy sources to solve the water and energy issues such as access to water within the context of a country, such as Algeria, that suffers from water scarcity. This mini-grid design will power a rural community water supply and treatment. Design of mini-grid for powering of rural community water supply and treatment using reliable, efficient and clean energy resources is one of the solutions to solve societal problem especial related to a water issue.

Mini-grids are a type of energy infrastructure system that generates electricity using different energy resources. Power generation; power storage; control, management, and measure; conversion and consumption are the main and fundamental functions of mini-grid systems (IRENA 2016).

The lack of access to safe water requires a suitable and efficient water supply and treatment systems. Depending on the water quality, different technologies could be used. This could be simple filtration and chlorine treatment or more elaborate techniques. For brackish water with high dissolved solids, desalination is required with reverse osmosis being arguable, in this case, one of the best technologies. Moreover, electricity is required to power these water systems. The link between water and energy, i.e., water-energy nexus, is well established. Energy is used in many aspects of water supply and infrastructures such as water and wastewater treatment, water supply, water transfer, etc. Usually, rural areas suffer unfortunately from access not only to safe water but also to adequate energy supply. The remoteness of the rural areas raises the challenge of extending the public services to these areas. These areas lend themselves then best to local solutions. Resorting to a local renewable-based off-grid electrical system to power a rural area water supply system is a sustainable, clean and affordable way to meet the sustainable safe water need of the rural community. This research deals with the design and the sizing of a mini to power a water supply system for a rural community in Africa.

The financial and social status in the water sector is also another key factor of the problem in clean and safe drinking water in Africa rural communities, particularly in the rural areas. It needs to balance such kind of difference for the sake of getting safe and clean water (Marson and Savin 2015).

1.2 Problem of statement

People from rural areas have obtained water from unprotected ponds and rivers. In Africa, there is a challenge to access energy. Today a large number of people lack access to safe drinking water especially those who live in rural areas. There are so many challenges such as difficulties managing energy resources and attracting investments, lack of inadequate power generation capacity, and difficulties serving low-income consumers are all problems that need to be addressed. To address issues in power generation, a grid system is one method especially in areas with hot and high direct solar irradiation. People from rural areas have obtained water from unprotected ponds and rivers. This causes different diseases such as Cholera, diarrhea and others. To address this issue, mini-grid development for rural water supply communities will be a good approach.

Rural areas mostly have challenges in access to safe and clean drinking water (Wibowo and Chang 2020). Most people from rural areas particularly in Africa still do not have piped household water supply. They used to fetch water from river, lakes and other, also used to buy water using big tank from other cities or neighbors and keep it for a long time. This could have an effect in health and reduce the quality of water as well as a waste of time during fetching water.

One of the main challenges in Africa is access to clean water in both urban and rural areas. Their limited water are few water sources in Africa to provide clean water access for all populations, particularly in rural areas. Surface water is always polluted and the cost of it for piping and access is high. For rural areas communities, ground water is the best method for providing clean water (Lewis 2021).

1.3 The objective of the project

1.3.1 Main objective

The main objective of this study is to design a mini-grid for powering a rural community water supply and treatment unit.

1.3.2 Specific objective

The specific objectives are:

- ✓ Identification, in a rural community, of the water supply sources and the quality of their water; and evaluation of the risks arising from the use of this water, namely the health risks related to waterborne diseases, the lack of water for productive use, the waste of time in fetching water of poor quality from an unreliable source and discussion of the possible solutions, water techniques based on the use of mini-grid power system, to remedy to this problem.
- ✓ Identification, in a rural community, of water use practices and water supply needs and discuss the use of mini-grid and ICT and digital technologies related solutions to address these issues.
- ✓ Identification of the locally available renewable energy sources and their potentials and discussion of their use in powering a mini-grid featuring ICT and digital technologies.
- ✓ Design and sizing of a mini-grid for powering safe water supply system for a rural community: a scheme that is reliable, efficient, clean and more importantly that relies on local resources and can lead to jobs creation. Different options, including different renewable sources and different mini-grid management schemes, are considered in order to determine the optimal mini-grid configuration.
- ✓ Comparative techno-economic study of mini-grid for powering safe water supply system for a rural community under different assumptions, considering different local energy sources and different water supply and treatment techniques.

1.4 Research questions

To address the problems explained in this study, the following questions will guide this project;

- ✓ Can the mini-grid power system provide continuous and sustainable power to the rural community water supply?

- ✓ What components and parameters will be used when designing the mini-grid for powering rural water supply?
- ✓ What contributions will the mini-grid bring to the problems in rural areas, economy and what are the likely environmental and social impacts?
- ✓ What are the digital technologies used in the water supply systems?
- ✓ What will be the contribution of mini-grid power generation to the sustainable development goal?

1.5 Scope of the study

The selected case study for this work is Marqab Bin Hafaf village due to the existence of challenges in drinking water, especially during the summertime. This work is to design a mini-grid for powering of water treatment and supply used for the community considering different parameters. Solar and wind energy resources are considered in the selected case study.

1.6 Study context

Africa, as a continent, is facing huge challenges in clean drinking water access, especially in rural areas. Algeria's in particular has most of its land engulfed by the desert and arid land. Despite this challenge, the country has huge solar potential for mini-grids development that could be able used to support rural areas in accessing clean and drinking water supplies.

The electricity access in Algeria is mainly from fossil fuel sources like natural gas and this generation of power is always associated with emissions of CO_2. Moreover, fossil fuels are depleting thus fast shifting into renewable energy sources is gaining so much interest as they are clean and reliable. The design of a mini-grid for clean water treatment supply in a rural community in Algeria is the point of focus of this study.

1.7 Obstacles

During the time of the research, I have faced some challenges. One of the challenges is language challenge. The official language of Algeria is French and Arabic and I cannot speak both languages and was a challenge to communicate with the communities and workers. But this could be managed through a research assistant who can speak both languages. An additional challenge was the restriction of movement caused by COVID – 19 pandemics.

1.8 Relevance of the study

The relevance of the study is:

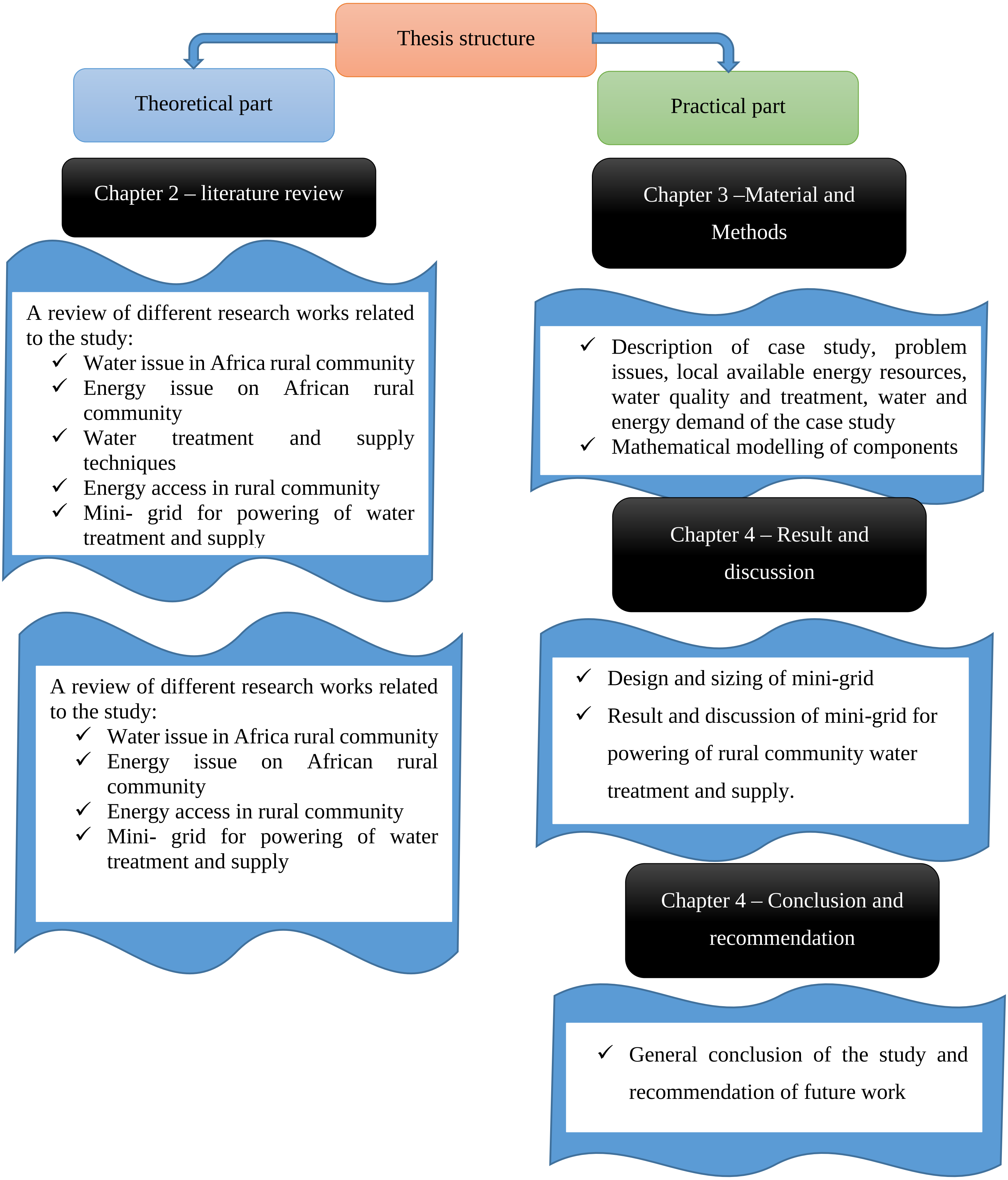
- ✓ Accessing safe and clean drinking water for rural area communities

- ✓ Increasing the quality of water that the community in rural areas using
- ✓ Increasing access to renewable energy technologies
- ✓ Introduction the access to internet technologies used for water supply systems
- ✓ Contributing the Sustainable Development Goals (SGDs) particularly in the issue of energy and water

1.9 Thesis structure

Figure 1.1 below outlines the main points of the present study. The work started with introduction of the study topic, which indicates the water and energy issues in Africa and its background, objectives, statement problem, objectives of the study, research questions, significant and scope of the study and the limitation of the study.

In general, the next section of the study is divided in to two parts (theoretical and practical parts) in which each parts have different particular sections. Each section is explained below figure in detail.



Chapter 2 – literature review

A review of different research works related to the study:

- ✓ Water issue in Africa rural community
- ✓ Energy issue on African rural community
- ✓ Water treatment and supply techniques
- ✓ Energy access in rural community
- ✓ Mini- grid for powering of water treatment and supply

A review of different research works related to the study:

- ✓ Water issue in Africa rural community
- ✓ Energy issue on African rural community
- ✓ Energy access in rural community
- ✓ Mini- grid for powering of water treatment and supply

Chapter 3 –Material and Methods

- ✓ Description of case study, problem issues, local available energy resources, water quality and treatment, water and energy demand of the case study
- ✓ Mathematical modelling of components

Chapter 4 – Result and discussion

- ✓ Design and sizing of mini-grid
- ✓ Result and discussion of mini-grid for powering of rural community water treatment and supply.

Chapter 4 – Conclusion and recommendation

- ✓ General conclusion of the study and recommendation of future work

Figure 1:1 Thesis structure

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Introduction

This section includes different literature reviews that are an in-depth grasp of the study. The part includes literature reviews related to the status of access to water, water-specific needs, and techniques and technologies best suited to provide water in Africa rural communities. Also, the section includes the status of access to energy, energy needs, and the techniques and technologies to provide electricity (energy) for rural communities.

2.2 Status of access to water Africa rural communities

Water is the most important resource for human survival; therefore, it must be properly treated and supplied. (Wandiga 2014). Water is used for various purposes like drinking, agriculture, industry, cooling, etc. Drinking water must meet the required standard quality in terms of physical, bacteriological, and chemical parameters, and it can be used for cooking and drinking in households (Brander 2003). Humans require sanitation as well. To reduce diseases, fetching challenges and other issues, people need access to clean drinking water and sanitation. According to the United Nations, 2.2 billion people throughout the world do not have access to safe drinking water, and 4.2 billion do not have access to properly managed sanitation (United Nations, 2017).

Water is one of the essential human needs that is used for different purposes such as drinking, bathing, washing, and cooking. The water used for human needs should be safe, pollution-free, and palatable. To be sure, the microbiological quality of water sources should not exceed the water quality recommendations' maximum limitations. In most African rural areas, the water quality is poor, unsafe, and not acceptable for human consumption. It is, for example, the case of the Venda region, Limpopo Province, South Africa (Obi et al. 2004). The development of access to safe drinking water in Africa particularly in rural areas is still falling behind. As reported by the World Bank, around 400 million people from Sub-Saharan Africa live without access to safe and clean drinking water, and the majority of the population is from rural areas (Magoum 2021).

The African continent consumes a small percentage of its natural water resources. As a result, the water crisis is also more complicated than a mere lack of water. Large spatial and temporal variability of resource availability, combined with the more arid climate that affects about 60% of the African continent; a widespread lack of coping capability to manage the irregular availability of water; and insufficient access to the most basic water and sanitation services, all of which contribute to living conditions that are not conducive to social development (Braune and Xu 2010).

Water also uses for irrigation system in which water access be distributed using different pumping mechanisms to irrigation areas (Burney, Naylor, and Postel 2013). The development of crop intensity and cultivation areas and reduction of losses can be achieved by using advanced irrigation systems. Access to irrigation systems has a great contribution to the reduction of poverty by developing chances or opportunities for stable incomes and increasing the production of multiple cropping and crop diversification (Sinyolo, Mudhara, and Wale 2014).

2.3 Water status in Africa

In Africa, collecting and safe drinking water in a rural area is a big challenge, particularly in rural areas. To address these issues, improved rural water supply technologies and approaches are required (Moriarty et al., 2013). As United Nations Environment Program (UNEP) data, there is a series of challenges to the threats of fresh water in Africa (Kim et al. 2016). Africa is a continent having different energy resources such as solar radiation, wind and water. But in technology using energy, the continent is not developed due to various factors such as economic and policy challenges. So that the continent could manage the problems in water treatment and supply processes by using renewable energy technologies such as mini-grid.

One of Africa's main challenges is getting a clean and safe water supply in rural and urban areas. In Africa, there are limited sources of water. One of the most common water supply sources in Africa is surface water. It is highly polluted and costly to build the infrastructure for piping the water to arid areas. Another best option for providing clean water in Africa is groundwater, particularly in rural areas, and groundwater is naturally protected from contamination of different things such as bacteria. Due to the high cost of drilling ground water, it is the main challenge in tapping clean water in Africa. This leads to affect many people to live without access to clean and safe water (Lewis, 2021).

Clean water is a fundamental human right and crucial for people's health, but the majority of the world's population lacks access to safe drinking water and sanitation. According to the 2015 report on the Millennium Development Goals, the five regions of the Caucasus and Central Asia, North Africa, Oceania, and Sub-Saharan Africa failed to reach the UN goals (Armah et al. 2018).

Water scarcity, poverty, and food insecurity affect a major section of Africa's population. Most countries in Sub-Saharan Africa lack the financial, human, and institutional resources to expand access to clean and safe water. Attempting to achieve water-related sustainable development goals in those countries remains a challenge (SDGs) (Jemmali 2018).

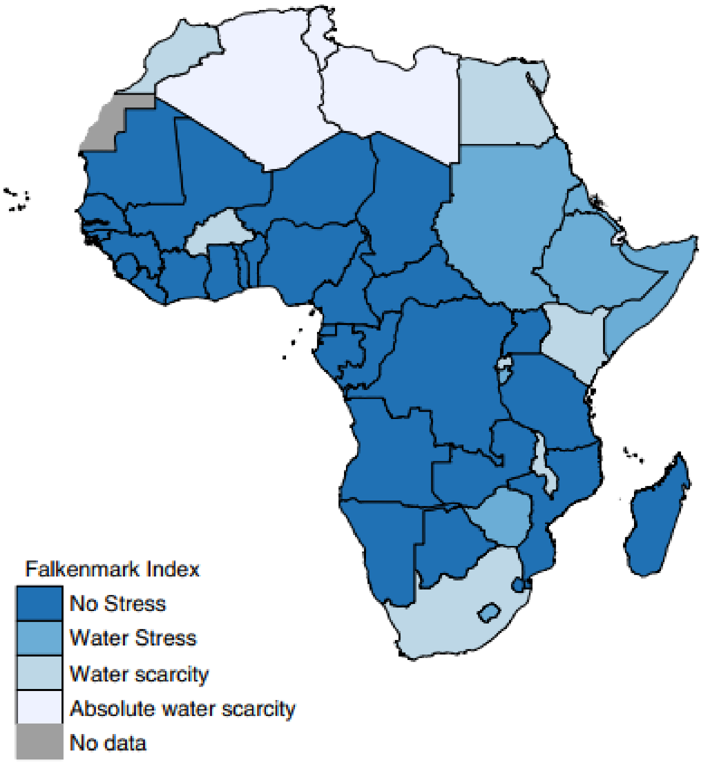


Figure 2:1 Water availability in Africa (Jemmali 2018)

The availability of freshwater is crucial in most African countries. As shown in Figure 1.2, North Africa, more particularly Tunisia, Algeria, and Libya, is the region with the most water scarcity. Most people in Sub-Saharan Africa still though have difficulty accessing safe drinking water, while Northern Africans have regular access to improved water. (Wang et al. 2014) Africa is the world's second-driest continent, behind Australia, with only 9% of the world's renewable water resources to feed 15% of the world's population. Water scarcity in Africa is exacerbated by insufficient water and wastewater treatment, which is exacerbated by rapid population growth and urbanization.

In Africa, children and women are more exposed to health risks, affecting in their school activities. This is due to the lack of safe and the struggle to access water in the continent. According to United Nations Children’s Fund (UNICEF) data, around 500 children die in a day due to the lack of safe water in Sub-Saharan Africa. Lack of clean and safe water has exposed to water-related diseases like Cholera and diarrhea. Africa does not lack water resources, but the main challenge is in its technologies to access, treat and supply to the people and poor management and policies in the continent. Most people depend on old water infrastructure to provide water for a household, irrigation, and other purposes, and most are designed and maintained poorly. (Odonkor 2020).

According to United Nations data, in 2020, 74% of the world's population could able to get access to safely managed drinking water services. National estimates were available for 138 countries and four of the eight SDG areas, accounting for 45 percent of the world's population. The rural areas

(60%) had lesser coverage than urban areas (86%), which housed two out of every three of the 5.8 billion individuals who used safely managed services. By 2020, 84 nations would have achieved universal coverage of at least basic drinking water services (>99%) (UNICEF 2021b).

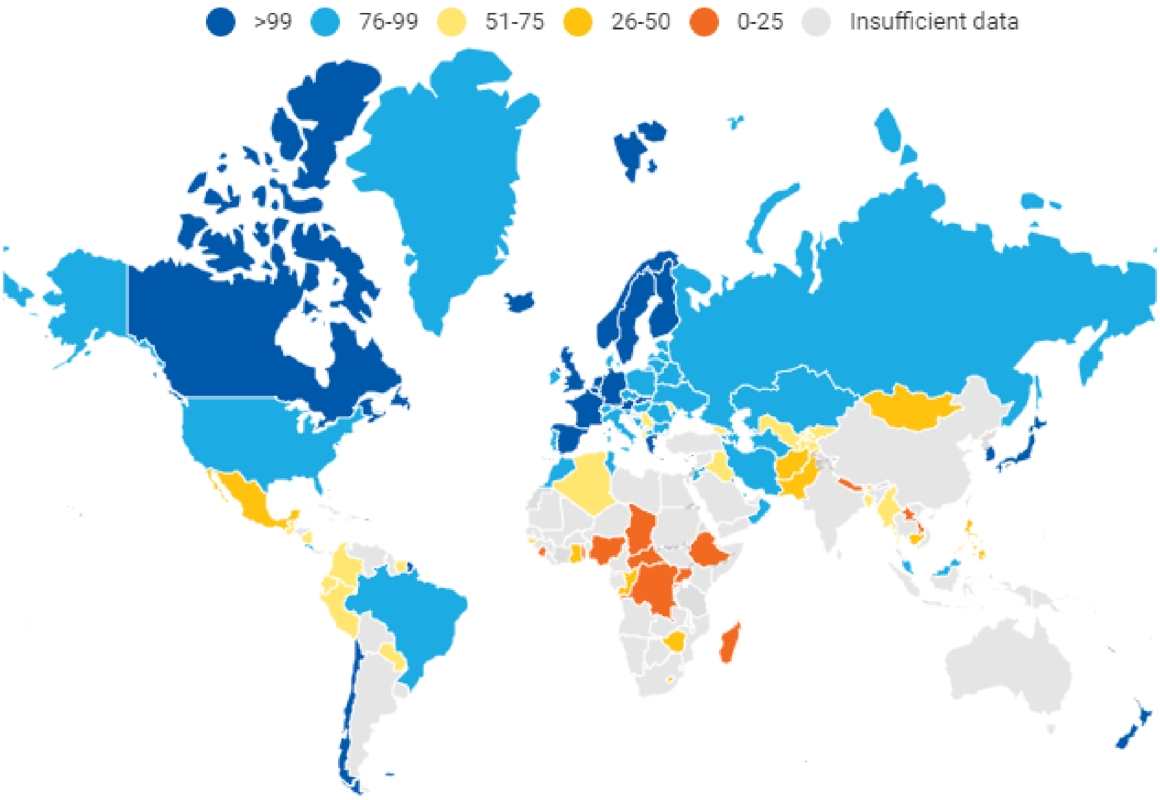


Figure 2:2 Proportion of population using safely managed to drink water services of the world, 2020 (%) (UNICEF 2021b)

From the above figure 2:3 information, Except for Morocco and Tunisia, most African populations live with a lack of safe drinking water. This tends to challenge the Sustainable Development Goals (SDG). The continent needs to advance technologies that could help to develop the water status.

2.4 Water Scarcity in North Africa

As shown in Figure 2.4, the Middle East and North Africa (MENA) region is the region with the greatest number of arid and desert areas and irrigation is the main concern in the region for food production. The Water demand in the MENA region is currently found in a large portion of its population. Despite its water scarcity, the region is rich in energy resources such as oil, solar and other renewable energy resources (Haddadin 2001).

Figure 2:3 MENA region

2.5 Overview of the water situation in Algeria

Algeria is a country that has surface water of 12.4 billion m^3 and underground water of 6.92 billion m^3, mainly in the Sahara. The mobilization and control of water resources are one of the Ministry of Water Resources' most pressing challenges in Algeria. In terms of water resources, the country is one of the poorest in the world, with a shortage threshold of 1,000 m^3/person/day set by the UNDP or the World Bank. Algeria is leveled 14th among the countries with a lack of water treatment and supply. Aside from the issue of water supply, issues with water treatment and poor water management mechanisms are also a barrier to accessing drinking water. In this context, Algeria's Ministry of Water Resources has planned to mobilize and protect water resources with the aim of achieving a sustainable water supply (Drouiche et al. 2012).

Algeria has a huge solar field in the Mediterranean basin, as well as a massive underground water reservoir in its several regions. Since this water is tainted with fluoride, it is extremely important. Water treatment plants were erected with the intention of reusing them. Several countries in the world also observe this type of protocol (Khechekhouche et al. 2020).

Algeria has diverse natural resources and its government was facing different problems and challenges (SE and C 2017). This needs a series solution to get access to safe and clean water using different renewable energy technologies such as mini-grid.

Drinking water supply issues have become a recurring issue in many countries, and access to safe drinking water is both a basic social right and an economic issue. In groundwater, it is better to use good and simple mechanisms, particularly in a country like Algeria. Algerian ground water has a deep depth and a high level of mineralization; and, due to the continent's uniqueness and climate, rivers may dry up frequently. Groundwater from the Continental Intercalary aquifers and the Terminal Complex is used to supply drinking water in Algeria's Sahara region, where the water contains a high fluor content, posing public health and toxic challenge issues (Sekkoum et al. 2012).

2.6 Water resources potential in Africa

Water resources are natural resources that are used for different purposes like drinking, irrigation, and industrial use. There is various type of sources of water such a; groundwater, rainwater, surface water, dam and catchments, and frozen water.

