The Use of Renewable Energy Technologies in the Libyan Energy System
Case Study: Brak City Region

vorgelegt von

M.Sc.

Giuma Ahmuda Sayah

geb. in Brak, Libyen

Von der Fakultät VI – Planen Bauen Umwelt
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Vorsitzender:	Prof. Dr. rer. pol. Kristin Wellner
Gutachter:	Prof. Dipl.-Ing. Rainer Mertes
Gutachter:	Prof. Dr.-Ing. Dieter Bunte

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Abstract

International organizations as well as nations worldwide are seeking to use renewable energy technologies in their energy generation mix in order to decrease dependence on fossil fuels and to promote climate protection. This study elaborates the problems facing Libya's energy system, and determines the potential for implementing renewable energy technologies to solve these problems.

Libya is dependent on oil and gas as primary energy sources for electricity generation. Governmental and corporate consideration of transitioning to renewable energy technologies, as well as consideration of carbon dioxide emissions from this sector, has so far been low. The development policy of the Libyan government does not meet the development requirements as well as climate protection, where confined in develop energy sector by installed power plants depend on fossil fuel as energy source. The current installed capacity is insufficient to meet Libyan society's demands, where the electricity outages are frequent in hours and in days in some country regions.

Libya has considerable potential for feasibly and viably implementing renewable energy technologies - especially solar and wind energy technologies. This may be concluded from the case study of the Brak City region, which focuses on a hybrid renewable energy system design. It determines the advantages of using these technologies, and their contributions to sustainably solving the problems facing the Libyan energy system. The scenarios analyzed in the case study show the cost of energy using renewable energy technologies is lower overall than the current cost.

From results of this study can be concluded that the implementation of the renewable energy technologies play an active role in filling the shortage gab in electricity production as well as that they meet the development needs of Libyan society. Renewable energy technologies can enable Libya's economic, social, and environmental development. At the global level, Libya has the potential to contribute with them to climate protection.

Zusammenfassung

Internationale Organisationen sowie Nationen streben weltweit nach Technologien zur Energieerzeugung mit erneuerbaren Energien. Auf diese Weise soll die Abhängigkeit von fossilen Brennstoffen verringert und der Klimaschutz gefördert werden. Diese Studie stellt die Probleme des libyschen Energiesystems dar und bestimmt, als Beitrag zur Problemlösung das Potenzial der Einführung von erneuerbaren Energietechnologien.

Libyen Stromerzeugung ist abhängig von dem Primären Energieträgen Öl und Gas. Überlegungen von Seiten der Regierung und von Unternehmen in Bezug auf die Einführung von erneuerbaren Energietechnologien, ebenso wie Überlegungen zu den Reduzierungen von Emissionen von Kohlendioxid in diesem Sektor, waren bisher gering. Die Entwicklungspolitik der libyschen Regierung erfüllt nicht die Anforderungen des Klima Schutzes. Die derzeit installierte Leistungsfähigkeit reicht nicht aus, um den gesellschaftlichen Anforderungen der lybischen Gesellschaft gerecht zu werden - Stromausfälle sind häufig in Stunden und in Tagen in einigen Regionen des Landes.

Libyen hat ein erhebliches Potenzial für realisierbare und mit vertretbarem Aufwand realisierbare Technologien für erneuerbare Energien - vor allem Solar- und Windenergietechnologien. Dies kann aus der Fallstudie des Brak City-Region geschlossen werden, die ein hybrid-erneuerbares Energie-System-Design konzipiert. Dieses bestimmt die Vorteile der Nutzung dieser Technologien, und ihre Beiträge zur nachhaltigen Lösung der Probleme die im libyschen Energiesystem bestehen. Die Szenarien, die in der Fallstudie analysiert werden, zeigen, dass die Kosten für Energietechnologien mit erneuerbaren Energien niedriger sind als die aktuellen Kosten.

Aus den Ergebnissen dieser Studie ergab, dass die Umsetzung der Technologien für erneuerbare Energien können zur Füllen der Mangel Gab bei der Stromerzeugung eine aktive Rolle führen werden sowie die Entwicklungsbedürfnisse der libysch Gesellschaft gerecht werden. Erneuerbare Energietechnologien können Libyens wirtschaftliche, soziale und ökologische Entwicklung ermöglichen. Auf globaler Ebene hat Libyen das Potenzial mit ihnen zum Klimaschutz beizutragen.