2.6.1 Groundwater potential in Africa

The potential of groundwater storage in Africa is around 0.66 million km3 (0.36–1.75 million km3). Despite the availability of ground water in the continent, not all of the amount is accessible, the estimated volume is more than 100 times that of Africa's yearly renewable freshwater resources. Groundwater resources are unevenly distributed: the highest volumes of groundwater are found in the massive sedimentary aquifers of Libya, Algeria, Egypt, and Sudan in North Africa (International Atomic Energy Agency 2020).

Ground water is the major source of Africa for drinking and irrigation purposes (MacDonald et al. 2012). The study (Adelana 2009) reported that the limited knowledge and management system of ground water in many countries of Africa is the major challenge to manipulate it. This could lead Africa to be failed in satisfying the water access for the people of Africa.

With increasing the number of populations, ground water is contributing a significant potential and it covers around 36% of global domestic water and 42% of agriculture water and it is also expected to continue providing in the future economic and population growth. The ground water storage and potential borehole are essential for increasing water supply and food security, improving health, and reducing poverty in Africa (Bonsor et al. 2018).

Large ground aquifer systems of Africa are found in Libya, Algeria, Sudan, Egypt, and Chad and they have Africa's greatest groundwater supplies. Because of the high porosity and thickness of these aquifers, groundwater storage can be as high as 75 106 m3/km2 which is equivalent to 75 m water depth. The average ground water volume basement rocks are 0.5 106 m3/km2 (equivalent to 0.5 m depth) (MacDonald, Taylor, and Bonsor 2013).

2.7 Africa Energy Resources Potential

Energy resources are resources from which useful energy can be recovered by means of conversion systems and always plays a critical role in human, economic, and social aspects. . Commonly there are two types of energy sources i.e., primary and secondary energy sources. Globally, energy security is a big concern (Leon Freris 2008).

2.7.1 Primary energy resources

Primary energy sources are a type of energy resources that are not performed at any conversion or transforming process and they are found in nature. On another hand, secondary energy is energy sources that are driven from primary energy sources and are energy carrier such as electricity, petrol, and hydrogen (Connor 2019). The following are the various type of primary energy sources:

- Renewable energy sources
  - ✓ Solar energy
  - ✓ Wind energy
  - ✓ Hydro and tidal energy
  - ✓ Geothermal energy
  - ✓ Biomass energy
- Non-renewable energy
  - ✓ Fossil fuels such as oil, coal, and natural gas
  - ✓ Mineral fuel such as natural uranium and natural thorium

2.7.1.1 Solar energy

Today, solar energy is widely used in most industries worldwide to generate heat and electricity for different purposes (Mekhilef, Saidur, and Safari 2011). Solar energy is a renewable energy source that has a significant contribution to lowering CO2 emissions and providing clean, affordable energy. With current trends of population growth and changes in consumption patterns, concerns over the impact of activities that seek to meet changing human needs on the environment and the need for access to clean energy have been heightened (Kannan and Vakeesan 2016).

Africa's solar radiation potential is huge [3, 4]. Africa has an average of 325 days of sunshine per year due to its geographic location. This potential fluctuates between worldwide horizontal solar irradiation and normal direct sun irradiation, according to studies. The solar photovoltaic (PV) potential for Africa has been assessed at 656730 TWh per year, while the concentrated solar power (CSP) potential has been estimated at 471690 TWh per year. East Africa has the greatest solar photovoltaic (PV) potential, followed by Southern, North, and West Africa. In Africa, the use of solar energy radiation has gotten the attention it deserves. (Fadare et al. 2010).

2.7.1.2 Wind Energy

Wind is one of the first types of energy that humans have harnessed (Group 2018). Wind potential in Africa is predicted to be 656 000 TWh per year. Wind energy potential is centered mostly in the

Atlantic Ocean coast of North Africa and the Sahel region, as well as the Red Sea and Horn of Africa. In mountain ranges, particularly in northern Africa, wind potential is also critical. Africa's wind energy potential is beginning to be acknowledged, with Egypt, Morocco, and Tunisia being the most well-known African wind energy producers. Egypt has installed the most wind energy, accounting for 97 percent of all wind power facilities with a total capacity of 550 MW. Morocco and Tunisia have wind energy capacities of 290 MW and 120 MW, respectively. Nigeria, with a capacity of 10 megawatts, Ethiopia, with a capacity of 120 megawatts, and Kenya, with a capacity of 300 megawatts, are all planning to build wind farms (Belward et al. 2012).

2.8 Techniques and technologies used to provide rural community water supply and treatment

Different technologies and techniques address water scarcity and quality, such as water pumping, water treatment, and desalination.

2.8.1 Water Pumping

A water pump is a technique of lifting or pick up water using different energy resources instead of traditional methods such as a hand bucket. The energy resources that can be used for pumping will be diesel, solar PV, and grid. The parameters such as water level, location, water demand, metrological conditions, maintenance, and operation costs can affect the water pumping system (Shouman, El Shenawy, and Badr 2016).

2.8.2 Diesel pumping system

The population growth of the world and the agriculture development leads to an increase in the need for freshwater resources in rural community areas where the places have no power, and more water is needed for drinking, agriculture, and cooling. The technology used for driving water pumps in those areas is mostly diesel and photovoltaic (Shouman et al. 2016). The use of diesel for water pumping has its own impact on the environment and global climate change since it uses fuel for driving and produces CO2 emissions and greenhouse gas. (Rehman and Sahin 2015) reported that using diesel for water pumps has 24069 tons of greenhouse gases annually, and that is eliminated using PV systems.

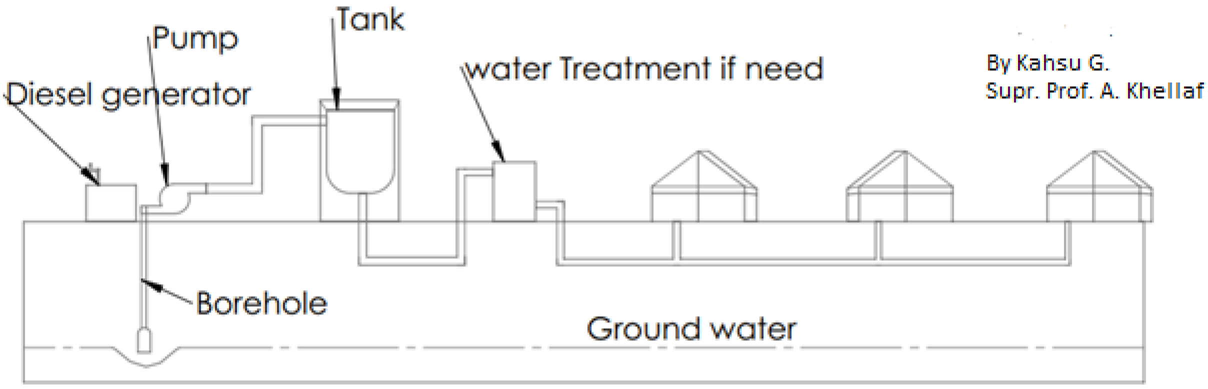


Figure 2:4 Water pumping using diesel engine (concept take from (German WASH Network 2021))

2.8.3 Solar Photovoltaic Water Pumping system

The photovoltaic pumping system is one of the advanced and most known solar energy technologies. It needs more reliable and considerable design systems to achieve the optimum operating pumping system. The situation of electric power in rural areas is one of the biggest challenges nowadays, particularly in water pumping systems for farming and drinking purposes. Diesel generators are found on the pumping system for powering water supply and treatment, but it is costly over the long run and environmentally unfriendly. Despite this, a solar PV system is one of the renewable energy resources and ecologically friendly used for electricity generation (Al-waeli et al. 2017). A review has proven (Chandel, Nagaraju Naik, and Chandel 2015) that Solar water pumping has been found to be more cost-effective than electricity or diesel-powered systems for irrigation and water supply in rural, urban, and distant areas. Also, a study (Sharma, Sharma, and Tiwari 2020) shows that a design optimization of a solar PV water pumping system employing various parameters has shown that the system is technically and economically viable.

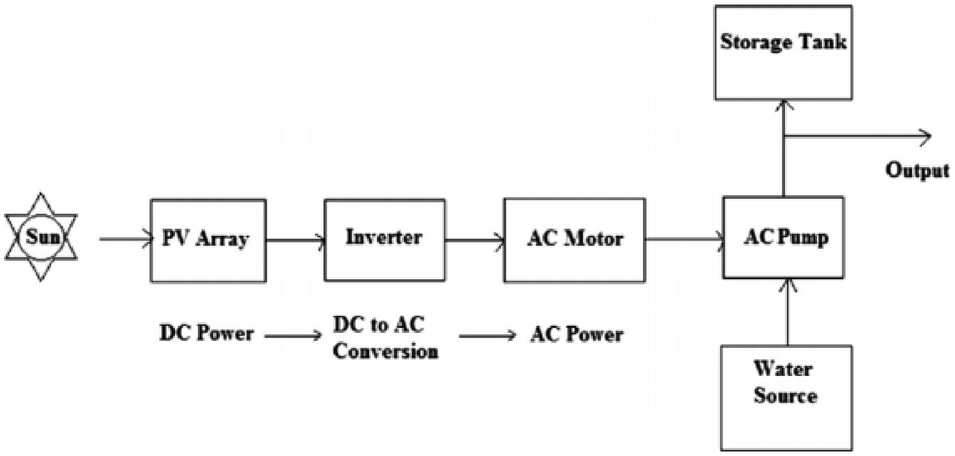


Figure 2:5 Photovoltaic water pumping system block diagram

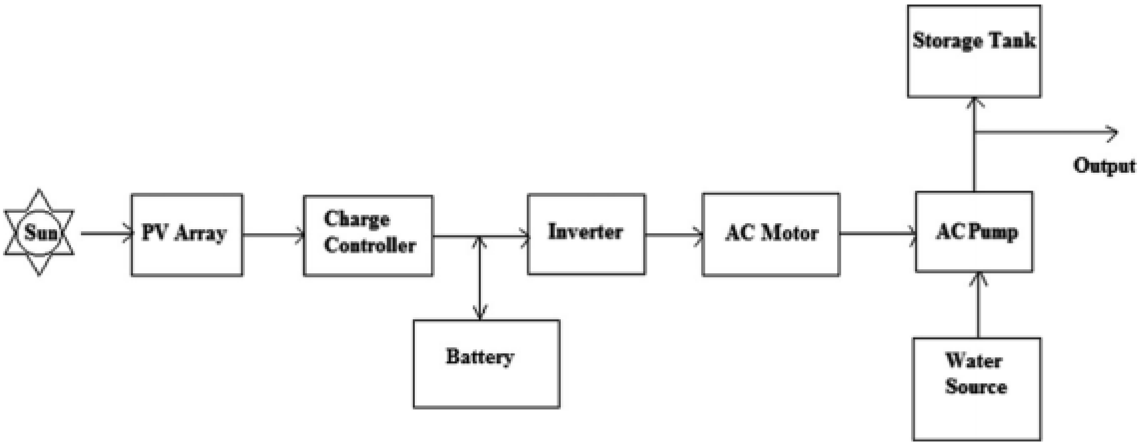


Figure 2:6 Photovoltaic water pumping system with battery storage block diagram

A PV water pump system consists of PV arrays, charge controller, inverter, AC motor, AC pump, battery, water sources, and storage tank (Arab 1998). These components need to be designed and assembled in a well-organized to have a smooth and reliable operating system.

The use of photovoltaic water pumping systems is increasing around the world. A solar-powered pump is a type of pump that is running on the power system of the sun. The photovoltaic array converts the direct sun energy into electricity used to pump water (Bangari 2015). A PV panel assembled with a DC or Ac rotating motor that changes the electrical power comes from the panels into mechanical energy. The figure below shows the working principle of a solar PV system for water pumping for irrigation purposes:

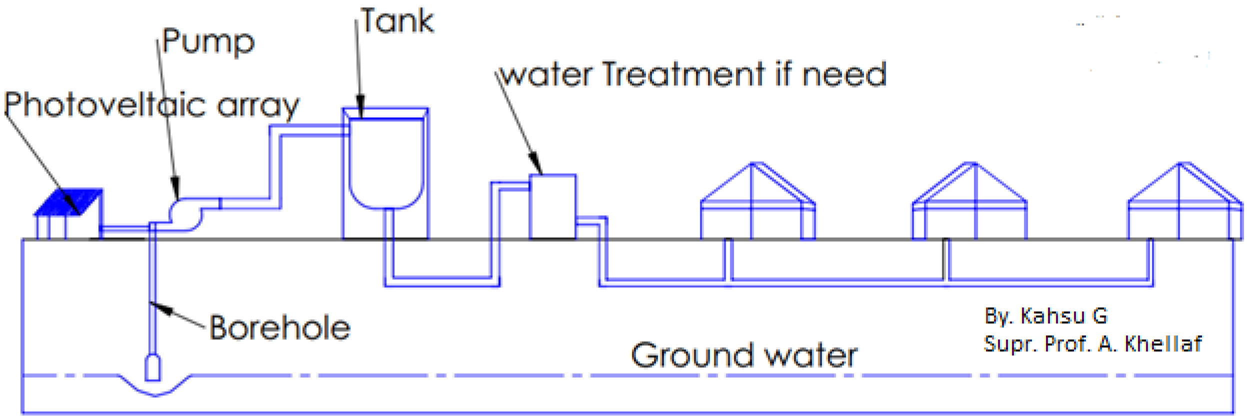


Figure 2:7 Photovoltaic solar water pumping system (concept take from (German WASH Network 2021))

As shown in the above figure, the PV pumping system consists of

- ✓ A part of PV modules arranged in a different way for power generation

- ✓ Pumping system to pump the water from the sources
- ✓ Water storage to store water
- ✓ Supply lines for irrigation purposes

(Chilundo, Mahanjane, and Neves 2018) reported that a solar PV system was installed in Mozambique to power the rural community water supply that is used for domestic purposes. The figure below is the installed solar PV system for domestic uses.

Solar photovoltaic water pumping systems (SPWPSs) have been claimed to be appropriate for small-scale irrigation in Algeria's Sahara regions. Daily water demand rates for small-scale irrigation with an area of less than 2 ha might easily be met by SPWPSs. Under the meteorological circumstances of the Algerian desert area, the performance of SPWPSs with four different configurations (2 parallel (P) x 2 series (S), 2P x 1S, 1P x 2S, and 1 module) at different heads between 10 m and 40 m. It was discovered that combining two photovoltaic array layouts (2P x 1S) and (1P x 2S) provides the best energy output (Gopal et al. 2013).

The study (Al-Waeli et al. 2017) reported that the major advantage of solar PV powered water pumping system for rural areas over Diesel pumping systems. In this concept the solar powered system has more cost-effect than Diesel pumping system and showed that it is having no CO2 emissions that leads to make great choice for pumping system.

2.8.4 Wind turbine pumping system

The study reported that a small scall wind turbine is designed for powering of water umping system used for rural community application (Jaafar, Bouaziz, and Ammar 2018). Also in (Girma, Molina, and Assefa 2015) study, using life cycle cost analysis, a design and economic comparison of wind mill and diesel water pumping systems is created, and the results demonstrate that windmill water pumping systems are more practical than diesel-based systems. Wind energy is one of the most important forms of renewable energy used for electricity generation. As the cost of fossil fuels rises, the globe has turned its attention to new modern, clean energy sources that are more environmentally beneficial and cheaper. In the nineteenth century, the United States created a multi-bladed windmill that is designed for irrigation. Later, a system working with horizontal axis windmills was also created to generate energy. As the technology's benefits became more apparent, more study was undertaken, resulting in a modern and updated design. Windmills with this design work well in areas where the wind speed is low to moderate. The aerofoil design of the blades is used for high wind speed locations, and such wind turbines are used to generate electricity. This technology has aided in the reduction of emissions and reliance on nonrenewable energy sources (Aized et al. 2019).

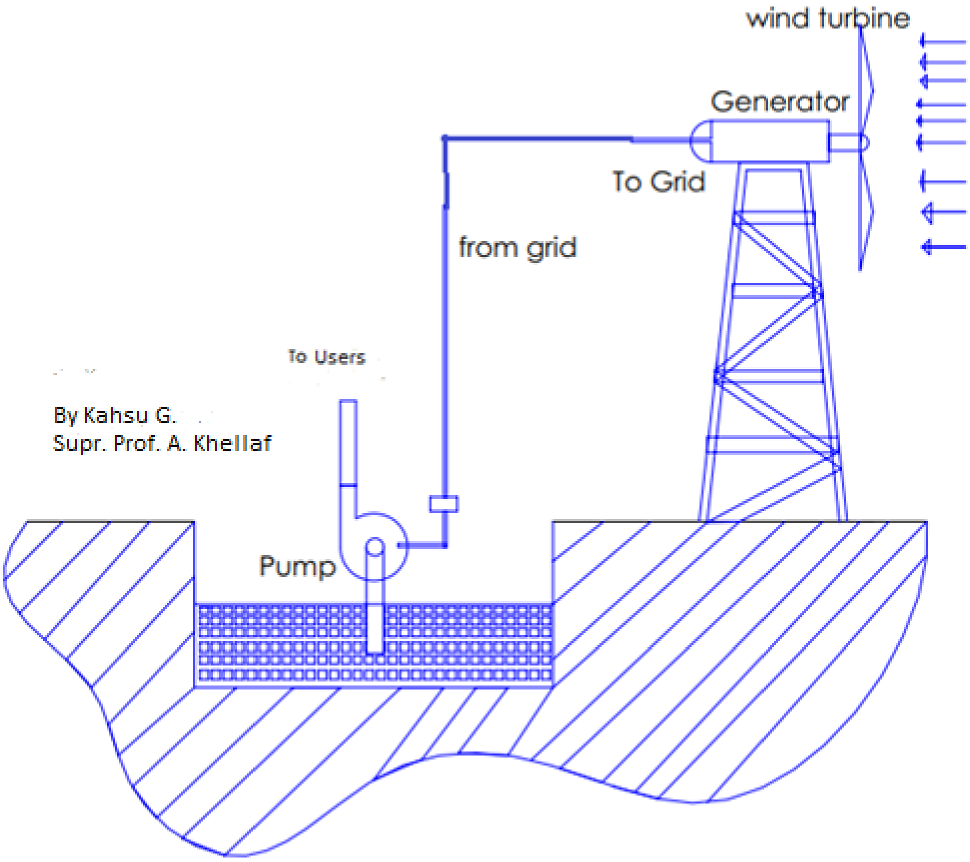


Figure 2:8 Wind energy water pumping system layout (Gopal et al. 2013).

2.8.5 Biomass water pumping system

Water for bathing, drinking, cleaning, and agriculture purposes is the main concern in developing countries, particularly in rural areas. The use of engine pumps and the electric pumps is the type of fossil fuel common in most agriculture and other water pumping systems. Biomass energy water pump is one of the renewable energy that can replace the conventional energy used for water pumping systems (Moonsri, Rakkanrane, and Prattanarak 2016).

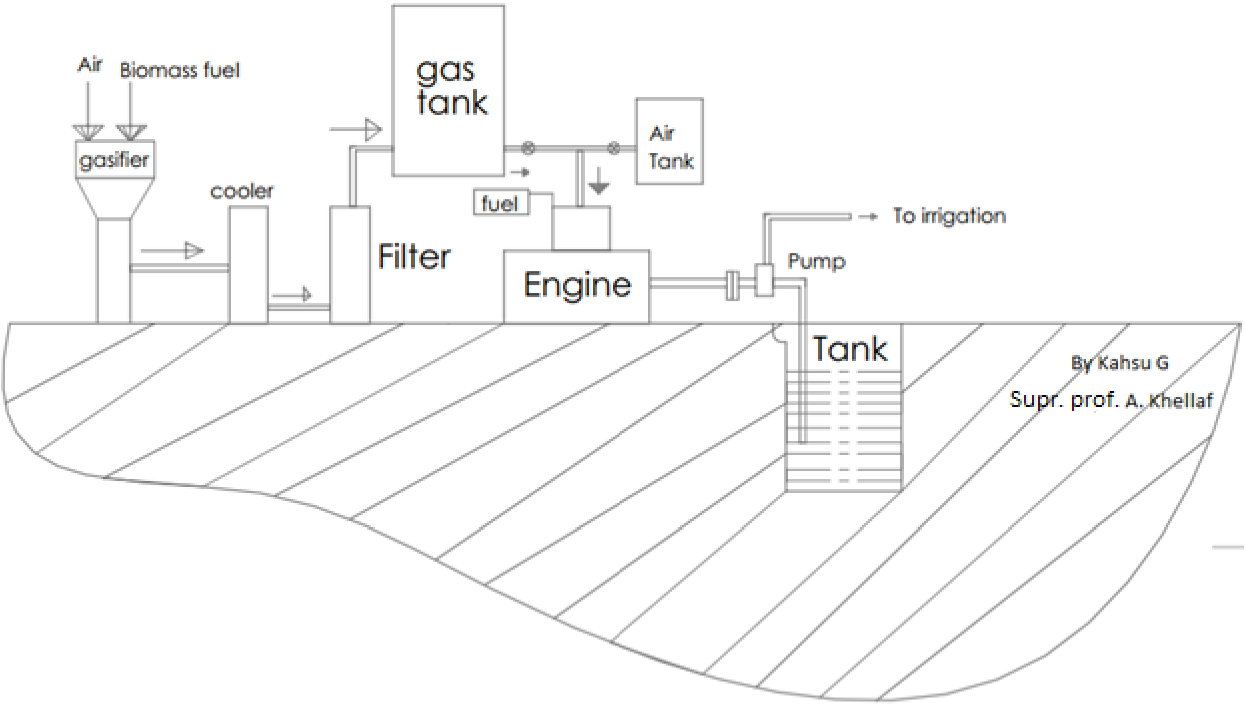


Figure 2:9 Biomass pumping system layout (Gopal et al. 2013).

2.8.6 Hybrid water pumping System

A design and evaluation of a stand-alone hybrid renewable energy system for pumping subterranean water for small farm irrigation are provided in the article (Khattab et al. 2016). A sizing algorithm is used to determine the best size of primary system components based on environmental variables, system requirements, and daily load demand data. Different renewable energy systems are compared using yearly simulations and hourly simulations using specialized commercial software simulation packages PVSYST and HOMER to simulate system performance and find the best configurations based on objective criteria. (Argaw 2004) reported that using different energy options such as wind with PV; wind, PV, and another renewable energy source; wind with diesel; or PV with diesel is the type of hybrid water pumping system combinations. Apart from a backup generator, it is possible to use a battery and inverter for the storage system of the system.

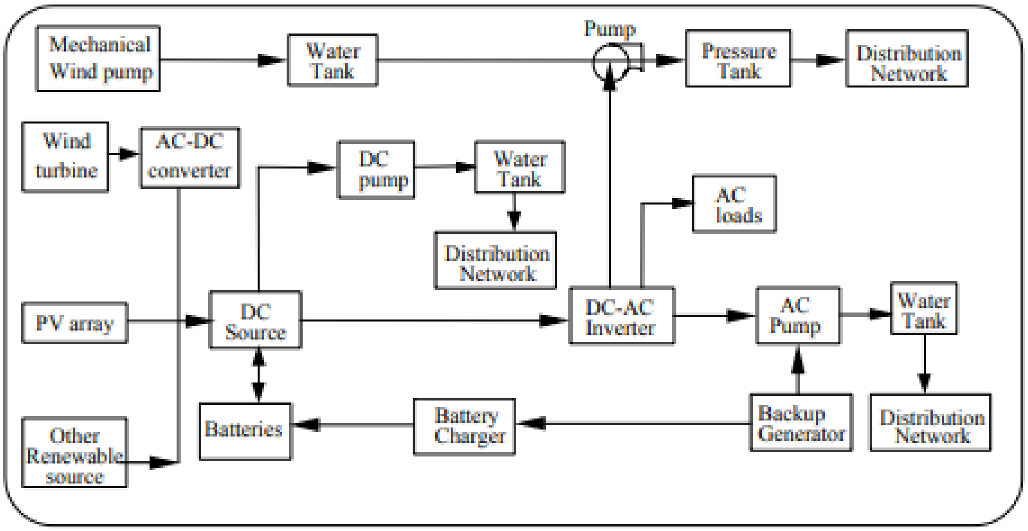


Figure 2:10 Hybrid energy sources pumping system layout (Gopal et al. 2013).

2.9 Water Treatment Techniques

In many countries, the process of desalination of seawater becomes common and well established for water supply, and it is feasible in terms of technical and economical to supply quality water from the source. The desalination process is divided into two, namely, evaporation and membrane systems (Morad, El-Maghawry, and Wasfy 2017).

(Karagiannis and Soldatos 2008) reported that, by 2025, two-thirds of the global population may face water shortage in both developed and developing countries so that it is necessary to develop water sources and reduce demand. This can be solved by increasing the technologies and techniques of water pumping, desalination, and treatment units.

Around 97.5% of the earth is covered with saltwater and a large number of populations living with a scarcity of water access. This challenge needs a solution with advanced technologies such as desalination of water from the sea, ocean, rivers, and lakes. The process must be designed with optimum efficiency, low cost, and be environmentally friendly (Chandrashekara and Yadav 2017).

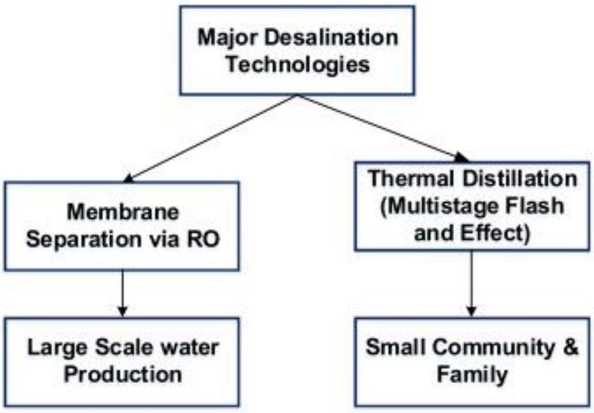


Figure 2:11 Desalination technology systems

Renewable energy technologies like solar and wind energy are the current attention for electricity generation, such as powering the desalination process. The reverse osmosis process (RO) membrane desalination process is one of the advanced technologies for water desalination since it has energy efficiency and low cost. In remote areas, solar and wind are used as energy resources to operate the reverse osmosis system, especially in rural area communities. In the reverse osmosis membrane desalination process, feedwater is first heated and then it flows through the porous hydrophobic membrane and a high-pressure potential applies on the water vapor to give fresh water and it condensed on the other side of the membrane.

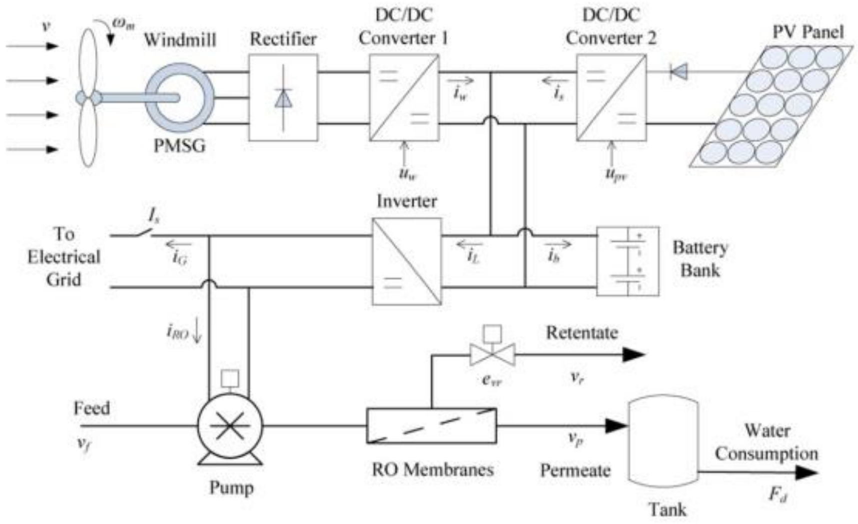


Figure 2:12 Hybrid (solar and wind) reverse osmosis desalination system (Qi, Liu, and Christofides 2012).

Water coming from sources need to treated to make safe for drinking purpose. There are water treatment systems to ensure the water quality uses for communities. The water treatment plant consists of a water pump, coagulation, sedimentation, filtration, disinfection, storage, and distribution. Water from lakes, rivers, and ground water use to pump to purification plants through pump station. After pumping, the purification process takes place, and coagulant chemicals need to add to the water and mix at a high rate. The coagulant process leads to sticking ant particulates in the water. Then the sedimentation process begins and, in this step, the floc has a chance to settle in the bottom of the tank, where it may be collected, while the clean water at the top is sent to be filtered. The next step is filtration in this system, and the water allows to pass through natural filters used to sift out any remaining particles in the water. Then water needs to protect from different bacteria, viruses, and others, and this step is called the disinfection process. The water is pumped into water storage tanks when the purifying procedure is done. When needed, clean, safe drinking water is pumped to homes and businesses (HENSLER 2018).

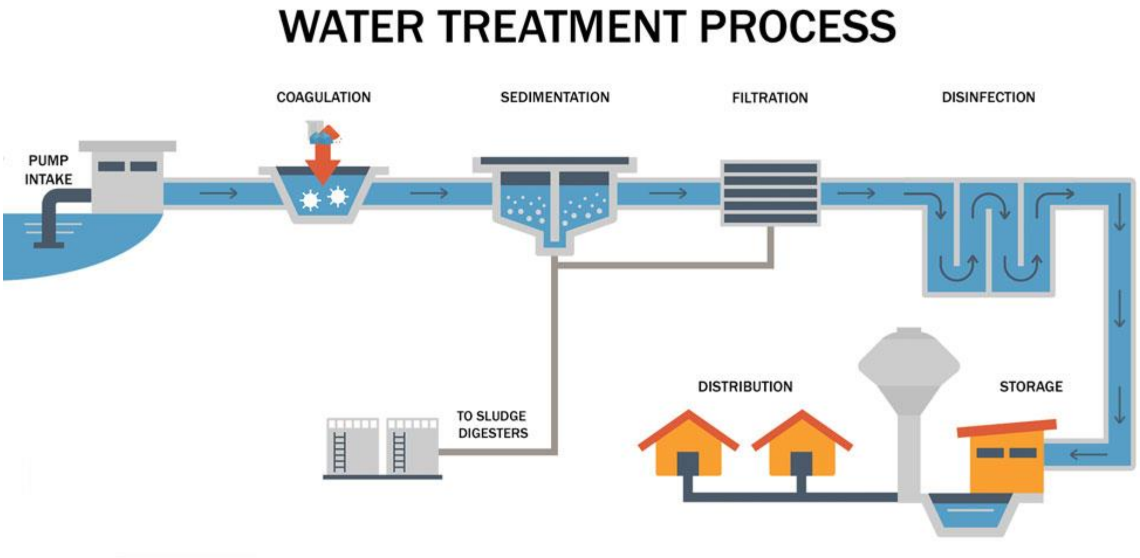


Figure 2:13 Water treatment process (HENSLER 2018)

2.10 Electrical Grid

An electrical grid is a type of electrical power generation system used to generate electricity and integrates different components such as transmission lines, the substation, transformer, storage, distribution line, and the consumers. The electrical grid is classified as a mini-grid, microgrid, and nano grid, depending on its capacity. A mini-grid is a combination of various sources such as PV, turbines and storage devices and the operating capacity is between 50 kW and 1 MW. Microgrids have similar concepts with mini-grid apart from their operating capacity, designed from 1 to 50 KW. Nano grids are used only for a single customer and are designed without transmission or distribution lines (Rycroft 2016).

2.11 Mini-grid

In developing countries, renewable energy technologies especially mini-grid systems, have been proven to provide clean and affordable energy access in rural and urban areas. Mini-grids are designed and assembled with different electrical components such as distribution systems, energy storage and electric generator to provide electric power to isolated or connected to the national grids (Ighravwe and Babatunde 2018). The paper presents a mini-grid hybrid system design that uses renewable energy sources and a diesel generator with a reverse osmosis desalination plant as a deferrable load to supply electricity and meet demand for clean water in remote areas (Setiawan, Zhao, and C. V. Nayar 2009).

2.12 Mini-grid Components

Mini-grids have different components. The following are the main components of a mini-grids:

- ✓ Energy sources (i.e., solar, wind, diesel, hydro, etc.)

- ✓ Storage
- ✓ Backup diesel generator
- ✓ Inverter
- ✓ Distribution
- ✓ End-uses

2.12.1.1 Energy sources

Energy sources are sources used to provide mechanical, chemical, and thermal energy then convert into electricity through of different mechanisms like turbines and PV arrays. These sources are the initial main energy producers.

2.12.1.2 Energy Storage

Energy storage is one of the essential devices in a mini-grid system. Storage is used to store excess power coming from AC power and uses it when needed (A. Algaddafi, A. Rahil, I. Daho 2015). There are various energy storage types such as electrochemical energy storage (i.e., batteries), mechanical energy storage (i.e., potential hydro, flywheel and compressed air energy storages), electrostatic and magnetic energy storage (i.e., supercapacitor and super magnetic), chemical and thermal energy storages (Nadeem et al. 2019).

2.12.1.3 Backup diesel generator

A diesel generator is an electrical device that is used as a backup power supply system. It is also used as an emergency power supply when there is no connection with the power grid or a power cut (Kusakana 2015).

2.12.1.4 Inverter

Energy from solar PV, wind, and battery bank is a direct current (DC) and is used to provide DC loads such as lights, fans, pumps and motors. There are other equipments such complete and phones use an alternative current (AC). A power inverter is one of the electrical devices used to change a direct current coming from different directions to an alternative current (Franklin 2018).

2.12.1.5 Distribution lines

Distribution lines are systems that extended from the transmission section to consumers and it has wires used to connect and transmit power from different parts. Distribution lines are also called overhead lines because of their design and assembling system (Singh 2017).

2.12.2 Classification of Mini-grids

Mini-grids are divided into two:

- ✓ Single generation system
- ✓ Hybrid system

2.12.2.1 Single Generation System

A single generation mini-grid system is designed with only one technologies resources (i.e., solar PV or wind or diesel, or biomass). For once economic and social growth, access to electricity is essential. Access to clean and reliable electricity, particularly in rural and arid areas, is still the primary concern issue. Solar photovoltaic systems have been proven that is great potential in providing power in rural areas, such as powering of water supply and treatment, household electric access, and other industrial power supply (Saulo and Omondi 2015).

Wind turbines are also used as a single power generation system, the currently common option for residential, agricultural, and industrial applications in both on-grid and off-grid (Predescu 2016). It is one of the fastest-growing energy sources (Junginger, Faaij, and Turkenburg 2005).

2.12.2.2 Hybrid mini-grid system

A hybrid system is a combination of more than two technologies. Different options such as solar, wind, hydro, biomass, and diesel can use as a combination to produce desired power. The study (Saheb-Koussa, Haddadi, and Belhamel 2009) reported that photovoltaic solar and wind energy are the primary sources for rural applications when appropriately designed. But, in most areas, those technologies suffer due to the fluctuation characteristics of the availability of wind and solar sources. This needs to design all the components with proper and all considerations like battery storage and extra energy (diesel generator) components.

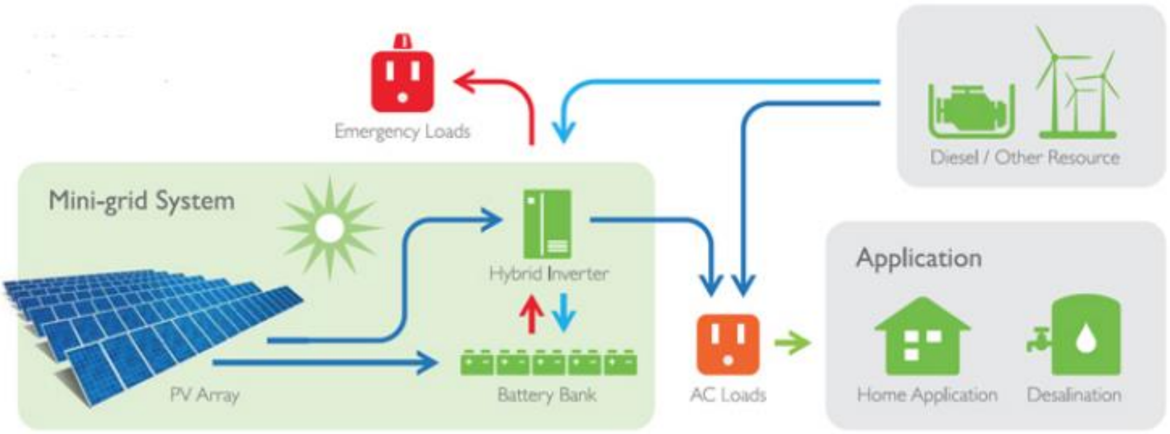


Figure 2:14 Hybrid mini-grid system (Sustainablity 2019)

As shown in the figure above, different energy technologies (solar, wind, diesel) are used to generate electric power. This combination gives more power and reduces greenhouse gas and CO2 emissions and access to clean, affordable, and reliable energy.

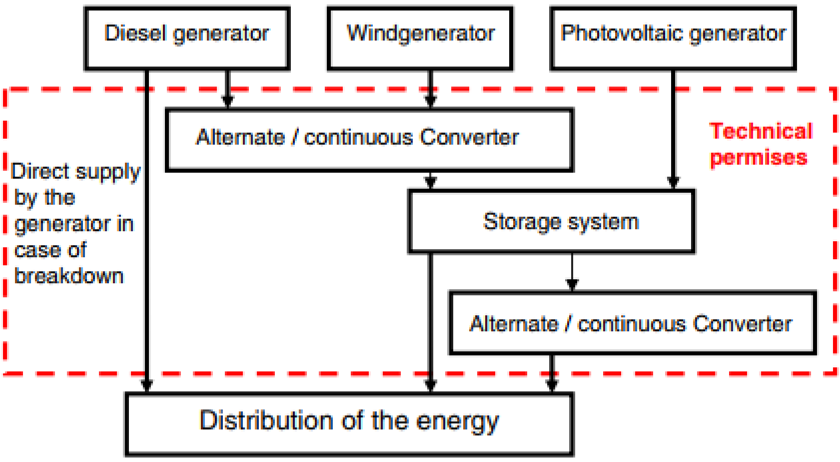


Figure 2:15 Schematic diagram of a hybrid system

2.13 Smart Mini-grid

One of the major challenges in enhancing energy security and energy access, manipulating energy resources and applying energy technologies is how to deal with them (Gujar, Datta, and Mohanty 2013). The major population in rural areas is dependent on kerosene, charcoal, and other resources, resulting in pollution and lousy living conditions and has been linked to respiratory ailments and potentially life-threatening fires. Renewable Energy such as mini-grids help to realize the worldwide aim of reliable, affordable and clean energy for all while also delivering a cost-effective option. This has an advantage environmental benefit in that, even though emerging countries contribute a small percentage of global greenhouse gas emissions, early adoption of clean energy solutions helps to assure a future trajectory (Nkiriki and Ustun 2017). Although numerous efforts have been made to collect mini-grid data, multiple sources continue to differ from one another. It's been difficult to estimate the global share of mini-grids, both grid-connected and off-grid, powered by renewable energy sources because it's been such a fast-moving sector in recent years (IRENA 2020).

An intelligent way of controlling and managing systems is essential to deal with challenges in applying energy technologies. A smart mini-grid is a system in which the components and distribution systems of the mini-grid are controlled and manned by an intelligent way of a process.

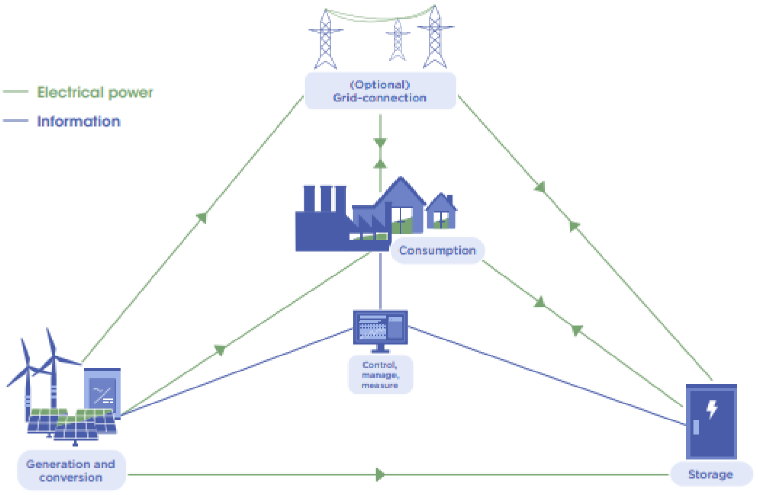


Figure 2:16 Smart mini-grid system (IRENA 2020)

2.14 Mini-grid for Powering of Rural Community Water Supply and Treatment

A mini-grid power supply is a renewable power supply generation used in rural areas considering the geographical situation of the area. The design consists of different energy resources such as solar, wind and others with batteries and other storage for backup purposes (Anon 2014). The mini-grid concept has an advantage over micro-hydro systems because of investment cost, load, and reliability. Because it is the best option for supplying isolated rural communities, the mini-grid concept is a good option for increasing social impact and improving local governance structures through direct local community participation (Shrestha et al. 2020).

(Comello, Reichelstein, and Sahoo 2017) reported that mini-grid system plays a significant potential for rural power supply in different aspects. The rural community can get safe and efficient drinking water and the effects and challenges of access water can be addressed through a mini-grid system.

Mini-grid power systems became the best solution for water supply and treatment mechanisms used for a rural community. In the selected location, the mini-grid operates hourly due to fluctuating solar energy parameters (Anon 2014). PV systems for remote applications are becoming increasingly popular around the world as their benefits over distribution line extension are realized. Remote water pumping for residents, small-scale irrigation, and livestock watering are just a few of the applications where such systems are already in use (Slabbert and Malengret 1998).

A traditional grid can also operate efficiently using a smart grid system. In this concept, the system monitoring and controlling the load management, electrical grid, and other factors to reduce and advance the bills in peak hours. It also advances the grid system by using bi-directional communication, appropriate control mechanisms and advanced power lines (Bhuyian et al. 2012). So, mini-grid systems can advance and work efficiently using different technology and ICT systems.

To protect global warming and climate change effects, it is necessary to shift from non-renewable energy like fossil fuel renewable energy such as solar, wind and hydro to reduce emissions of CO2 and NO_X, which can affect the environment (Setiawan, Zhao, and C. V Nayar 2009). The world is in a state of a dilemma between satisfying the current renewable energy demand and the need to reduce CO_2 emission by two to prevent climate change and supply energy sources (Allali, Tamali, and Rahli 2015). The energy demand is expected to double in the next 40 years, thus putting pressure on economic activities in both developed and developing countries. A large quantity of energy is turning to good account throughout the world and needs the highly effective approach of reducing CO2 emissions and increasing renewable energy. Grid and other renewable systems are key for developing energy and reducing CO2 emissions and used for rural area water supply and treatment process.

Mini-grid system for powering of water supply help for getting safe and efficient water for rural community. In addition, since it is renewable energy it is environmentally friendly. (Stambouli et al. 2012) reported that the presence of oil and natural gas can cover for the next 5o or 70 years. Therefore, for countries like Algeria, using renewable energy like solar, wind, and other renewable options is the fundamental priority.

The study (Baharudin et al. 2012) develops a mini-grid system with different energy resources to supply safe water supply for rural areas and emergency relief conditions. The study consists of a mini-grid power system and desalination plant with an analysis of the economic status of the whole design life cycle. The basic benefit of the project is to supply clean water for a rural community.

Th paper (Chilundo et al. 2018) has proven that designing a renewable energy technology such solar PV system for the purpose of a water pumping system is the best way of transition for developing countries. The use of solar photovoltaic technology for supplying water has been common particularly in remote and desert areas as well as in urban areas. General, the use of renewable energy technologies such as solar, wind, hydro, biomass and geothermal will be a great alternative for supplying water and electricity in general in a rural area.

A study designed a solar system with hydrogen storage for powering rural community electricity. This is a clean technology that uses hydrogen storage, an electrolyzer, and a fuel cell that can replace the battery storage and diesel generator (Ali and Andrews 2006). This new technology and it is environmentally friendly that has a great future in energy applications. As reported in (SONS 2011), aside from renewable energy sources like the wind and the sun, hydrogen (H) is an important clean, renewable energy source. Hydrogen is plentiful throughout the universe. Also a study (Gray et al. 2011) shows that hydrogen storage for off-grid system is a suitable application.

CHAPTER 3

3 MATERIALS AND METHODS

3.1 Introduction

This section covers all of the methods and materials utilized in the creation of a small grid for powering rural community water treatment and distribution. The first strategy employed in this study was to identify challenges in the rural community in terms of water, renewable energy, and technologies. Following the discovery of difficulties, a mini-grid is designed using HOMER software to address the community's water issue, taking into account various characteristics and methodologies. In this design of a mini-grid for powering rural community water supply and treatment, parameters that under consideration are considered, site selection, water resources, water demand, water treatment, and energy resources.

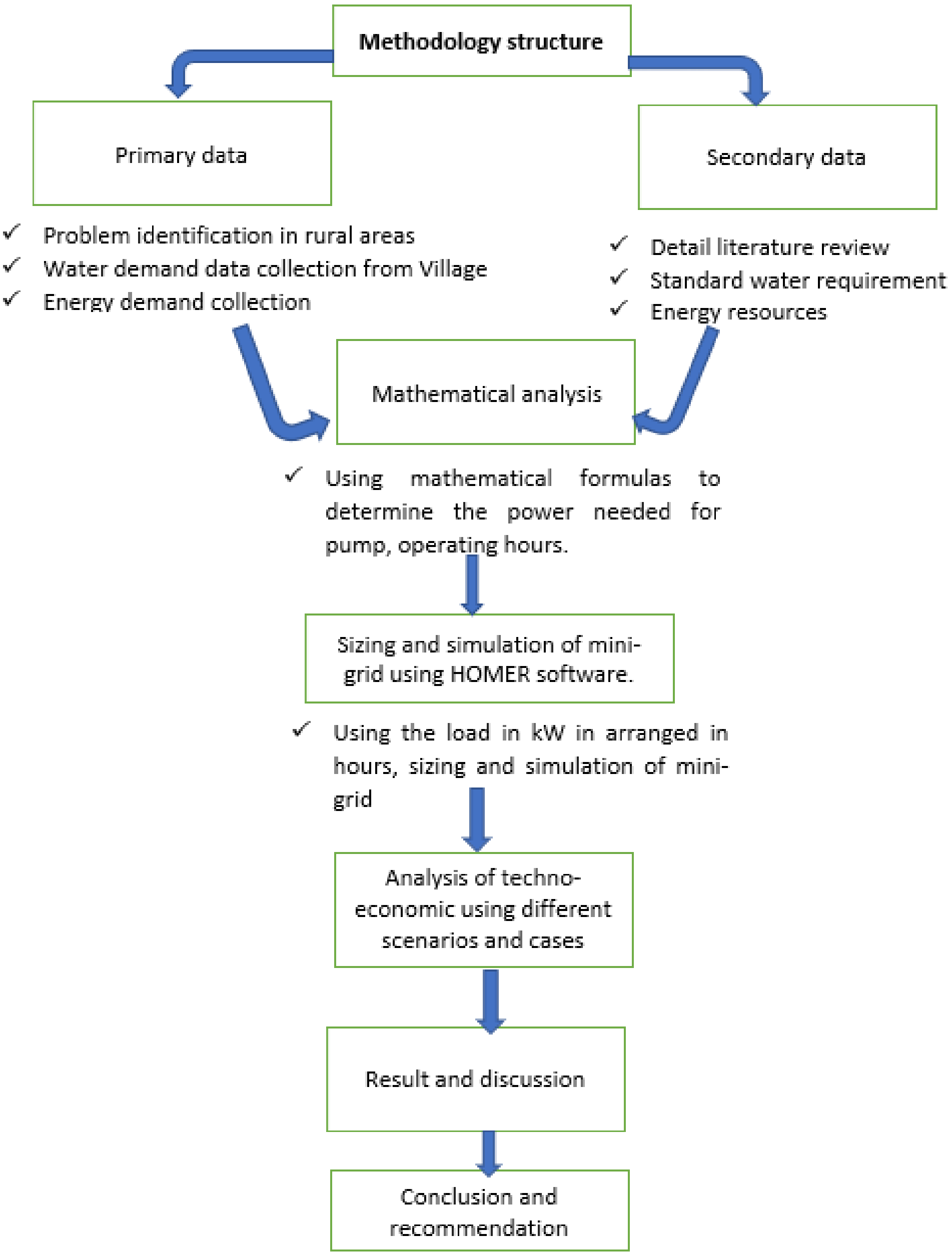


Figure 3:1 Methodology structure

3.2 Case study

Site selection is one of the crucial parameters in designing a mini-grid for powering rural water supply and treatment units to secure a sustainable water supply scheme. During site selection, the quality, availability, kind of water resource, and volume of water necessary are the major determinants.

The case study for this concept of a mini-grid for powering rural community water treatment and supply is in Djelfa, Haut Plateau region, northern Algeria, in the village of Murqab Bin Hafaf. The climate is similar to that of a steppe, with dry summers and cold winters. The settlement is located 8.5 kilometers west of the city of Djelfa. Agriculture activities in the village include onion, potato, carrot, and tomato irrigation, as well as chicken and sheep farms.

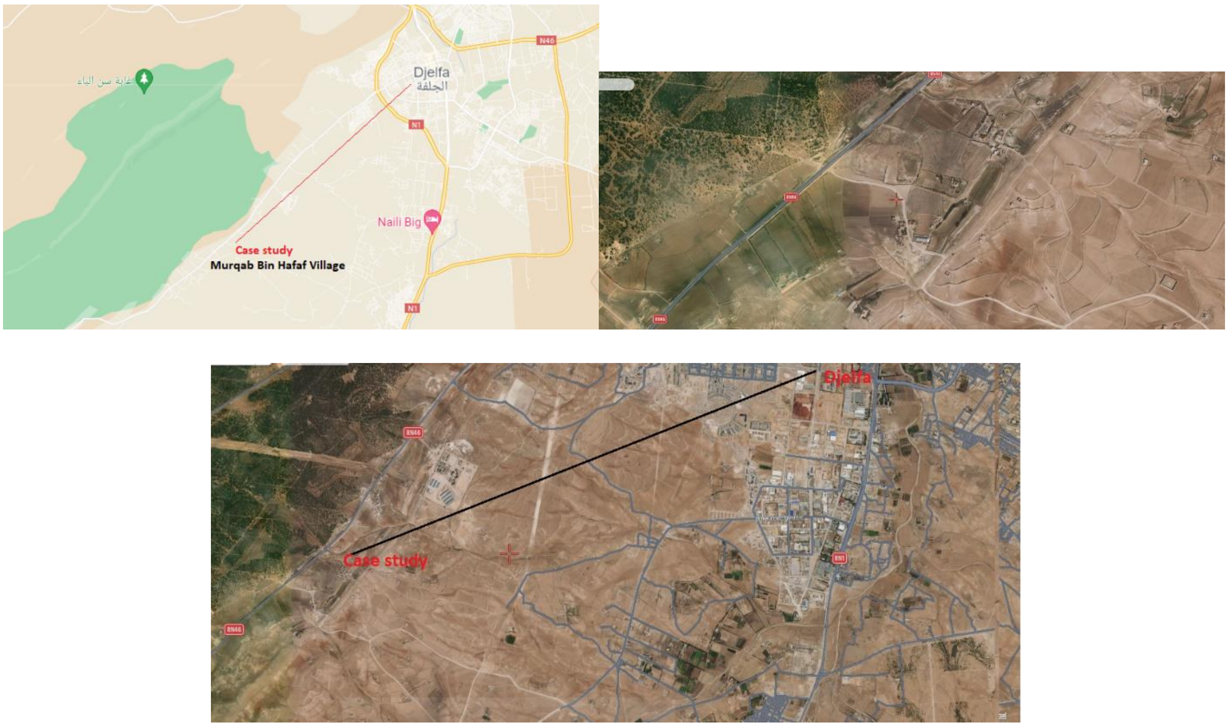


Figure 3:2 Case study location (Source: satellite world map)

3.2.1 Issues existing in the village

Lack of access to water is a global problem, and it is one of the major obstacles to achieving the Millennium Development Goals in the area of drinking water. In many countries, the amount of time it takes to get access to water is a major issue. People in Murqab bin Hafaf village used to buy water from Djelfa city and occasionally from a borehole used for irrigation near the hamlet, which was stored in a large tank that could feed them for a long period. They spend more than 30 minutes fetching water. This results in additional time spent and a decrease in water quality. Because they are purchasing with a large tank, there will be water contact with metals and other contaminants. This problem contradicts the Millennium Development Goals, which call for everyone to have access to safe and clean drinking water.

Figure 3:3 Collecting of water using tank and track in the village (photo taken during site selection)

3.3 Water resources in the region

The basic water resource in the northern art of Algeria is ground water which is exploited using the method of wells and springs. The aquifers found in the region are recharged with an amount of 1.9 billion cubic meters per year and around 2.4 billion cubic meters per year is the total withdrawals. The basic challenges in developing access to ground water are increasing the illegal wells, lack of working in collaboration between the water authorities, lack of effective management in ground water, and connected to poor knowledge of the resource (Water 2019).

In Algeria, the major sources of water for drinking, agriculture, and industry are groundwater. Groundwater irrigation from relatively young and shallow coastal aquifers, which are actively recharged by rainfall, is used for agriculture in Algeria's north. In the southern part of the country, deep sedimentary aquifers with huge amounts of ‘fossil' groundwater that is not being actively recharged (Survey 2021).

3.4 Water Demand of the Village

Water demand is the key factor to consider when designing of mini-grid for powering rural community water supply and treatment. The amount of supplying water for rural communities is the level of water demand. A rural community's water demand is assessed based on daily per capita water use and its population. For the rural community water delivery system to be reliable at any time of day, peak hour demand must be calculated. The peak hour demand of the rural community is the time when the most water is consumed, which is usually around midday and lowest at night.

The first step in this design is knowing the determination of the water needs for the village community. The total water demand is calculated based on activities carried out by the community. The community of Murqab Bin Hafaf uses water for drinking purposes and agriculture and economic activities.

In general, the total water demand includes water needs for the people who live in the village (i.e., for drinking, sanitation, bathing and cooking), water demand for vegetables, water for animal farms (chicken and sheep), water for school and clinic. In this study, the number of households, number of hectares for the vegetable, number of animals, number of students, and number of beds for the clinic have been collected in detail. After detailed data collection, the standard water requirement for each website has been collected and calculated for the total numbers using excel.

Based on the data collected from the village Murqab Bin Hafaf**,** the total water demand is assessed below in a table. To calculate the water demand for each activity the following formula and concepts were used:

- ➢ Water demand for humans = Number of households * Average size of the household for Algeria* standard water requirement

  Where,

  - ✓ Number of households = 230
  - ✓ The average size of the household for Algeria (latest data for 2021) = 5.23 people (Statista 2021)
  - ✓ standard water requirement human activities such as for drinking is 5 litters, for sanitation services 20 litters, for bathing 15 litters, and for cooking and kitchen 50 litters (Gleick 1996).
- ➢ Water demand for irrigation activities = size of the agriculture land * recommended water for the type of vegetable. The standard water requirement of each crop is as follows(Malhotra 2016) (Models, Koudahe, and Djaman 2020) (Malkia and Etsouri 2018):

    - ✓ Standard water requirement for onion per season = 0.5m
    - ✓ Standard water requirement for potatoes per season = 0.71m
    - ✓ Standard water requirement for tomatoes per season = 0.441m
    - ✓ Standard water requirement for carrots per season = 0.441m
    - ✓ Standard water requirement for green paper per season = 0.64m
    - ✓ Standard water requirement for lettuce per season = 0.3048m
    - ✓ Standard water requirement for corn per season = 0.762m
- ➢ Water demand for animal farms: the standard water requirement for each animal in the village are as follows (Mourad, Jaafar, and Daghir 2019):
    - ✓ Standard water requirement Chicken per day= 0.68
    - ✓ Standard water requirement Sheep per day = 8.52
- ➢ Water demand for clinic = 350 litters (Singh 2015)
- ➢ Water demand for school (Byford 2014)
    - ✓ For student = 30 litter per day
    - ✓ For teacher = 30 litters per day
- ➢ Teacher residence = 50 litters per day (the Revisor of Statutes 2012)

The detailed calculation of water demand for each activity calculated and the results are listed in Appendix A (Table 7.1, 7.2, 7.3,7.4, 7.5).

Table 3:1 Total water demand of the village in (m^3/day/month)

Activity	Total water demand in m3 in day
Household	60
Irrigation	4023.083333
Animal farm	7.188
School	6.64
clinic	3.15

After the careful estimation of the standard water demand for each activity, the water demand is arranged for each season in m^3/ day since the water demand varies from season to season as Table 7.6 in appendix A shows. Based on the above data, the mini-grid for powering of water treatment and supply is designed. The total energy demand is calculated using the formulas for piping used to pump the ground water to supply water.

3.5 Energy demand for the community

The total energy demand is the total energy needed to pump the water from the water well with a given depth to the store located at the maximum height. The minimum base reference height is the depth of the water well in which the ground water is found. The maximum height of the system is measured from the place of the pump station to the location of storage that can provide water to the maximum house location. Using piping relations (Al-Waeli et al. 2017) the power (in kW) needed for water pumping for each specific volume and pumping hours are assessed using an excel spread sheet. Details of this assessment are reported in appendix B (Table 7.7 and Table 7.8).

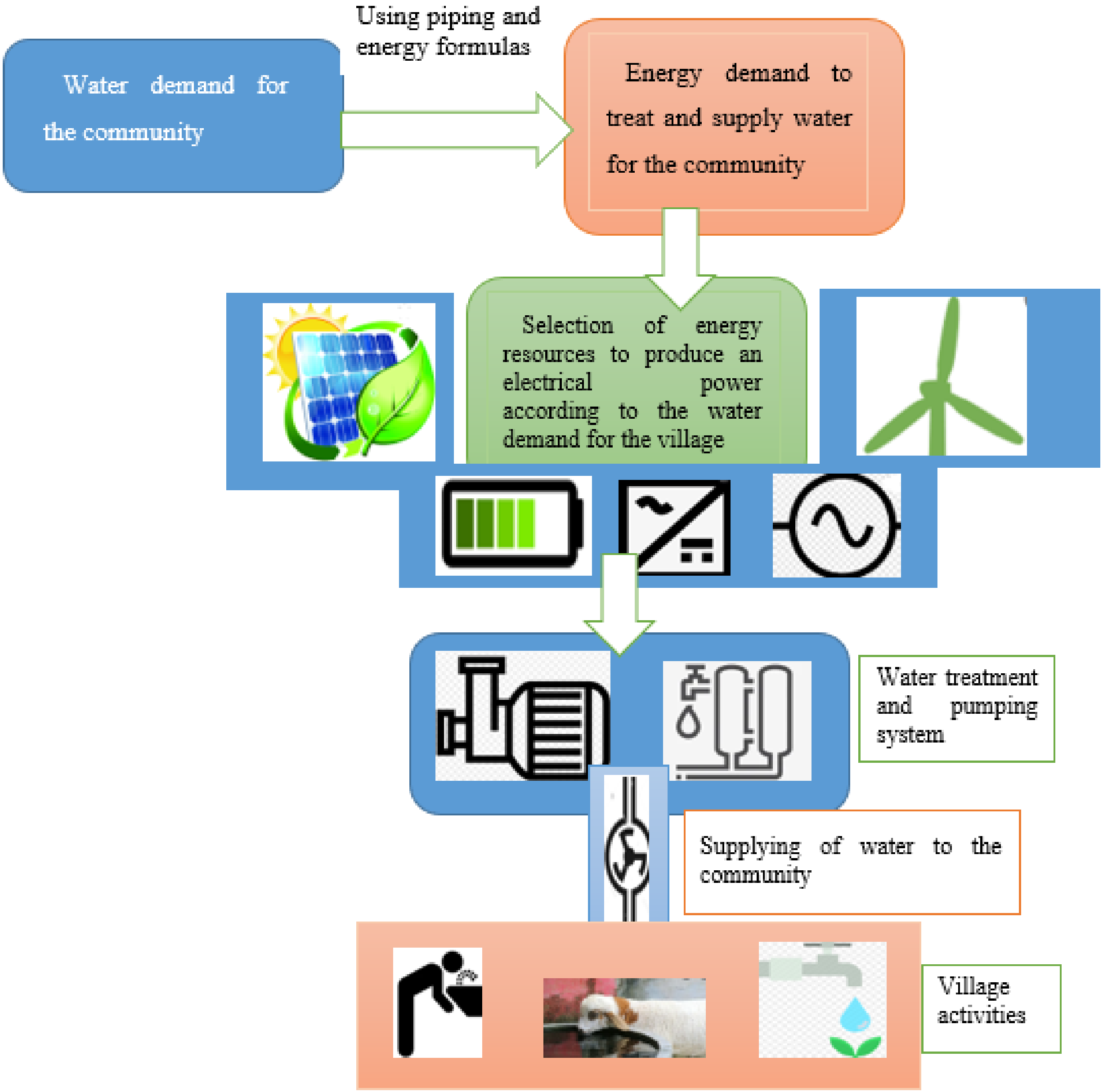


Figure 3:4 System flow chart

3.5.1 Water Treatment

Water is used for human activities such as for drinking, bathing, cooking, kitchen and dishwashing and the water used must be safe and free of contaminants. This could be managed by using water treatment process (D. Dohare 2014). Water used for irrigation does not need to be treated unless if the water is salty because it can harm the soil. Human and animal activities in the surrounding areas can readily pollute surface water sources. Heavy rain and flooding can also make the water murky. Surface water must be treated for these reasons if it is to be used as a source of drinking water. Water treatment for a rural community water supply is costly due to the required chemicals and additional electricity. In the design of this mini-grid, all the parameters must be under consideration.

In this design, the mini-grid is used to pump ground water for drinking and agriculture purposes. (Form 2000) reported that groundwater plays a great role in providing water for drinking, irrigation and industrial purposes. There are many reasons why ground water is the best choice for water supply. One of the reasons groundwater is always available where there are limited surface water sources. The second reason, ground water is usually having good quality and requires less treatment to make it safe and clean for drinking and the quality does not change throughout the year. Another reason, ground water is found in many areas of developing continents such as Africa. In addition, ground water doesn’t need a large reservoir to store water.

There are different techniques used for water treatment. In general, there are two types of water treatment to remove organisms, salts and metals from water. The first one is a membrane and thermal water treatment methods. The membrane method is a system in which a physical separation technique uses mechanical pressure, electrical energy or vibration as the driving force mechanism for passing through a semipermeable membrane. The second system (i.e., thermal approach), on the other hand, uses heat to evaporate water from a saline solution. After that, the evaporated water is distilled and recovered (Esmaeilion 2020).

The study (Wibowo and Chang 2020) reported that the use of membrane separation technologies, particularly reverse osmosis, has increased dramatically, and reverse osmosis is now one of the most extensively used methods for the removal of an organism, minerals and desalination process. Also, the study (Esmaeilion 2020) proven that the reverse osmosis system has known as the most common desalination process because it has low cost and takes low energy. In this study, a reverse osmosis water treatment technique with 2 kWh/m^3 capacity is used for treating ground water for human activities.

3.6 Energy resources selection

One of the main parameters of design consideration in mini-grid design for powering of rural community water supply and treatment is a selection of the energy sources. The basic requirements for energy sources are; location of the power sources, reliability of power sources, technical and economic aspects of the power sources, and factors in social and institutional of the energy sources.

Renewable energy resources such as solar, wind, geothermal and hydro are proven that clean, reliable, and environmentally friendly resources. In this study, solar and wind energy resources with battery storage are considered. The site location region has great potential in solar and wind resources.

3.6.1 Solar radiation potential of the region

The average monthly daily solar radiation of the Djelfa region is shown in Figure 3.4. The data is taken from HOMER software sources data.

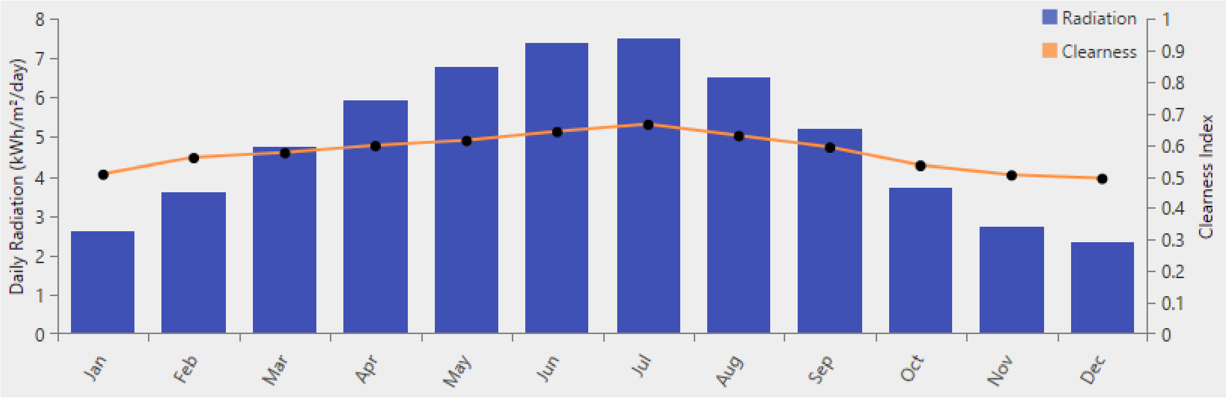


Figure 3:5 Solar radiation potential of Djelfa region

Figure 3.5 indicates that the solar radiation potential of the Djelfa region is important. The average daily solar radiation of the region is 4.91 kWh/m^2/day. The solar radiation potential of the region is low during the winter and autumn seasons. Despite, the solar radiation potential during summer high with a maximum value of 7.49 kWh/m^2/day.

3.6.2 The wind energy potential of the region

Figure 3.6 shows the wind speed potential of the Djelfa region and the monthly average speed at 50m above the surface of the earth. The annual average wind speed of the region is 6.07 m/s. It has good wind speed potential during winter and autumn. The maximum wind speed is 6.77 m/s in April. The lowest wind speed is during summer with a minimum value of 5.12 m/s.

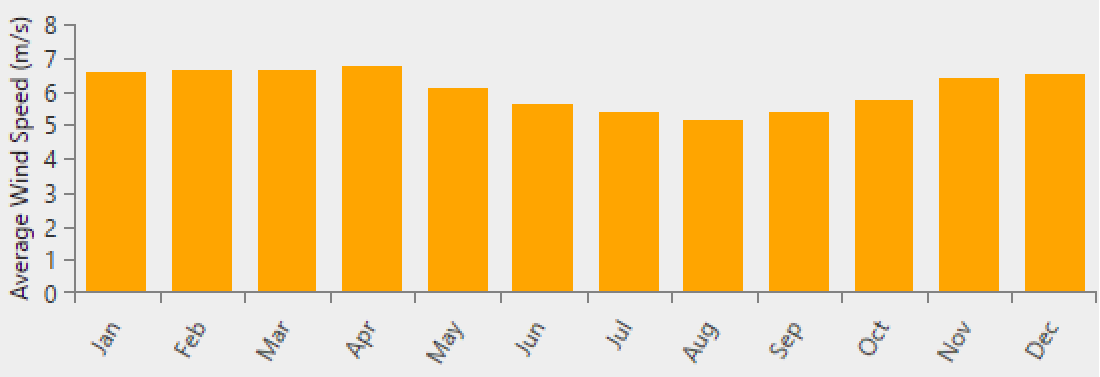


Figure 3:6 wind speed potential of Djelfa region

In general, the region has good solar radiation during summer but has low in wind speed. And, it has good wind speed during winter and autumn but it has low solar radiation during those seasons. So, in this study, both wind and solar energy with grid connection is considered to have a suitable design system.

3.6.3 The temperature profile of the region

The temperature profile of Djelfa is shown below in figure 3.7. The region has a low-temperature profile during winter and autumn with a minimum value of daily temperature 5.17 °C and has a maximum daily temperature in summer with a value of 28.05 °C.

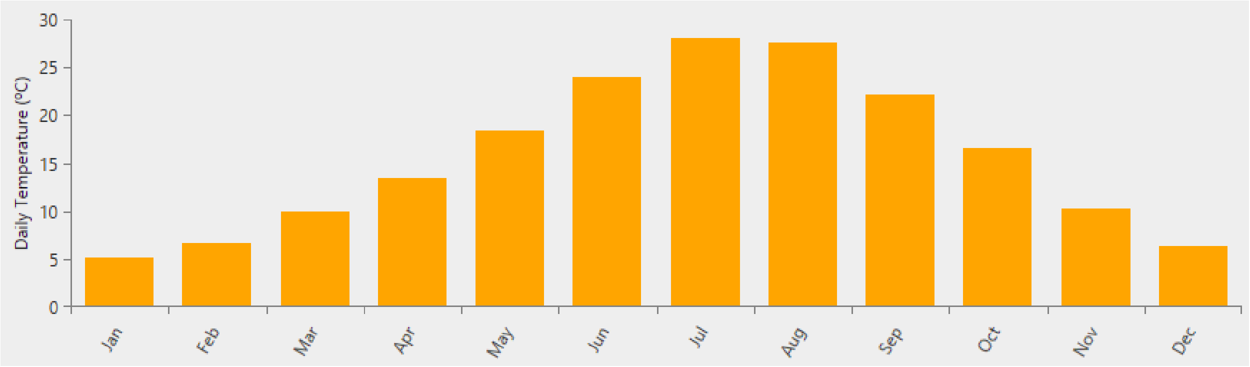


Figure 3:7 Daily temperature profile of Djelfa

3.7 Sizing, Selection of Equipment, and Performance Evaluation and Simulation of the System

This step involves the design, sizing, and simulation of a mini-grid depending on different parameters and factors. For the performance evaluation and simulation, HOMER (Hybrid Optimization of Multiple Energy Resources) is used.

3.7.1 HOMER Software

HOMER (Hybrid Optimization of Multiple Energy Resources) is a software application which is developed by the National Renewable Energy Laboratory (NREL), United States. This software is used to design for off-grid and on-grid power systems in terms of technical and financial aspects. It also admits different energy resource options and it can calculate different permutations of possible designs depending on the given input data and simulate the power system (Control 2016).

3.7.2 Mathematical modeling

3.7.3 Pump selection

In this study, three pumps are used, one is a submersible centrifugal pump, the second one is used to pump the treated water used for drinking water of the community and the third one is to pump the water for irrigation systems. The sizing of the pump needs the use of the given formula below (Al-Waeli et al. 2017):

$$P = \frac{\rho * g(Htotal)}{\eta overaall} * Q \qquad (1)$$

Where:

ρ= Density of water = 1000kg/m3

g= gravitational acceleration = 9.81m/s^2

$Htotal$= total pumping head

Q = volumetric flow rate

ηb= efficiency of a pump

ηe= efficiency of a pump motor

ηv = Volumetric efficiency

$\eta overall$ = *0.85 considering as general average for efficiency* (Al-Waeli et al. 2017).

- ✓ Total head from the pump location to the storage = 43 m
- ✓ Height of the tank located at the maximum heigh = 12m
- ✓ Height of tank before treatment = 3 m
- ✓ Height of the water borehole = 110 m (information from the village)

The detailed energy demand is calculated using the above input data and equation 1. In this design, three different size pump was selected. The first pump is a submerged pump used for irrigation. The second pump is also a submerged pump used to pump the water that needs treatment. The third one a pump used to pump the treated water to the storage. This design operates with a maximum hour of 8 during spring, fall, and autumn. And maximum of 9 hours during summer. The rest of the energy generated by the system is considered to sell to the grid. This helps to lower the Levelized Cost of Energy of the system and increase the importance and attraction of the design.

After calculating the power need for each season, the three pump were selected and then calculated their operating hours per day using excel. The selected pumps are discussed below (Technology 2018, Amazon 2021):

Table 3:2 Pump selection

No	Pump type	Specification

1	Submerged pump 1	✓ Power = 250 kW ✓ Model = SMP 12 360/5B ✓ Motor = TR 12
2	Submerged pump 2	✓ Power = 3.5 kW ✓ Model = SMP 12 360/5B ✓ 3.5 kW electric power
3	Pump 3	✓ Power = 1.7 kW ✓ Model = B07N6N63CW ✓ Material = Stainless Steel AISI 304 ✓ Frequency = 50 Hz ✓ Motor with 1.7 kW

Table 3:3 Pump working hours

Months	Sub Pump1	Sub Pump2	Pump 3
March	1	8	8
April	1	8	8
May	1	8	8
June	9	7	7
July	9	7	7
August	6	7	7
September	0	8	8
Octeber	0	8	8
November	0	8	8
December	0	8	8
January	0	8	8
February	0	8	8

3.7.4 Solar PV

Solar photovoltaic (PV) systems turn sunlight into electricity and are a renewable energy source (Awasthi et al. 2020). There are no moving parts in PV systems. Solar energy is a green, clean, and economical source of energy, and the globe is now investigating and exploring this technology, with solar PV systems as a result. Clean and affordable energy is highlighted in the sustainable development goals, particularly Goal 7. As a result, solar PV systems play an important role in achieving sustainable development goals because they provide clean and affordable energy systems.

A PV array a collection of a module which is consisting of solar cells with positive and negative charges for current produce (Shaikh 2017).

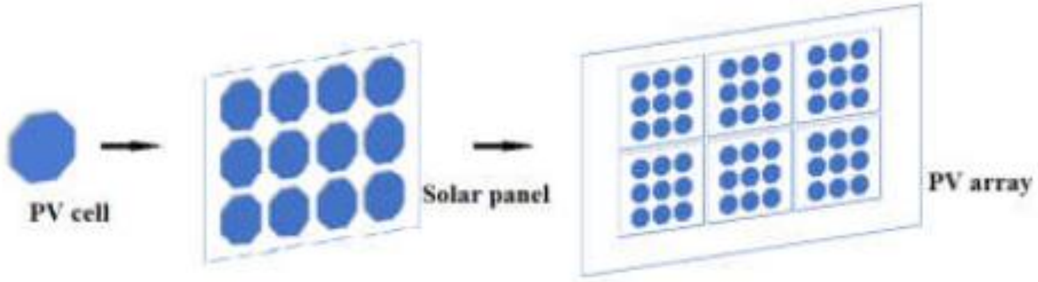


Figure 3:8 Cells collection forming PV arrays (Tevi et al. 2018)

3.7.5 Wind turbine

Wind energy is a mechanism of using wind for generating electricity. A wind turbine is used to convert the kinetic energy of wind into mechanical rotation. The mechanical rotation produced by a turbine then converts to electrical energy. The wind is caused by atmospheric pressure gradients causing air to move. Wind moves from higher to lower pressure areas. The greater the air pressure gradient, the greater the wind speed and, as a result, the greater the wind power that can be caught by wind energy-converting apparatus (Christensen 2009). The type of turbine used in this study is a 10 kW wind turbine with a height of 60 m.

3.8 Cost analysis

3.8.1 Cost of Energy

The Levelized cost of energy (COE) is defined as the average cost of useful energy generated by the designed system. Mathematically, it is calculated by dividing the annualized cost of generating power by the total useful energy production. Its equation is defined below (Ammar et al. 2016):

$$COE = \frac{Annual\ cost\ (\frac{\$}{year})}{Total\ electrical\ load\ served(\frac{kWh}{year})} \qquad (2)$$

In this study of mini-grid design for powering of rural community water treatment and supply, HOMER software is used to calculate all the costs related to the Levelized cost of energy and net present cost.

3.8.2 Net present cost

The total net present cost (NPC) of a given system is calculated by the present value of all costs incurred over the system's lifespan minus the present value of all revenue earned over the system's lifetime. The NPC includes the capital costs, operations and maintenance costs, replacement costs, fuel costs, emissions penalties, and the cost of obtaining power from the grid. The basic sources of revenue are salvage value and grid sales revenue. Using HOMER software, the total NPC is calculated by adding all discounted cash flows in each year of the project's life cycle (Pro 2021). The NPC formula is given below (Ammar et al. 2016):

$$NPC = \frac{Cann.tot}{CRF(i,Rproj)} \qquad (3)$$

Where:

- ✓ NPC = net resent cost
- ✓ Cann.tot = annual total cost in \$/year
- ✓ CRF = capital recovery factory
- ✓ I = interest rate (%)
- ✓ Rproj = project lifetime (year)

3.9 ICT and technologies in mini-grid systems

An internet-based mini-grid is used to integrate the performance and efficiency of the system renewables, power flows and accommodates technology destruction (Liu et al. 2020). The power loss, fault detection in solar PV and wind turbines, the flow of water could able to control using different technologies such as sensors, pressure regulators, flow regulators and other methods.

In this study, it is considered a power for controlling units such as sensors and computers that are used to control the power and flow system. The purpose of using internet-based digitization is to maintain instantaneous power and flow system, to reduce risks from small damage and emergencies. Table 7.7 (appendix B) below is including the main components used in mini-grid design for managing and controlling system:

3.9.1 Sensor

A sensor is an electronic device that detects physical input from given parameters and converts it into programmed data that can be analyzed by humans or machines (Jost 2019). In this design, sensors are considered to control the system wind turbine faults, Solar PV faults, pressure regulator and treatment control.

3.9.2 Desktop

A desktop is a computer display that used includes a document, data, and information used for implementing and processing an object, program, design and system. In this study, the energy demand is considered a desktop that is used to save, process, and manipulate data during the mini-grid water treatment and supply operation time.

3.10 Design layout description

The main target of this study is to design a mini-grid for powering water from underground. In this design, there are two mechanisms. The first system is the pumping of water for drinking purpose which need treatment. And the second mechanism is the pumping of water for irrigation purposes which is no need for treatment. So that in both mechanisms, there is a common submerged water pump that is used to withdraw water from underground.

A schematic representation of the whole system is reported in Figure 3.9. As shown in the figure, the system has two lines and each line have their components. It designed using SOLIDWORK oftware. SOLIDWORK software is a mechanical design and construction program for mechanical, electrical, and software components (University 2019).

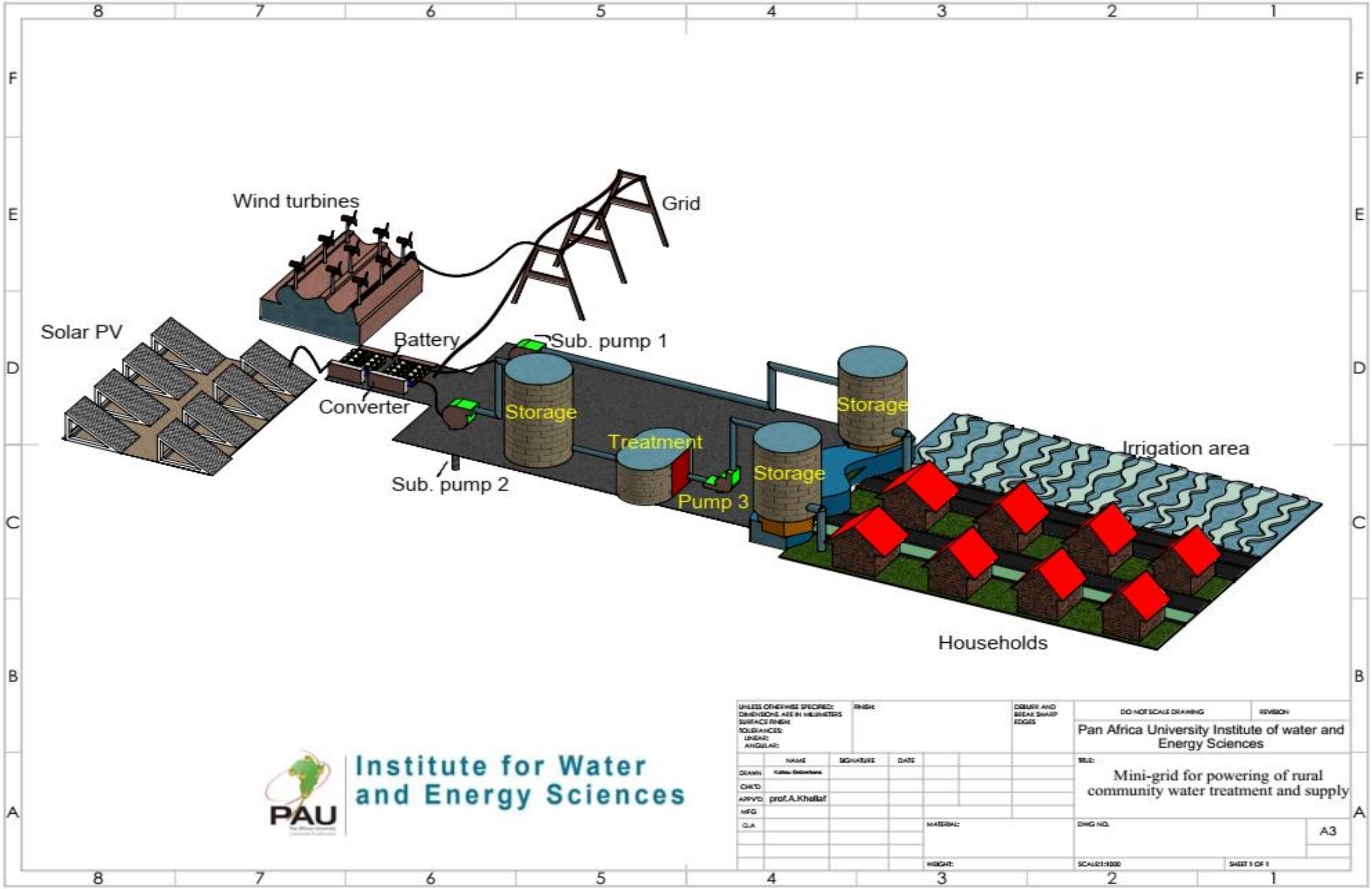


Figure 3:9 Layout mini grid design for rural community water supply and treatment (drawn by author using Solidwork software)

CHAPTER 4

4 RESULT AND DISCUSSION

4.1 Introduction

This chapter includes two parts. The first part includes the results and discussions of a survey from the community to identify the problems and to analyze their knowledge and understanding of renewable energy technologies. The second part includes the result and discussion of mini-grid sizing and simulation with different cases. In general, the off-grid and on-grid for powering of rural area water treatment and pumping with different options were discussed. Also, the optimization result of the system is analyzed.

4.2 Survey assessment

The main purpose of this survey is to identify the community water use practices and the community water needs. A total of 20 people were contacted and the result is as follows.

Table 4:1 survey assessment from the community

No	Questionaries	Choose			
1	Which of the following water sources for drinking, sanitation, bathing, and irrigation are available in your household?	Piped household supply	Common borehole	Bottled water and sachet water	Other
			100%	100%	
2	How long (in minutes) does it take to fetch water and return home?	Less than 5 minutes	5 minutes	10 minutes	More than 10 minutes
				12%	88%
3	Is water for drinking, irrigation available throughout the year?	Yes		No	
				100%	
4	Is there any ICT or digital technologies in your community?	yes		no	
				100%	

6	Rate the awareness level on renewable energy of your community?	Very low	low	medium	high	Very high
		79%	21%			
7	Which energy resources are available in your community?	Renewable energy (solar, wind, hydro etc.)	Nonrenewable (fossil fuel)			
			100%			
8	How do you rate the renewable energy development status of your community or country?	Undeveloped	Neutral	Developed		
		100%				
9	What challenges do you have for the development of renewable energy technologies in your community?	Finance	Technology	Policy		
		45%	55%	25%		

The results of water practices and energy technologies used in rural areas are reported in Table 4.1. In the rural community, water is obtained by purchasing it from Djelfa city, particularly during the summer, as well as from a well in their irrigation area (but the water source near to the village is not always available). Because the village is 8.5 kilometers from the city, the majority of them (88 percent) used to spend more than 10 minutes gathering water for drinking, bathing, cooking, and sanitation. The water supply is not always accessible throughout the year. Advanced water management systems are required for groundwater, such as lowering water losses during fetching, collecting, and supplying. This could be managed through pumping and pumping water to houses, irrigation areas, economic activities, and farms. Technologies are also rare in rural areas moreover in Africa (Nel, Booysen, and Van Der Merwe 2014), and this survey provides rural communities need to have access to a water supply system with digital technologies.

The survey, on the other hand, measures awareness and knowledge of renewable energy technology, with 79 percent reporting extremely poor awareness and 21 percent reporting low awareness. As a result, rural communities must educate themselves about renewable energy so that they can contribute to the achievement of the Sustainable Development Targets, notably goals 6 and 7. It also demonstrates that renewable energy production in rural areas has not progressed. Finances, technologies, and policies are the most significant obstacles to establishing renewable energy technology and water availability in rural communities.

4.3 HOMER analysis

Homer software is used to design the long-term functioning of a variety of micropower system types, such as solar PV, wind, grid, and other components. It is also used for simulation, optimization and sensitivity analysis of the mini-grid system. The software proposes the best configuration based on the lowest net current cost after simulating a number of combinations using the given data.

In this study, three scenarios with the different cases are discussed.

- ✓ An off-grid system with different cases
- ✓ An on-grid system with different cases
- ✓ A hydrogen-based off-grid system

4.3.1 Load profile

The load profile for the mini-grid design is calculated in kW and operating hours using pumping formulas. All the loads and operating hours were arranged in an excel file for each month. Below are the daily, monthly, and annual loads for the mini-grid design for powering the Murqab Bin Hafaf rural community water treatment and supply system. Figures 4.1, 4.2, and 4.3 show the daily, monthly, and yearly energy demand of the village.

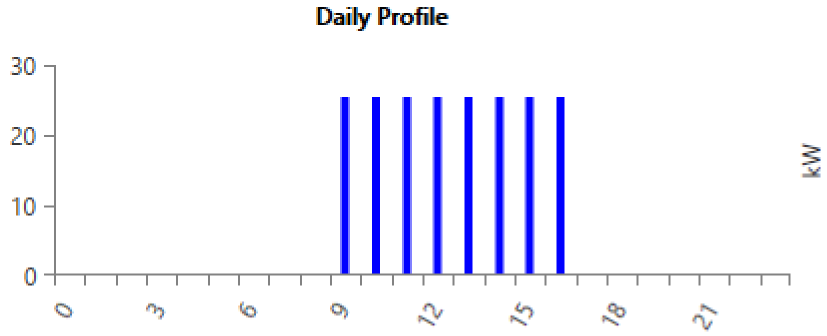


Figure 4:1 Daily load profile

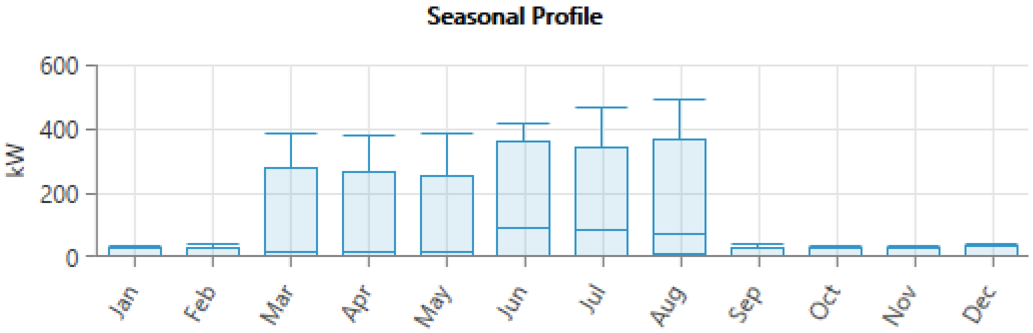


Figure 4:2 Seasonal load profile

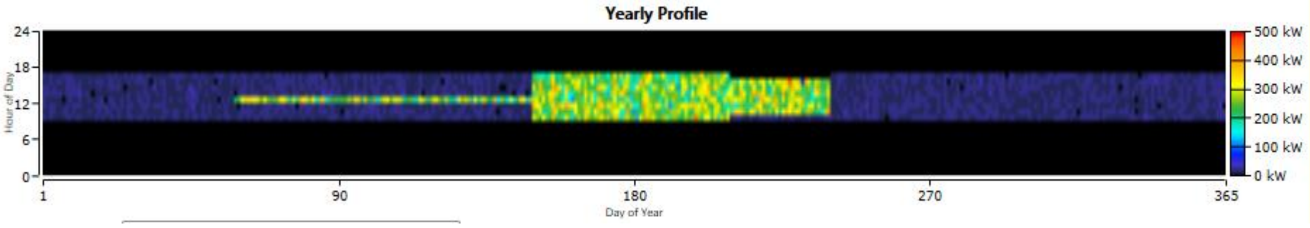


Figure 4:3 Yearly load profile

4.3.2 Component selection

In this study, the type of components used for the design and simulation are Canadian Solar Max Power CS6U-340M, Generic 10 kW, 1kWh Lead Acid and Generic, 25kW Fixed Capacity Genset, UNSYS PCS² IM 132kVA TL UL converter and grid (for the on-grid system). The Canadian Solar Max Power CS6U-340M was used in the design with a capital cost of $329.50, the replacement cost of $250 and the operational and maintenance cost of $10 (SOLARIS 2021). The wind turbine used in the design is having a capital cost of $20000, a replacement cost of $15000 and an operational and maintenance cost of $150 (Future 2021). The lead-acid battery capital cost is $549, the replacement cost of 500, and the operational and maintenance cost $10 (Dive, 2020, Brinsmead & Hayward, 2015). The converter price is $23000 capital cost, $15000 replacement cost, and $150 operational and maintenance cost (Alibaba 2021). The generator capital price is $11999, replacement cost $7000, operational and maintenance is $0.1/op.hr (DIRECT 2021) and fuel cost is $0.212 (GlobalPetrolPrices.com 2021).

Table 4:2 Component selection

No	Component	specification	Capacitity	Capital cost ($)	Replacement ($)	Operating and maintenance cost ($)
1	Solar PV	Canadian Solar Max Power CS6U-340M	0.34	329.5	250	10
2	Wind turbine	Generic 10 kW	10 kW	20000	15000	150
3	Battery	1kWh Lead Acid and Generic	1kW	549	500	10
4	Converter	UNSYS PCS² IM 132kVA TL UL	132 kVA	23000	15000	20
5	Generator	25kW Fixed Capacity Genset	25 kW	11999	7000	0.1/op.hr and fuel cost 0.212

4.3.3 Off-grid system analysis

An off-grid system is a system that is not connected to an electricity grid and it required a battery for storage purposes (Reviews 2016). In this study, the off-grid system includes solar PV, wind turbine, converter, battery, and backup generator to have a suitable operating system during pumping operation.

Different cases or options are considered during the design and simulation of the off-grid system using HOMER software. The different options are discussed below.

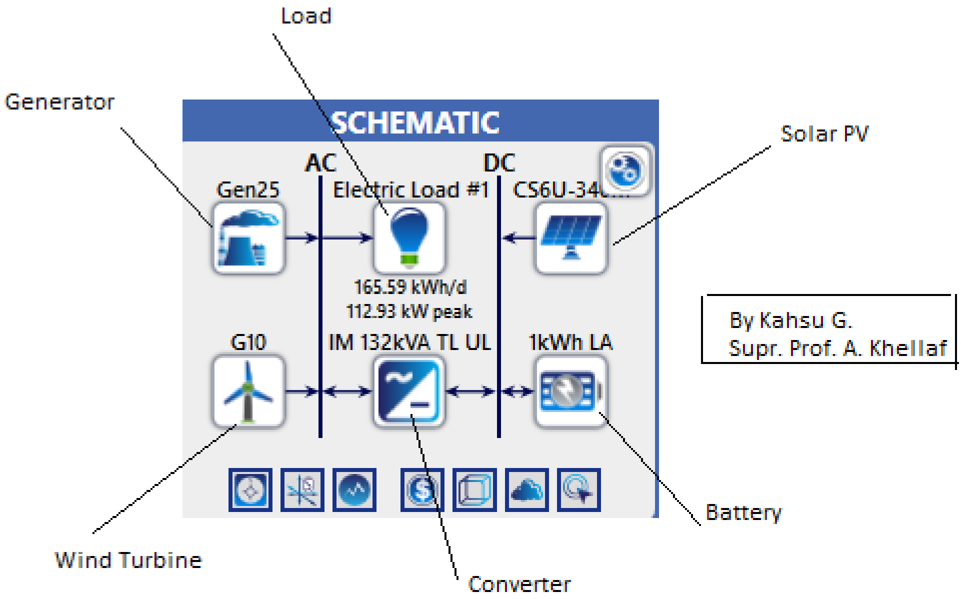
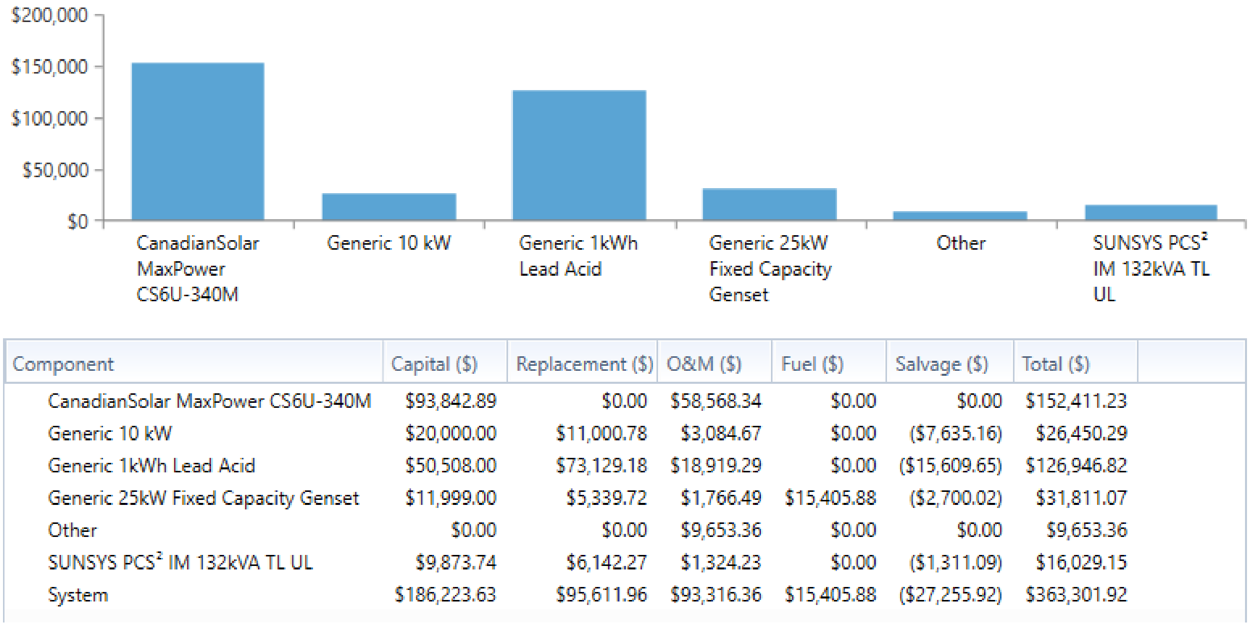


Figure 4.4 Off-grid schematic for powering of water treatment and supply

4.3.3.1 Case 1: PV/Wind/Generator/battery with converter

In this case, solar PV is used to generate electricity from the sun, a generator for backup power, a battery for storage, and a converter to convert direct current to alternating current. The cost summary of this type of configuration is shown in Figure 4.5.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
CanadianSolar MaxPower CS6U-340M	$93,842.89	$0.00	$58,568.34	$0.00	$0.00	$152,411.23
Generic 10 kW	$20,000.00	$11,000.78	$3,084.67	$0.00	($7,635.16)	$26,450.29
Generic 1kWh Lead Acid	$50,508.00	$73,129.18	$18,919.29	$0.00	($15,609.65)	$126,946.82
Generic 25kW Fixed Capacity Genset	$11,999.00	$5,339.72	$1,766.49	$15,405.88	($2,700.02)	$31,811.07
Other	$0.00	$0.00	$9,653.36	$0.00	$0.00	$9,653.36
SUNSYS PCS² IM 132kVA TL UL	$9,873.74	$6,142.27	$1,324.23	$0.00	($1,311.09)	$16,029.15
System	$186,223.63	$95,611.96	$93,316.36	$15,405.88	($27,255.92)	$363,301.92

Figure 4:5 Cost summary of PV/Wind turbine/generator/battery/converter system

Figure 4.5 shows that the total capital cost is $186223.63 ($93842.89 for solar PV, $20000 for wind turbine, $50508 for battery, $11999 for generator and $9873.74 for converter). The total replacement cost is $95390.96, the fuel cost is $14125.78 and the savage value of the system is $28174.4. The emission penalty (other) of the system is $9653.36. The total NPC value of the system is $350990.4, the Levelized cost of energy (COE) is 0.2852 $/kWh and the operating cost is $8012.22. Figure 4.6 shows that the cash flow coat of the system for 25 years.

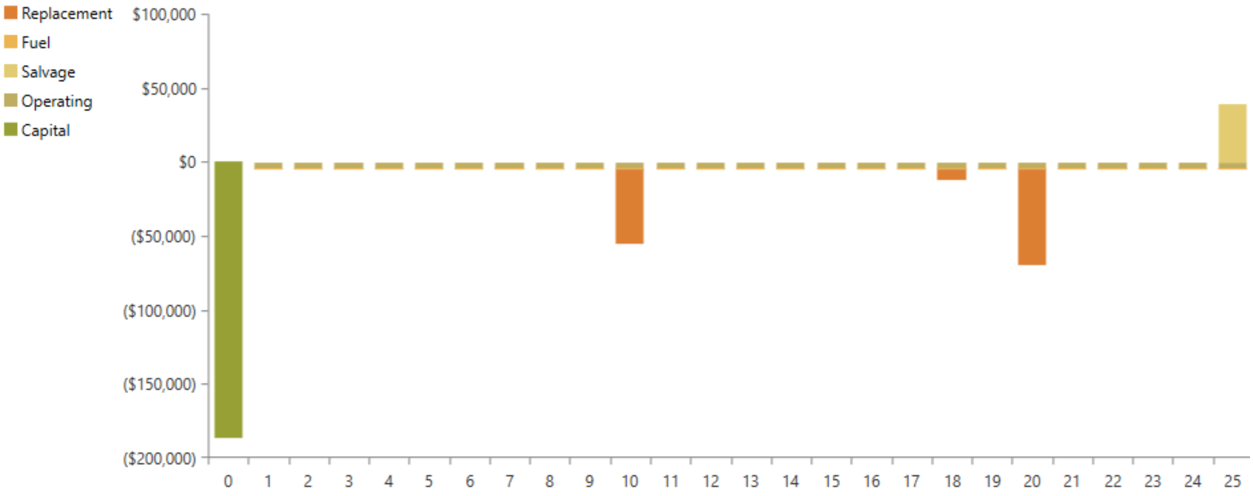


Figure 4:6 Cash flow of PV/wind/generator/battery/converter system

The monthly electricity produced by the system is shown in Figure 4.7. The total electric produce from PV is 79,4% (162.099), from the wind turbine is 15.5 (31618 kWh/yr) and from the generator is 5.07% (10348 kWh/yr).

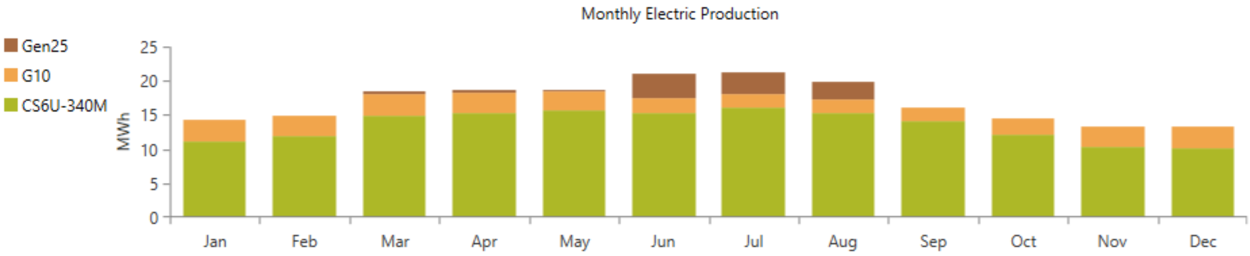
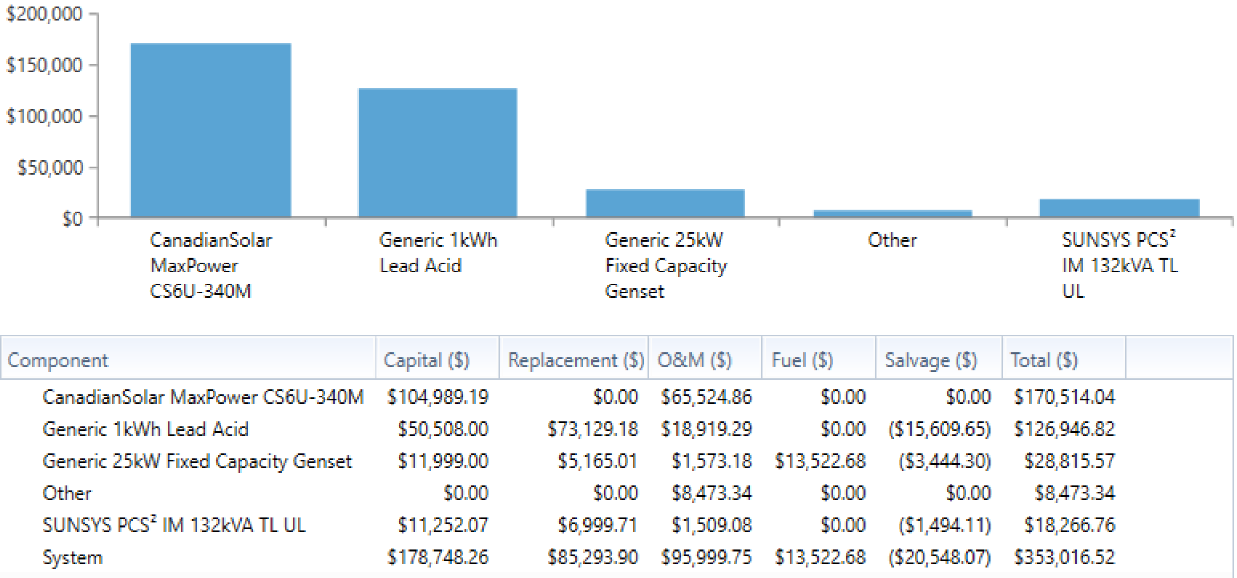


Figure 4:7 Monthly electricity production of PV/generator/battery/converter system

4.3.3.2 Case 2: PV/generator/Battery/converter system

In this system, a solar PV, backup generator, battery, and converter are assembled using homer software to generate electricity for powering of rural community water treatment and supply. After design and simulation of the configuration resulted in it is own total NPC, Levelized COE, and operating costs. The total cost summary of this system is shown in Figure 4.8:



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
CanadianSolar MaxPower CS6U-340M	$104,989.19	$0.00	$65,524.86	$0.00	$0.00	$170,514.04
Generic 1kWh Lead Acid	$50,508.00	$73,129.18	$18,919.29	$0.00	($15,609.65)	$126,946.82
Generic 25kW Fixed Capacity Genset	$11,999.00	$5,165.01	$1,573.18	$13,522.68	($3,444.30)	$28,815.57
Other	$0.00	$0.00	$8,473.34	$0.00	$0.00	$8,473.34
SUNSYS PCS² IM 132kVA TL UL	$11,252.07	$6,999.71	$1,509.08	$0.00	($1,494.11)	$18,266.76
System	$178,748.26	$85,293.90	$95,999.75	$13,522.68	($20,548.07)	$353,016.52

Figure 4:8 Cost summary PV/generator/Battery/converter system

Figure 4.8, the total capital cost of the system is $178748.26, the total replacement cost of $85293.9, the total operational and maintenance cost of $95999.75, the total fuel cost of $13522.68, and the total salvage value of the system is $20548.07. The system gives a total NPC value of $353016.5 and Levelized COE is 0.2863 $/kWh and the operational cost is $8474.25. The cost cash flow of the system over 25 years is shown in Figure 4.9.

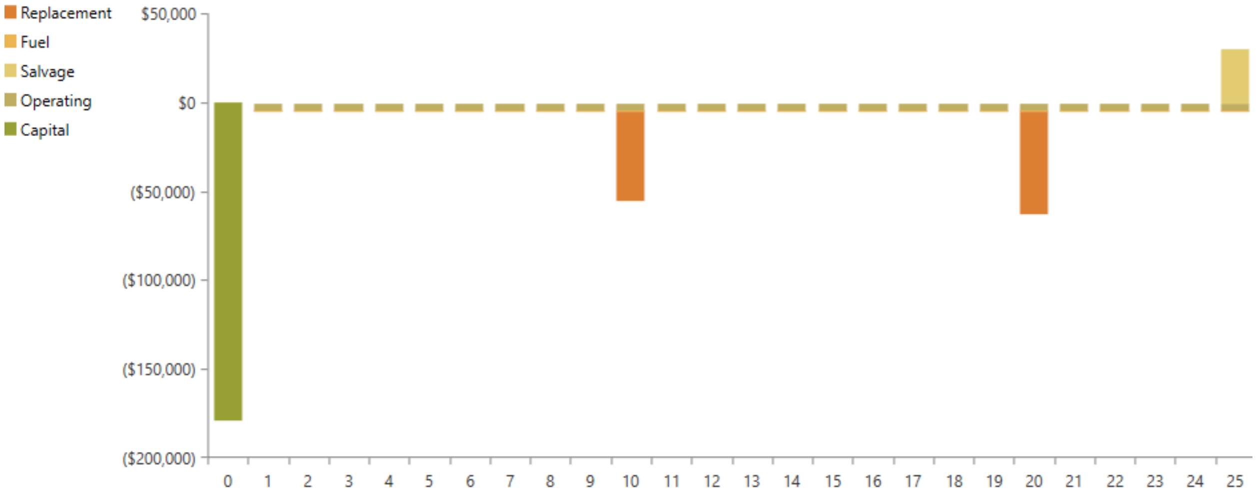


Figure 4:9 Cash flow PV/generator/battery/converter system

The main electricity production of this kind of system is from solar PV. As the result of the simulation the total electricity production from the PV is 95.2 % (181350 kWh/yr) and from the generator is 4.75 (9.05 kWh/yr). The figure indicated the monthly electric production of PV/generator/battery/converter water treatment and pumping system.

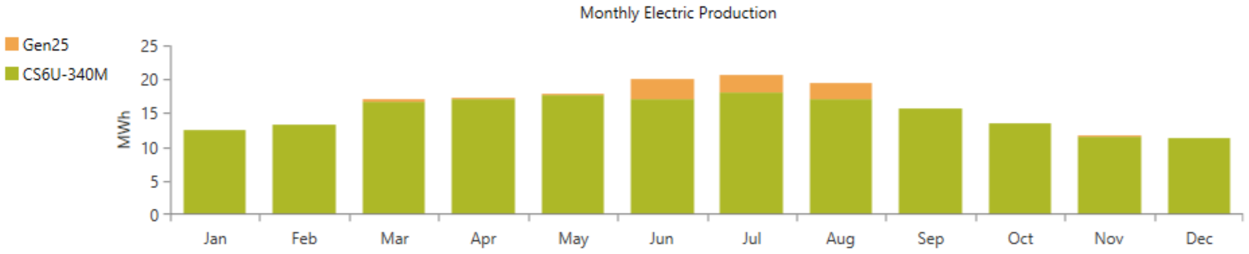
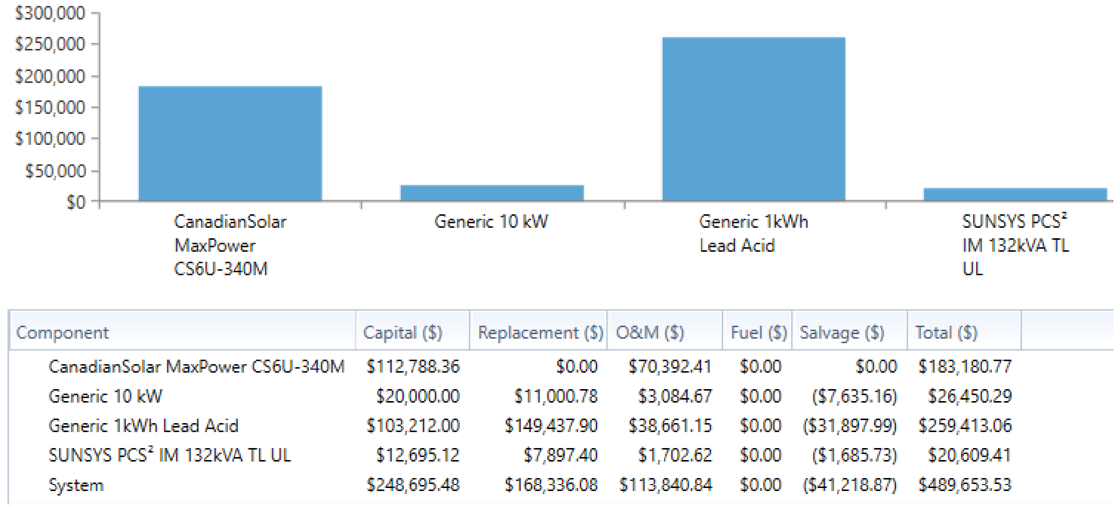


Figure 4:10 Monthly electric production of PV/generator/battery/converter system

4.3.3.3 Case 3: PV/wind /battery/converter system

Solar PV, wind, battery, and converter are assembled at once to generate electricity for powering the community water treatment and supply unit. The total cost summary of the system resulting from the HOMER simulation is shown in Figure 4.11.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
CanadianSolar MaxPower CS6U-340M	$112,788.36	$0.00	$70,392.41	$0.00	$0.00	$183,180.77
Generic 10 kW	$20,000.00	$11,000.78	$3,084.67	$0.00	($7,635.16)	$26,450.29
Generic 1kWh Lead Acid	$103,212.00	$149,437.90	$38,661.15	$0.00	($31,897.99)	$259,413.06
SUNSYS PCS² IM 132kVA TL UL	$12,695.12	$7,897.40	$1,702.62	$0.00	($1,685.73)	$20,609.41
System	$248,695.48	$168,336.08	$113,840.84	$0.00	($41,218.87)	$489,653.53

Figure 4:11 Cost summary of PV/wind /battery/converter system water treatment and supply unit

The total NPC of the system is $489653, the Levelized cost of the system is $0.4056 and the total operating cost is $11717.22. The cost cash flow of the system within 25 years is shown in Figure 4.12. The total salvage value of the system is $41218.87.

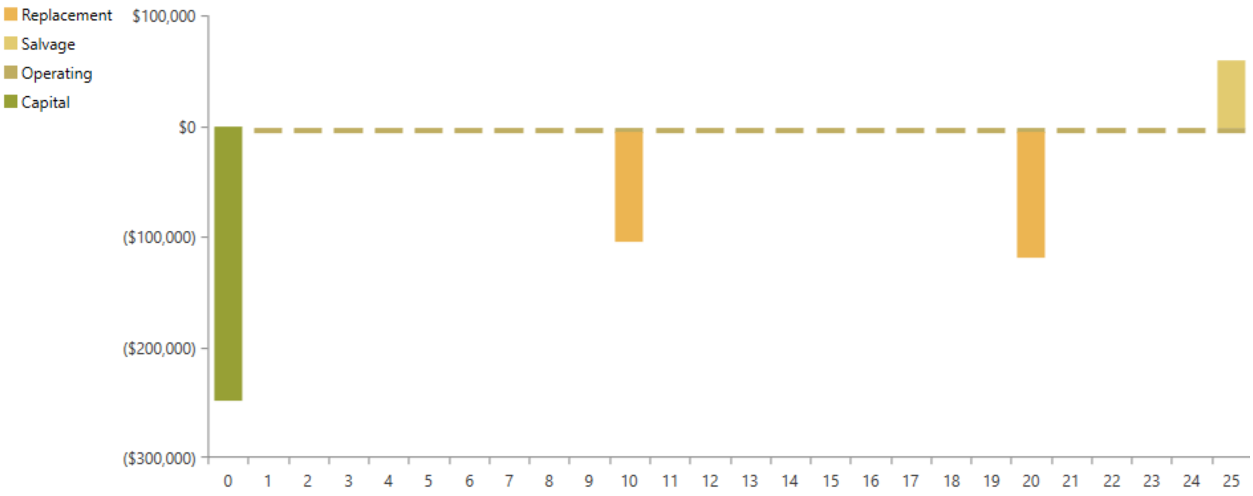


Figure 4:12 Coat cash flow PV/wind/battery/converter system

The electric production of this system is mainly from solar PV and wind turbines. From the total of electric generation, solar PV produces 86 % (194.824 kWh/yr) and wind turbines produce 14 % (31618 kWh/yr). Figure 4.13 shows the monthly electric production from PV, wind turbine, battery, and converter configuration system.

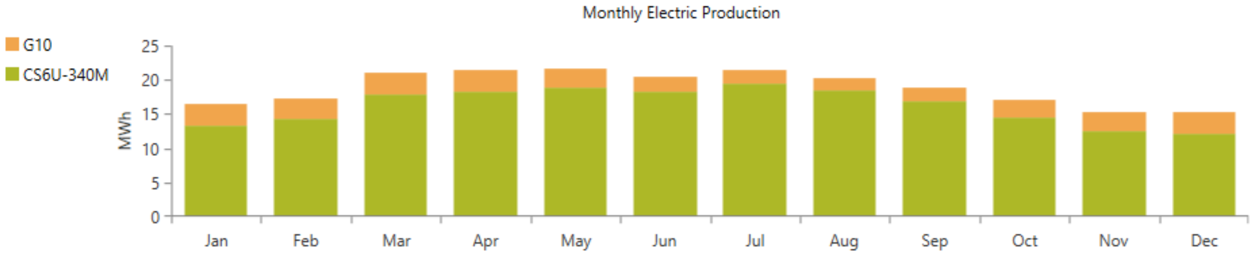


Figure 4:13 Monthly electric production of PV/wind/battery/converter system

4.3.3.4 Sensitivity analysis

Under a set of a given value, sensitivity analysis shows how different values of an independent variable affect a specific dependent variable. To put it another way, sensitivity studies look at how different sources of uncertainty in a mathematical model contribute to the total uncertainty of the model. This technique provides the result of more input variables within the system design and simulation (Investopedia 2021). Figure 4.14 shows the optimal system of the off-grid system consists of two parts which are the combination of generator/solar PV/battery and generator/solar PV/wind/battery.

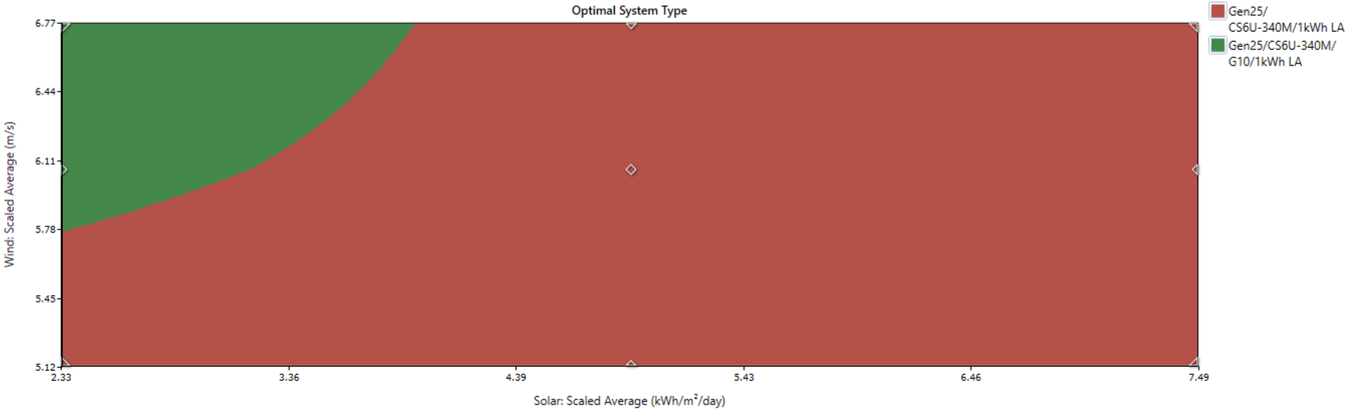


Figure 4:14 Sensitivity analysis

As shown in Figure 4.14, there are two optimal systems. The first one is the combination of a generator, solar PV, Wind turbine, and battery. The optimal case of this system starts from the wind scaled average value of 5.7 m/s and the solar scaled average value of 2.33 kWh/m^2/day with upward curved slop up to the wind scaled average value of 6.77 m/s and the solar scaled average value of 3.99 kWh/m^2/day (the green color areas). The second optimal option is the generator, solar PV, wind, and battery and this system is having a good optimal case. This case covers the rest of the areas from case one that is red in color.

4.3.3.5 Emission penalties

The social cost of carbon is a monetary estimate of the economic harm caused by such consequences, expressed as the total damages caused by emitting one ton of carbon dioxide into the atmosphere. In this part, the generator produces an emission so that it is considered the amount of emission and its penalty. The societal cost of carbon is estimated to be above \$50 per ton (Fund 2021). In this study, the cost of emission will consider \$50.

No	Case	emission	Amount (kg/yr.)	Total Penalty cost ($)
1	PV/Wind turbine/Gen/Battery/Conv	Carbon dioxide	9251	9653.36
		Carbon monoxide	57.7	
		Unburned hydrocarbon	2.54	
		Particulate Matter	0.346	
		Sulfur Dioxide	22.7	
		Nitrogen dioxide	54.3	
2	PV/Generator/Battery/Converter	Carbon dioxide	8120	8473.34
		Carbon monoxide	50.7	
		Unburned hydrocarbon	2.23	
		Particulate Matter	0.304	
		Sulfur Dioxide	19.9	
		Nitrogen dioxide	47.6	

4.3.4 On-grid system analysis

An on-grid system is a system in which the system is connected to public electricity grid (Reviews 2016). In this paper, different renewable energy options with the grid are considered and discussed. The following cases are investigated using HOMER software for their design and simulation and the assessment of their economic viability. The cost of electricity in Algeria is considered during this design process. As of the report of (GlobalPetrolPrices.com 2021), the electricity price of Algeria is 0.039$/kwh for households and 0.033$/kwh for business activities.

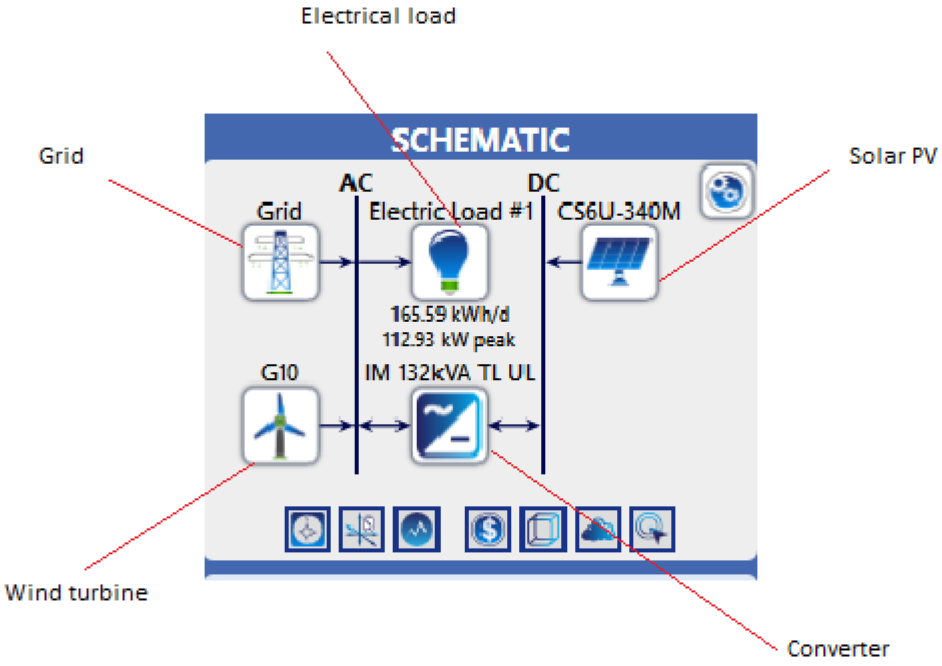
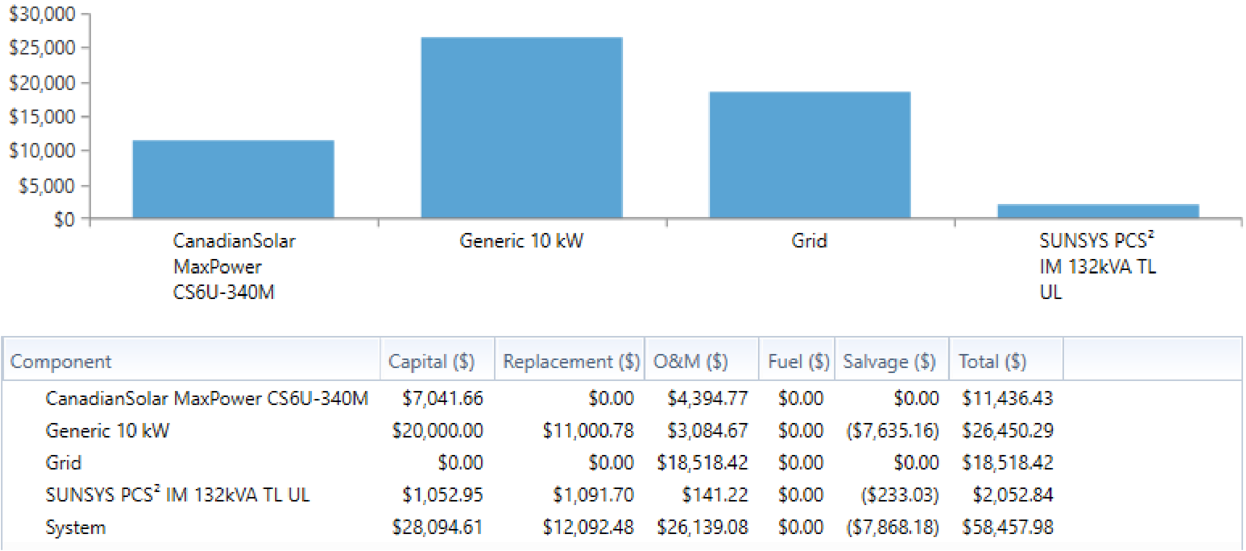


Figure 4:15 Grid-connected schematic water treatment and supply system

4.3.4.1 Case 1: PV/Wind/Grid/Converter system

This case includes solar PV, wind and grid-connected together with convertor to power the water pumping system. The total NPC and COE over 25 years are $58457.98 and 0.03276 $/kWh respectively. The operating cost of the system is $1476.5. The detail of the system economic results is shown in Figure 4:16.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
CanadianSolar MaxPower CS6U-340M	$7,041.66	$0.00	$4,394.77	$0.00	$0.00	$11,436.43
Generic 10 kW	$20,000.00	$11,000.78	$3,084.67	$0.00	($7,635.16)	$26,450.29
Grid	$0.00	$0.00	$18,518.42	$0.00	$0.00	$18,518.42
SUNSYS PCS^2 IM 132kVA TL UL	$1,052.95	$1,091.70	$141.22	$0.00	($233.03)	$2,052.84
System	$28,094.61	$12,092.48	$26,139.08	$0.00	($7,868.18)	$58,457.98

Figure 4:16 Cost summary of PV/Wind/Grid water treatment and supply system

The cash flow of this type of mini-grid for powering of water treatment and supply over the lifetime indicates that the total cost of selected solar PV is $11436.43 with a capital cost of the is

$7041.66, operating and maintenance cost of $4394.77. Also, the total cost for the wind turbine is $26450.29 with the capital cost of $200000, the replacement cost of $11000.78, and the operating and maintenance cost of $3084.67. The inverter has a total cost of $2052.84. The salvage value of the system is $7868.18. The total cost cash flow over 25 years is shown in Figure 4.17.

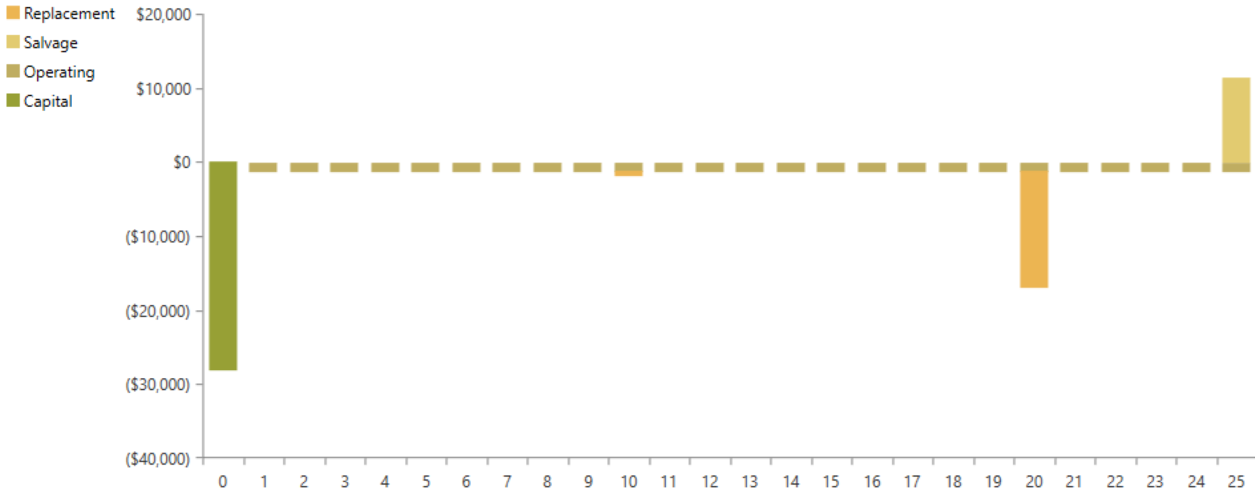


Figure 4:17 Cost Cash flow of PV/Wind/Grid/Battery/Converter water treatment and supply system

The electrical production of the system shows that 36.3% of the energy comes from the wind which is 316180 kWh/yr, 14% from the PV which is 12163 /kWh/yr, and 49.8% from the grid that is 43352 kWh/yr. This proves most of the energy comes from wind. Excess electricity is used to sell to the grid and used to purchase when a shortage of power happens this is a great benefit for the project because instead of wasting excess energy it is better to sell back to the grid for the suitability of the system.

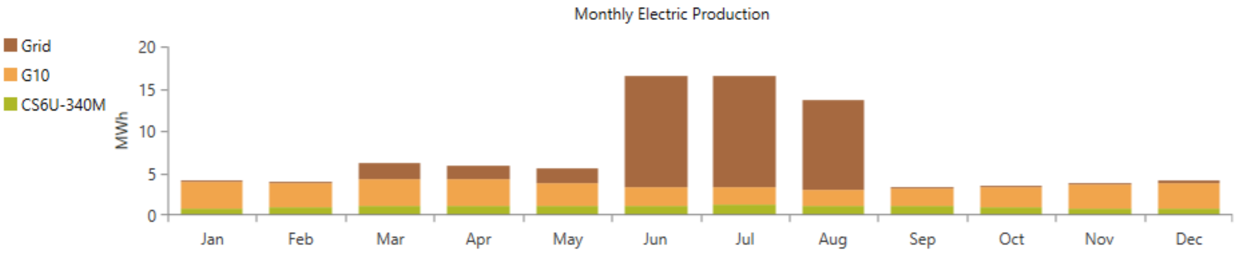
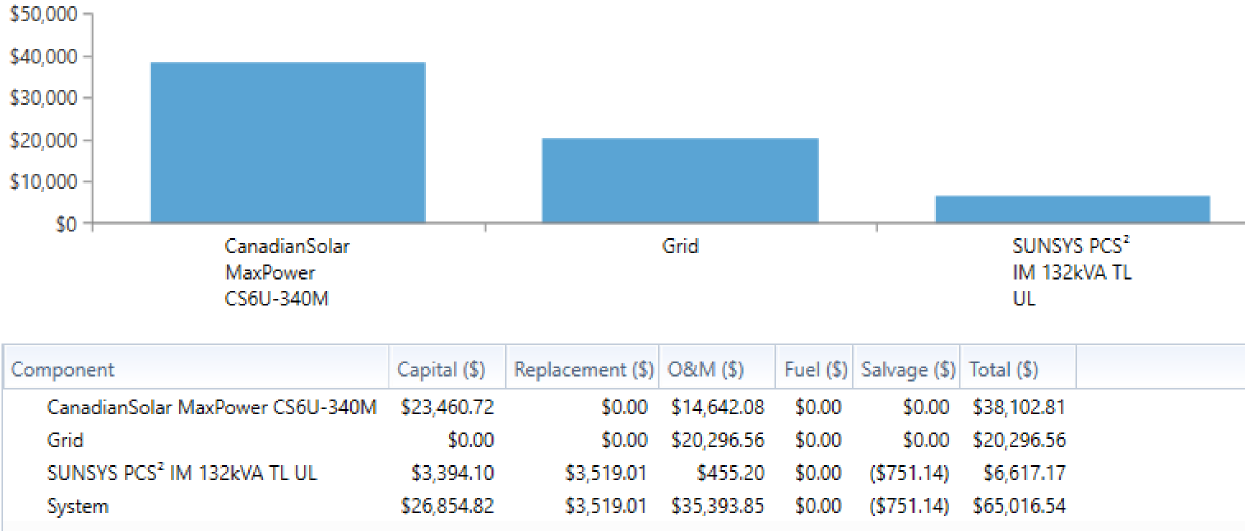


Figure 4:18 Monthly electric production of PV/Wind/Grid/Battery/Converter water treatment and supply system

4.3.4.2 Case 2: PV/Grid with Converter

This system is a combination of solar PV, converter connected with the public electricity grid. The PV is used to generate renewable energy and uses a convertor to convert the direct current into an alternating current. In case of no power, the system uses an electric supply from the grid.

The arrangement of this system shows that the total NPC, operating cost, and COE is $65016.54, $1855.71, and $0.04041 respectively. Figure 4.18 shows the general cost summary of the system.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
CanadianSolar MaxPower CS6U-340M	$23,460.72	$0.00	$14,642.08	$0.00	$0.00	$38,102.81
Grid	$0.00	$0.00	$20,296.56	$0.00	$0.00	$20,296.56
SUNSYS PCS² IM 132kVA TL UL	$3,394.10	$3,519.01	$455.20	$0.00	($751.14)	$6,617.17
System	$26,854.82	$3,519.01	$35,393.85	$0.00	($751.14)	$65,016.54

Figure 4:19 Cost summary of PV/Grid/Converter water treatment and supply system

The total cost of the PV component is $38101.81. The total cost used from the grid is $20,296.56 and the total cost of the converter is $6617.17. The total salvage value of the system is $751.14. The cash cost through the 25 years of the life cycle of the system is shown in Figure 4.20:

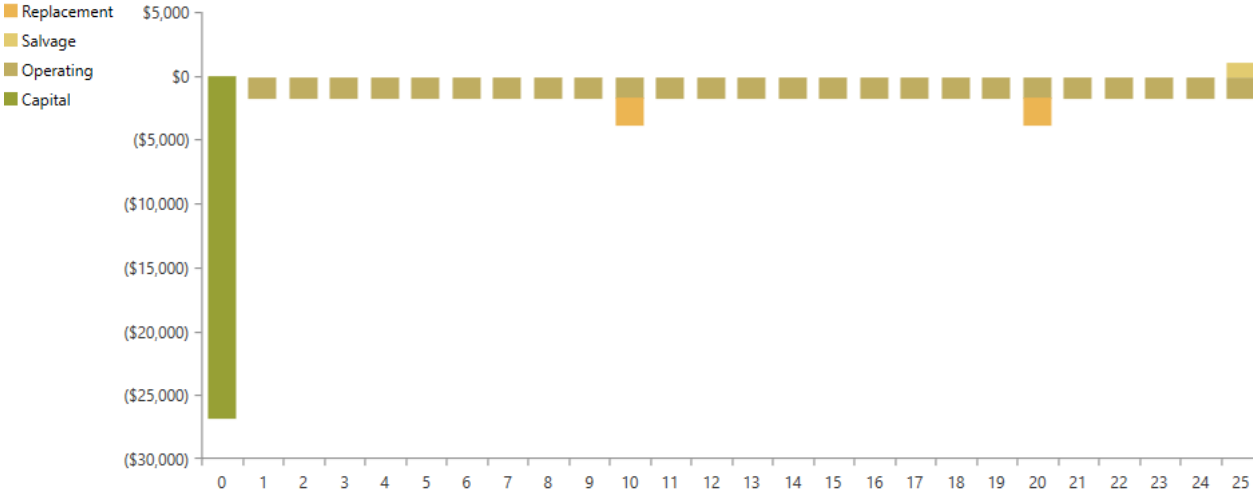


Figure 4:20 PV/Grid/Converter with converter cash flow

The electrical production of the system shows that the energy generated is from the solar PV and the grid. The percentage of the electric generated from PV is 51.0% which is 40524 kWh/yr and from the grid is 49.0% that is 38995 kWh/yr. In this system, a total of 21,228 kWh per year is purchased from the grid.

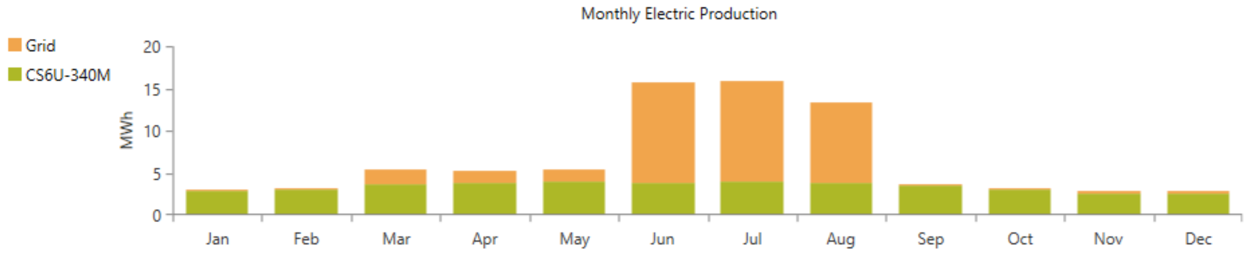
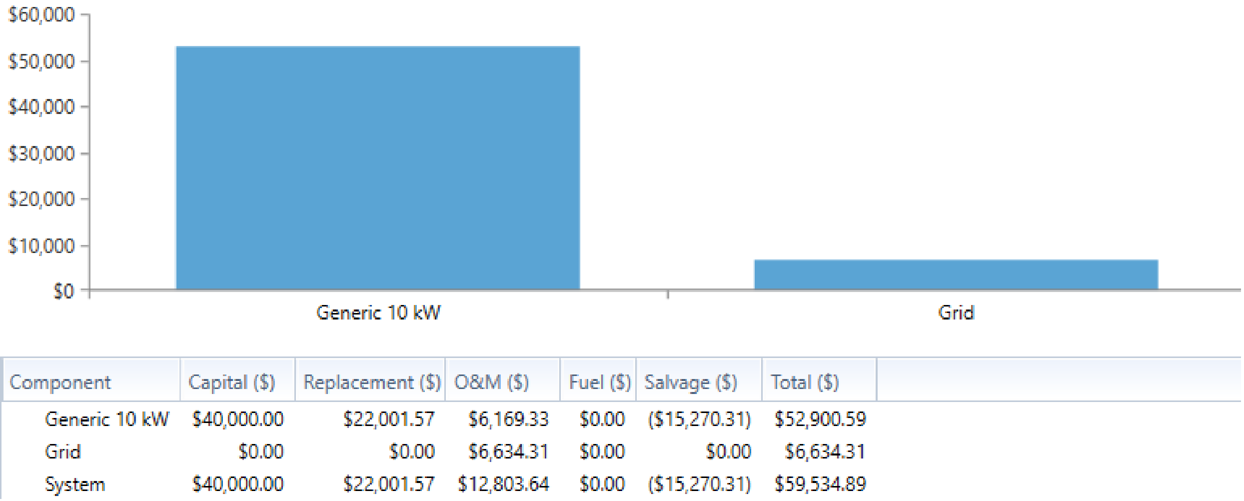


Figure 4:21 Monthly electric production of PV/Grid/Converter with converter water treatment and supply system

4.3.4.3 Case 3: Wind/Grid system

This type of configuration includes a wind turbine connected with a grid. The electric production of the system is from wind turbines and the grid. The total NPC of this system is $59534.89, COE is 0.02671$/kWh and the operating and maintenance cost of $949.94. The graphical and detailed cost summary of the system is shown in Figure 4.22.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 10 kW	$40,000.00	$22,001.57	$6,169.33	$0.00	($15,270.31)	$52,900.59
Grid	$0.00	$0.00	$6,634.31	$0.00	$0.00	$6,634.31
System	$40,000.00	$22,001.57	$12,803.64	$0.00	($15,270.31)	$59,534.89

Figure 4:22 Cost summary of Wind/Grid water treatment and supply system

Figure 4.23 shows that the cash flow of the wind/grid water treatment and supply system. As the graph shows that, the wind turbine has a capital cost of $40000, the replacement cost of $22,001.57, $6169.33 of operating and maintenance cost and $15,270.31 of salvage value. The total cost of the grid is $6634.31. The system's simple payback is 4.81 years.

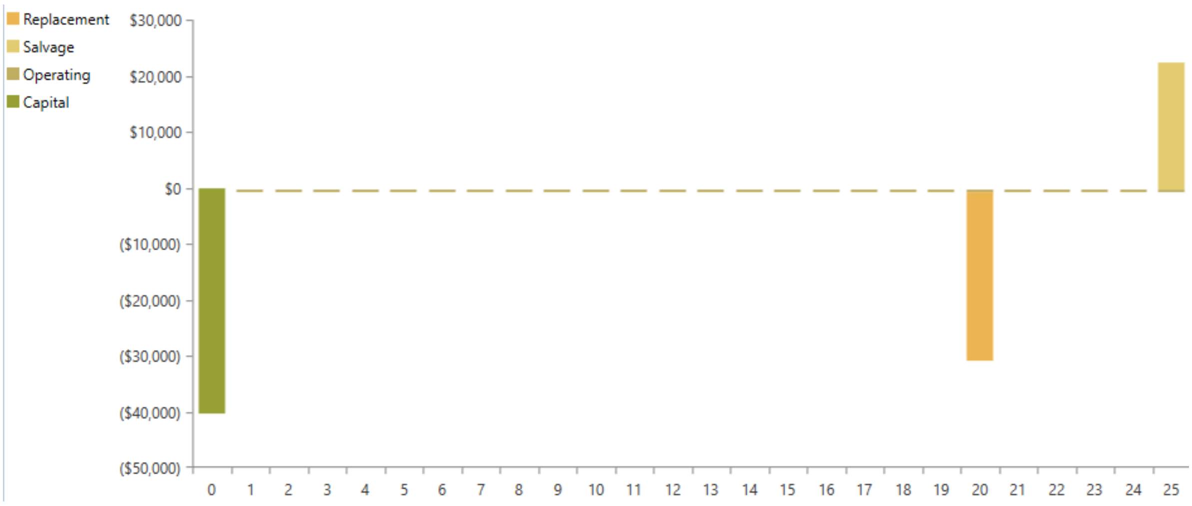


Figure 4:23 Cash flow of wind/grid water treatment and supply system

The electric production of the system is mostly from wind and the backup power from the grid. The figure is shown that the total monthly electricity production of the wind/grid configuration system.

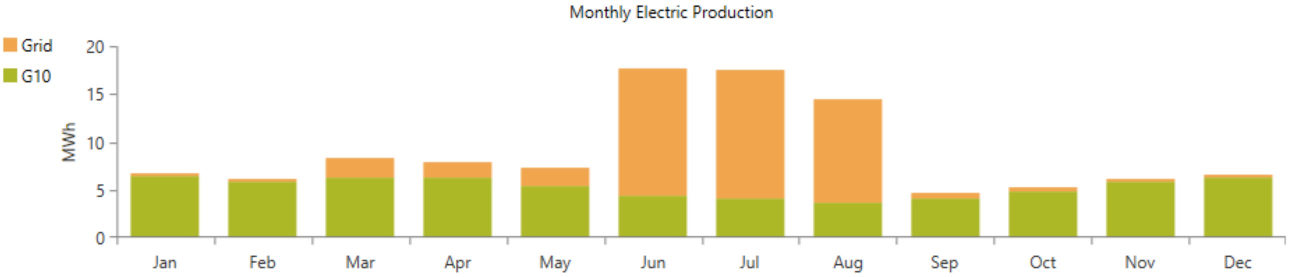


Figure 4:24 Monthly electric production of Wind/Grid water treatment and supply system

As shown in figure 4:24 58.3% (64236 kWh/yr) of the annual energy generated is from the wind turbine and 41.7 (45.16 kWh/yr) is from the grid.

4.3.4.4 Sensitivity analysis

This part deals with the sensitivity analysis of the on-grid configuration of the mini-grid design. Figure 4.25 below is arranged with the solar-scaled average value in the X-axis and wind speed scaled value in the Y-axis. The optimal system has three parts i.e., PV/Grid, Wind turbine/Grid system, and solar PV/Wind turbine/grid system

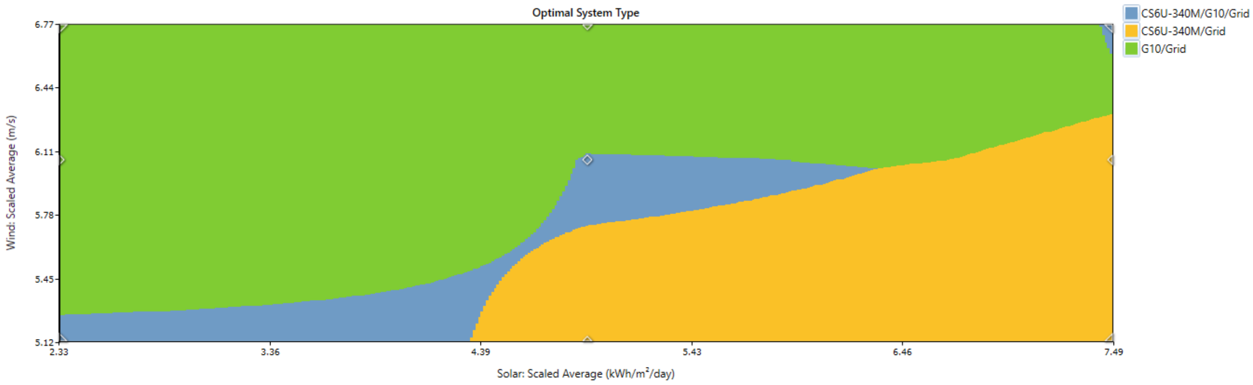


Figure 4:25 Sensitivity analysis of on-grid system

The optimal system of the on-grid system has three parts. The first part includes PV and grid together. This type of configuration is optimized from the wind scaled average value of 5.12 m/s and the solar scaled average value of 4.34 kWh/m^2/day up to the value of wind scaled average value of 5.51 m/s and the solar scaled average value of 4.56 kWh/m^2/day and wind scaled average value of 5.71 m/s and the solar scaled average value of 4.87 kWh/m^2/day and then continue with a straight line slop up to wind scaled average value of 6.31 m/s and the solar scaled average value of 7.49 kWh/m^2/day with the area closed at wind scaled average value of 5.12 m/s and the solar scaled average value of 7.49 kWh/m^2/day (yellow color area). The second option of optimal system is the wind turbine with the grid. This type of schematic is optimized from the wind scaled average value in m/s and the solar scaled average value in kWh/m^2/day of 2.33 and 5.26:, 3.36 and 5.26, 4.44, 5.52, 4.89 and 6.09, 6.33 and 6.01, and 7.49 and 6.31, 7.49 and 6.6, 7.44 and 6.77 respectively and the area closed point at wind scaled average value of 6.77 m/s and the solar scaled average value of 2.33 kWh/m^2/day (the green color area). The third configuration is solar PV/Wind turbine/grid system with is the remained part of the area (the blue color).

4.3.5 Hydrogen based off-grid system

Electrolysis is a system that can convert electricity to gaseous hydrogen and store it indefinitely, making it a "green" fuel source for satisfying any time-varying energy need. The inherent application flexibility of hydrogen encourages the development of distributed renewable-hydrogen energy systems that can be tailored to meet a specific demand requirement for fuel or electricity (Scamman et al. 2014).

4.3.5.1 Electrolyzer

An electrolyzer is an electrochemical device that uses the electrolysis process in which the process of dividing water into two parts is hydrogen and oxygen. There are different types of an electrolyzer and the alkaline electrolyzer is the most utilized and has low cost (Mubaarak et al. 2020). The energy used to process the electrolysis system is from the excess renewable energy (solar and wind) of the system. In this design of mini-grid for powering of rural community water treatment and supply, the electrolyzer capital cost is $1500, replacement cost is $1000, operational and maintenance cost is $20/year, l5 years life cycle and 85% of operating efficiency (Mubaarak et al. 2020).

4.3.5.2 Hydrogen tank

The hydrogen generated from the electrolyzer needs to be stored in a tank before it is used by the fuel cell. The tank capacity is estimated to be in the range of 0–1200 kg, and the hydrogen tank lifetime is estimated to be 25 years. In this design, the capital cost of the hydrogen tank is $1400/kg, the replacement cost is $867/kg and the operating and maintenance cost is $20/kg (Mubaarak et al. 2020).

4.3.5.3 Fuel cell

A hydrogen fuel cell is a type of electrochemical power system that is a combination of hydrogen and oxygen which able to produce electricity through a chemical reaction mechanism (Mubaarak et al. 2020). The fuel cell used in this study is stored hydrogen in the hydrogen tank. A 100-kW capacity of the fuel cell was used and the technical and economical characteristics of the fuel cell is 3000 $/kW capital cost, 2500 replacement cost, and 0.003000 $/hr of operating and maintenance cost. Also, the intercept coefficient of the fuel cell is considered 0.0003 kg/hr/kW with a curve's slop of 0.21 kg/hr/kW and the life cycle is 40000 hrs (Mubaarak et al. 2020).

4.3.5.4 Schematic of off-grid system with electrolyzer and fuel cell

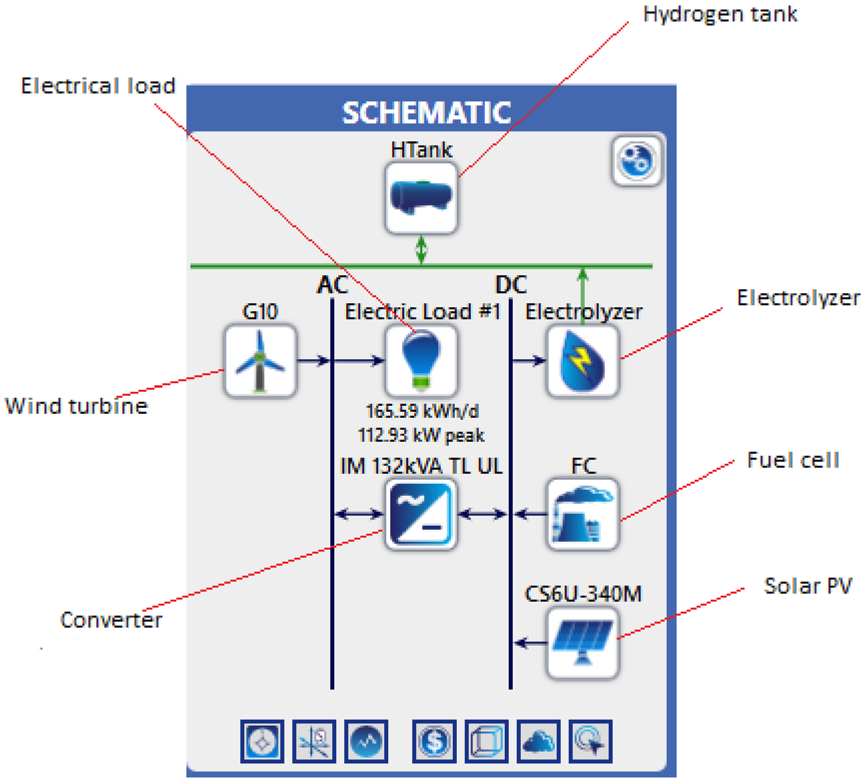
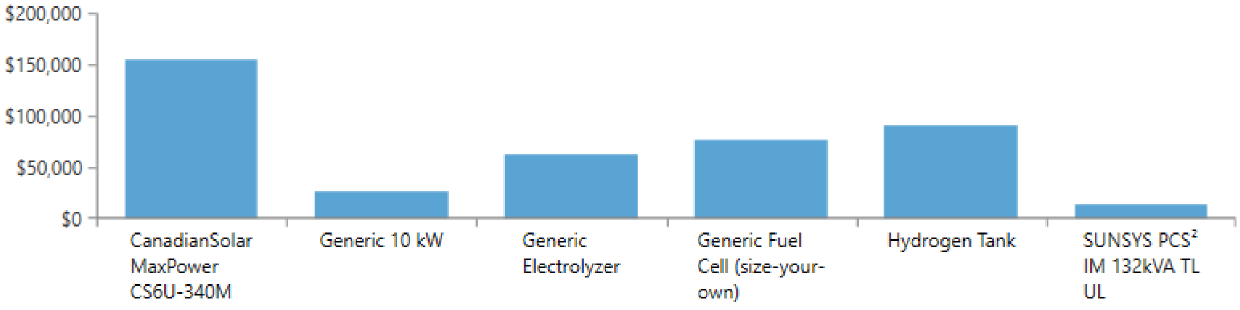


Figure 4:26 Schematic of off-grid system with electrolyzer and fuel cell

The given schematic design of off-grid with electrolyzer and fuel cell uses storage hydrogen that could replace battery storage and diesel generator. From the simulation the net present cost (NPC) of the system is $423037.6, operating cost of $5762.17 and the Levelized cost of energy (COE) is 0.3897 $/kWh. Figure 4.27 is the total cost of the system.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
CanadianSolar MaxPower CS6U-340M	$95,145.40	$0.00	$59,381.25	$0.00	$0.00	$154,526.65
Generic 10 kW	$20,000.00	$11,000.78	$3,084.67	$0.00	($7,635.16)	$26,450.29
Generic Electrolyzer	$37,500.00	$19,812.50	$10,282.22	$0.00	($5,655.67)	$61,939.05
Generic Fuel Cell (size-your-own)	$75,000.00	$0.00	$15,993.99	$0.00	($14,925.67)	$76,068.32
Hydrogen Tank	$70,000.00	$0.00	$20,564.44	$0.00	$0.00	$90,564.44
SUNSYS PCS² IM 132kVA TL UL	$6,896.49	$6,578.28	$1,418.23	$0.00	($1,404.15)	$13,488.84
System	$304,541.89	$37,391.56	$110,724.79	$0.00	($29,620.65)	$423,037.60

Figure 4:27 Cost summary of mini-grid with electrolyzer and fuel cell

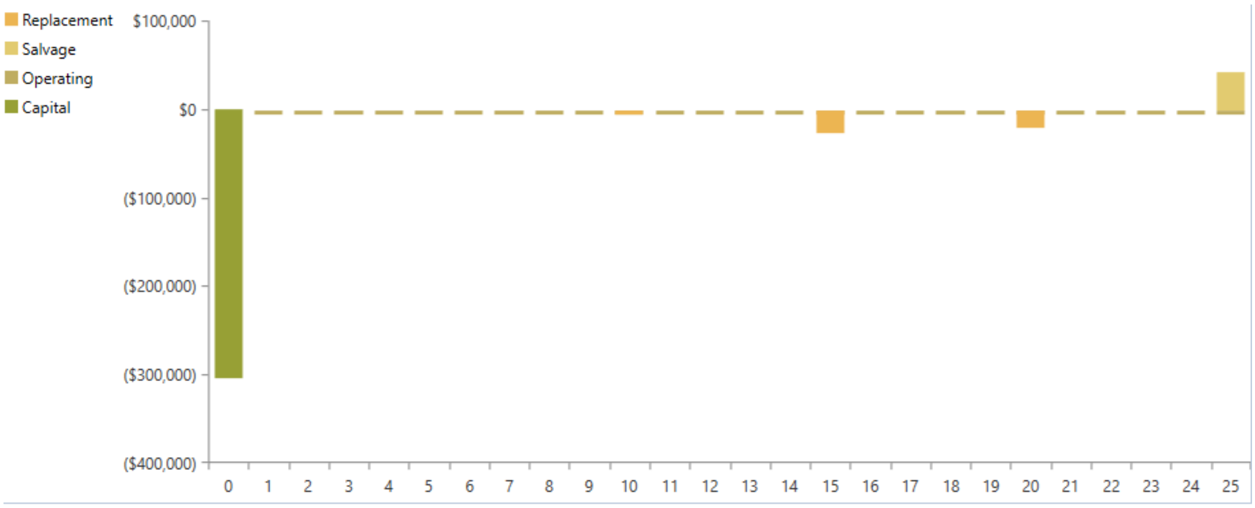


Figure 4:28 Cost cash flow mini-grid with electrolyzer and fuel cell

The electrical production of the system was from solar PV, wind and the fuel cell. From the total system, electric production 81.5% (164.349 kWh/yr) is from solar PV, 15.7% (31.618 kWh/ye) from wind turbine and 2.86% (5776 kWh/yr) is from electrolyzer and fuel cell.

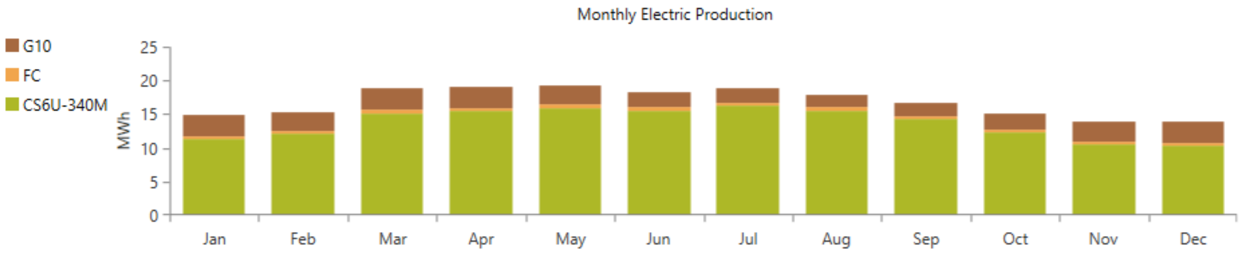


Figure 4:29 Monthly electric production of the mini-grid with electrolyzer and fuel cell

4.3.6 Result summary

The table below is the overall conclusion for all systems that have been discussed during the result and discussion section. This includes the value of operating, net present cost (NPC) and the Levelized cost of energy (COE) for all configuration systems of mini-grid for powering of water treatment and supply unit.

Table 4:3 Result summery

Type	No	Schematic	Operating ($)	NPC ($)	Levelized COE ($)
On - Grid	1	PV/Wind turbine/Grid//Converter	1476.5	58457.98	0.03276
	2	PV/Grid//Converter	1855.71	65016.54	0.04041

	3	Wind/Grid	949.94	59534.89	0.2671
Off - grid	1	PV/Wind/Generator/Battery/Converter	8610.9	363301.9	0.2952
	2	PV/Generator/Battery/Converter	8474.25	353016.5	0.2863
	3	PV/Wind/Battery/Converter	11717.22	489653	0.4056
Off - grid with electrolyzer and fuel cell	1	PV/Wind/Converter/Electrolyzer/Hydrogen tank/Fuel cell	5762.17	423037.6	0.3897

In general, three major configuration systems were analyzed i.e., standalone (off-grid) system, on-grid system, and hydrogen-based off-grid system. Among the whole configuration, the grid-connected system has the lowest cost as it has more revenue from electricity. From the grid-connected cases, the combination of wind turbine and grid has the best economically viable with an NPC value of $59534.89 and a Levelized cost of 0.2671$/kWh. So, it is the best solution for a site close to a central grid.

The stand-alone configuration analysis system has three cases. The three cases are PV/Wind turbine/Generator/Battery/Converter, PV/Generator/Battery/converter, and PV/Wind/Battery/Converter systems. From those cases, the combination of PV, generator, battery, and converter system is the most economically viable for remote areas that have an NPC Value of $353016.5 and Levelized COE 0.2863 $/kWh.

The hydrogen-based off-grid system has a high cost compared to other systems with an NPC value of $423037.6 and a Levelized COE value of 0.3897 $/kWh. But it has low cost than some of the off-grid cases such as the PV/Wind/Battery/Converter configuration system. This system does not emit any CO_2. So, it is more environmentally friendly and with the cost of hydrogen technology coming down fast, it is surely the best solution in the future.

CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The present work accompanied the design of a mini-grid for powering of water treatment and supply in Marqab Bin Hafaf village, Djelfa, Algeria. The design and sizing of a mini-grid for powering a safe water supply system for the rural community using HOMER software have been completed, and it is reliable, efficient, clean, and, most significantly, it is based on local resources. In order to find the optimal mini-grid configuration, many possibilities, including various renewable sources, are studied, as well as the comparative techno-economic of the mini-grid under various assumptions. The study had three scenarios with different cases: the first scenario is an on-grid system which has different parts such as PV/wind turbine/grid/battery/converter, PV/grid/battery/converter, and wind turbine/grid. The second scenario is an off-grid schematic that has PV/generator/wind turbine/batter/converter, PV/generator/battery/converter and PV/wind/battery/converter. The third scenario is an off-grid with an electrolyzer and fuel cell storage system (green technology). The economic analysis of the different cases was carried out using the net present cost (NPC) and Levelized cost of energy (COE) of the system. The following conclusions are from the result analysis of the different systems:

- ✓ The on-grid systems, specifically the PV, wind, grid, and converter combination, have the lowest Levelized cost of electricity (COE) of 0.02671 $/kWh and the lowest net present cost (NPC) of $ 59534.89.
- ✓ The NPC and COE values of off-grid systems are higher than those of on-grid systems. The combination of PV, wind turbine, generator, battery, and converter has the lowest COE of 0.4388 $/kWh and the lowest NPC of $526605.9 of the three off-grid systems.
- ✓ The hydrogen off-grid mini-grid system is a new technology which a green renewable energy system having electrolyzer with a fuel cell that uses stored hydrogen as a working mechanism. From the design and simulation, the technical economical result was given as NPC $423037.6 of and COE value 0.3897 $/kWh. Since this technology advanced with no emission, individuals, private sectors, investors, governmental and no governmental organization need to support in terms of technologies, finance, and policies to increase the access particularly in Africa.

In general, an on-grid system with the lowest COE value is the best and most cost-effective mini-grid design for powering rural community water treatment and supply units because excess electricity generated by the system is sold to the grid (resulting in more revenue from electricity), resulting in a system with no waste of renewable electricity produced by the system and it is the best solution for a site close to a central grid. Off-grid with generator backup power has the largest COE value as compared to grid-connected, and it comes with an emission penalty. Although the hydrogen-based off-grid solution is more expensive than others, it produces no CO2. As a result, it is more environmentally friendly, and with the cost of hydrogen technology falling rapidly, it is undoubtedly the greatest future solution.

5.2 Recommendation

With rapid population growth, the energy demand in Algeria and In Africa in general rapidly increasing from time to time. The electrification of Algeria mostly depends on fossil fuel which is a nonrenewable type of energy. Currently, the country is launching and planning to increase the development of renewable energy technologies such as solar, wind, and others. So, to achieve this goal and satisfy the sustainable development goal of accessing clean, reliable, and affordable energy targets and access safe water and sustainable supply of water, mini-grid design for the rural community is having great potential.

The mini-grid design can solve the electricity access and water access in rural areas and this needs more development. The following were recommendations for future works:

- ✓ Three scenarios were considered in this study (two scenarios having three different cases each and one scenario having one case). Even if it is possible to examine an efficient, cost-effective, with less environmental impact, etc. by considering a few scenarios, numerous configurations and scenarios can be adopted to investigate the most efficient, cost-competitive, dependable, and with less environmental effect. It is recommended to consider many and different scenarios and cases in order to identify the most cost-effective, reliable, efficient, and environmentally friendly option.
- ✓ In this design, SOLID WORK and HOMER software were used for the mechanical visualization, technical and economic analysis. Future woks could use additional software to increase the limitations exciting in that software.

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7 APPENDIX

7.1 Appendix A: Water demand of the village

Table 7:1 Water demand for household

	Activities	Description		Type of Activity	Number household	Average size of household in Algeria	Number Of people	Standard water demand in liters per person in a day	Total Water demand in liters per person or activity in a day	Total Water demand in m3 per person or activity in a day	Monthly water demand in m3 per person
1	People	This study is considering all the people who are living in the village. Visitors and other people who come to the village are not under consideration.	A	Drinking	230	5.23	1203	5	6014.5	6.0145	180.435
			B	Sanitation				20	24058	24.058	721.74
			C	Bathing				15	18043.5	18.0435	541.305
			D	cooking and kitchen				10	12029	12.029	360.87
Total							**1200**	**50**	**60145**	**60**	**1804.35**

Table 7:2 Water demand for animal farm

No	Activities	Number farm	Total number of animals per day	Standard water requirement in litter per animal in a day	Total Water demand in liters in a day	Total Water demand in m3 in a day	Monthly water demand in m3
1	Chicken production	6	1800	0.68	1224	1.224	36.72
1	Sheep	20	700	8.52	5964	5.964	178.92
Total			2500	9.2	7188	7.188	215.64

Table 7:3 Water demand for irrigation

No	Activities	Description	Part	Vegetable/fruits crop type	Size in hectare	Size in m2	Months of cultivating	Standard water requirement in m in a season	Total water requirement in m3 per season	Water demand in m3 per day	Cultivating season
1	Agriculture	The agriculture activities in Marqab used to produce potatoes, tomatoes, onions carrots, green papers, lettuce and corn.	A	Potatoes	5	50000	2	0.71	35500	591.6666667	Summer
			B	Onion	6	60000	3	**0.5**	30000	333.3333333	Summer
			B	Tomatoes	6	60000	3	0.336	20160	224	Summer
			C	Carrots	4.5	45000	2	0.441	19845	330.75	Summer
			D	Green pepper	4	40000	2	0.64	25600	426.6666667	Summer
			F	Lettuce	5	50000	3	0.3048	15240	254	spring and summer
			G	Corn	22	220000	3	0.762	167640	1862.666667	Summer
Total					52.5	525000	18	3.6938	313985	4023.083333	

Table 7:4 Water demand for school

No	Activity	Description		Number	Standard water requirement in liter per person per day	Total Standard water requirement in liter per person per day	Total Standard water requirement in m3 per person per day	Monthly water m3 demand	Annual water in m3 demand
1	School	The school is closed during summer	Students	200	30	6000	6	180	1620
			Teachers	8	30	240	0.24	7.2	64.8
2	Teacher housing	Residence for teachers		8	50	400	0.4	12	108
Total				**216**	**110**	**6640**	**6.64**	**199.2**	**1792.8**

Table 7:5 Water demand for clinic

No	Activity	Description		Number	Standard water requirement in liter per person per day	Total Standard water requirement in liter per bed per day	Total Standard water requirement in m3 per bed per day	Monthly water demand	Annual water demand
1	Clinic	A public service	Bed	9	350	3150	3.15	94.5	1134

Table 7:6 Seasonal water demand

Season	Month	Water demand in m3 per day						
		Drinking, bathing and sanitation water	Irrigation	Animal farm	School	Clinic	Total volume of water per day need treatment	Total volume of water per day no need of treatment
Spring	March	60.145	254.00	7.188	6.64	3.15	77.123	254.00
	April	60.145	254.00	7.188	6.64	3.15	77.123	254.00
	May	60.145	254.00	7.188	6.64	3.15	77.123	254.00
Summer	June	60.145	4023.08	7.188	0	3.15	70.483	4023.08
	July	60.145	4023.08	7.188	0	3.15	70.483	4023.08
	August	60.145	2674.00	7.188	0	3.15	70.483	2674.00
Autumn	September	60.145	0	7.188	6.64	3.15	77.123	0
	October	60.145	0	7.188	6.64	3.15	77.123	0
	November	60.145	0	7.188	6.64	3.15	77.123	0
Winter	December	60.145	0.00	7.188	6.64	3.15	77.123	0.00
	January	60.145	0.00	7.188	6.64	3.15	77.123	0.00
	February	60.145	0.00	7.188	6.64	3.15	77.123	0.00

7.2 Appendix B: Energy demand

Table 7:7 Energy demand for pumping water

		Water demand in m3 per day			Energy demand for Reverse osmosis (kWh/day)	Pump energy demand (Watt)			Pump energy demand (kWh/day)			Total Energy demand (kWh/day)
Season	Month	Water demand need treatment	Water demands no need of treatment	Total water demand		Sub. Pump 1	Sub. Pump 2	Pump 3	Pump 1	Pump 2	Sub. Pump	
Spring	March	77.123	254.00	331.12	154.246	16794.8	3492.36761	1699.8	403.1	83.8	40.8	681.9
	April	77.123	254.00	331.12	154.246	16794.8	3492.36761	1699.8	403.1	83.8	40.8	681.9
	May	77.123	254.00	331.12	154.246	16794.8	3492.36761	1699.8	403.1	83.8	40.8	681.9
summer	June	70.483	4023.08	4093.57	140.966	266011.6	3191.68791	1553.5	6384.3	76.6	37.3	6639.1
	July	70.483	4023.08	4093.57	140.966	266011.6	3191.68791	1553.5	6384.3	76.6	37.3	6639.1
	August	70.483	2674.00	2744.48	140.966	176808.4	3191.68791	1553.5	4243.4	76.6	37.3	4498.3
Autumn	September	77.123	0.00	77.12	154.246	0.0	3492.36761	1699.8	0.0	83.8	40.8	278.9
	October	77.123	0.00	77.12	154.246	0.0	3492.36761	1699.8	0.0	83.8	40.8	278.9
	November	77.123	0.00	77.12	154.246	0.0	3492.36761	1699.8	0.0	83.8	40.8	278.9
winter	December	77.123	0.00	77.12	154.246	0.0	3492.36761	1699.8	0.0	83.8	40.8	278.9
	January	77.123	0.00	77.12	154.246	0.0	3492.36761	1699.8	0.0	83.8	40.8	278.9
	February	77.123	0.00	77.12	154.246	0.0	3492.36761	1699.8	0.0	83.8	40.8	278.9

Table 7:8 Energy demand for electronics and light

Number	Device	Quantity	Power capacity rate (watt)	Total power capacity (watt)	Power (kWh/day)
1	Dell XPS 8920 computer desktop	3	250	750	18
2	fluorescent T12	6	43	258	6.192
3	Wind fault detection sensor	1	8	8	0.192
4	PV fault detection sensor	1	8	8	0.192
7	Water treatment sensor	1	8	8	0.192
8	Pressure regulator sensor	3	8	24	0.576
				1056	25.344

Table 7:9 Hourly arranged energy demand for spring season

Season	Activities	Energy demand (kw)		Energy needs in a given time interval																					
				AM											PM										
			0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16	16 to 17	17 to 18	18 to 19	19 to 20	20 to 21	21 to 22	22 to 23
Spring	Sub. Pump 1	250													250										
	Sub. Pump 2	3.5										3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5						
	Pump 3	1.7										1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7						
	Reverse osmosis	19.2										19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2						
	Electronics	1.056	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	1.056	1.056	1.056	1.056	1.056	1.056	1.056	1.056	0.258	0.258	0.258	0.258	0.258	0.258
	Total		0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	25.5	25.5	25.5	275.5	25.5	25.5	25.5	25.5	0.258	0.258	0.258	0.258	0.258	0.258

Table 7:10 Hourly arranged energy demand for summer season

Season	Activitrties	Energy demand (kw)		Energy needs in a given time interval																						
				AM												PM										
			0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16	16 to 17	17 to 18	18 to 19	19 to 20	20 to 21	21 to 22	22 to 23
Summer	Sub. Pump 1	250										250.0	250.0	250.0	250.0	250.0	250.0	250.0	250.0	250.0					
	Sub. Pump 2	3.5										3.5	3.5	3.5	3.5	3.5	3.5	3.5							
	Pump 3	1.7										1.7	1.7	1.7	1.7	1.7	1.7	1.7		0.0	0				
	Reverse osmosis	19.2										19.2	19.2	19.2	19.2	19.2	19.2	19.2							
	Electronics	1.056										1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1					
	Total		0	0	0	0	0	0	0	0	0	275.5	275.5	275.5	275.5	275.5	275.5	275.5	251.1	251.1	0	0	0	0	0
										0	0	25.5	275.5	275.5	275.5	275.5	275.5	275.5		August load					

Table 7:11 Hourly arranged energy demand for Autumn season

				Energy needs in a given time interval																						
				AM											PM										
Season	Activities	Energy demand (kw)	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16	16 to 17	17 to 18	18 to 19	19 to 20	20 to 21	21 to 22	22 to 23
Autumn	Sub. Pump 1	250																							
	Sub. Pump 2	3.5										3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5						
	Pump 3	1.7										1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7						
	Reverse osmosis	19.2										19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2						
	Electronics	1.056	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	1.056	1.056	1.056	1.056	1.056	1.056	1.056	1.056	0.258	0.258	0.258	0.258	0.258	0.258
	Total		0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	0.258	0.258	0.258	0.258	0.258	0.258

Table 7:12 Hourly arranged energy demand for winter season

Season	Activities	Energy demand (kw)		Energy needs in a given time interval in kw																					
				AM											PM										
			0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16	16 to 17	17 to 18	18 to 19	19 to 20	20 to 21	21 to 22	22 to 23
Winter	Sub. Pump 1	250																							
	Sub. Pump 2	3.5										3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5						
	Pump 3	1.7										1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7						
	Reverse osmosis	19.2										19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2						
	Electronics	1.056	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	1.056	1.056	1.056	1.056	1.056	1.056	1.056	1.056	0.258	0.258	0.258	0.258	0.258	0.258
	Total		0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	0.258	0.258	0.258	0.258	0.258	0.258