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List of Abbreviations

AC	Alternating Current
A-Si	Amorphous Silicon
Apr	April
Aug	August
CdTe	Cadmium Telluride
CO2	Carbon Dioxide
CSP	Concentrating Solar Power
CIGS	Copper Indium Gallium Selenide
COE	Cost of Energy
CC	Cycle Charging
D map	Data Map
Dec	December
°C	Degree Celsius
DG	Diesel Generator
DC	Direct Current
EPRI	Electric Power Research Institute
EGS	Enhanced Geothermal Systems
Feb	February
GECOL	General Electricity Company of Libya
GNC	General National Congress
GNP	General of the National Parliament
GPC	General People Congress
GHPs	Geothermal heat pumps
GHI	Global Horizontal Irradiation
GDP	Gross Domestic Product
HVDC	High Voltage Direct Current
HAWTs	Horizontal Axis Wind Turbines
HES	Hybrid Energy System
HOMER	Hybrid Optimization of Multiple Energy Resources
HRES	Hybrid Renewable Energy System
IEA	International Energy Agency
IMF	International Monetary Fund
IRENA	International Renewable Energy Agency
Jan	January
Jul	July
Jun	June
Km	Kilometer
kW	Kilowatt

kWh	Kilowatt-hour
$kWh/m^2/d$	Kilowatt-hour per Square Meter per Day
kWh/yr	Kilowatt-hour per Year
kWm	Kilowatt-meter
kWp	Kilowatt-peak
LCOE	Levelized Cost of Energy
Lisco	Libyan Iron and Steel Company
LF	Load Following
MMRP	Man-Made River Project
Mar	March
May	May
MW	Megawatt
MWh	Megawatt-hour
MWh/d	Megawatt-hour per Day
MENA	Middle East and North Africa
Mon.	Monthly
NASA	National Aeronautics and Space Administration
NPC	Net Present Cost
Nov	November
Oct	October
O&M	Operation and Maintenance
OST	Optimal System Type
PV	Photovoltaic
RE	Renewable Energy
REAOL	Renewable Energy Authority of Libya
REN21	Renewable Energy Policy Network for the 21^{st} Century
RET	Renewable Energy Technology
Sep	September
Solargis	Solar Geographical Information System
SWH	Solar Water Heating
Km^2	Square kilometer
TWh/yr	Terawatt-hour per year
UNEP	United Nations Environment Programme
$ or USD	United State Dollar
$/kWh	United State Dollar per Kilowatt-hour
$/L	United State Dollar per Liter
VAWTs	Vertical Axis Wind Turbines
WB	World Bank
WDI	World Development Indicator

1. Introduction

1.1. Problem Statement

Currently and also in the near future the most pressing environmental issue is climate change and global warming. Nations react on this with increasing of use of renewable energy (RE) sources to reduce conventional electricity generation. Michaelides argues that, “The most pressing environmental issue of the early twenty-first century is the accumulation of carbon dioxide (CO2) and the expected global warming. Global warming has becomes an urgent political issue in many countries” (2012, p.35). Libya is dependent on carbon primary energy for electricity generation. There is no official political or corporate support for using indigenous RE sources in its energy system (General Electricity Company of Libya (GECOL), 2012, p.4)[1]. The environmental consequence of conventional energy production in Libya is high CO2 emissions. In 2008 62.1% of total fuel combustion is used for energy production (World Bank (WB), 2012, p.179)[2]. In consequence huge budget spending can be noticed to decrease such emissions and upgrade electricity supply system with higher-efficiency technologies, while the up to day development does not meet society requirements as well as climate protection requirements. Than even nowadays new installed capacities for electricity generation fuelled by petroleum derivatives [3]. Additionally, must be mentioned the subsidies with which the Libyan government minimizes the cost of electricity tariff for their citizens. Round about 1% of the Gross Domestic Product (GDP) meaning 0.9 billions of United States Dollar (USD) is spend to subsidy the electricity price (International Monetary Fund (IMF), 2013, p.2)[4].

International organizations and nation states worldwide are supporting transitions from fossil fuel energy to RE sources. Many countries have developed policies promoting renewable energy technology (RET) to decrease emissions, and raising energy system

[1] This is the recent research issued by GECOL in this area represented in Statistics Report 2012, electricity production technology and fuel type.
[2] WB publications, World Development Indicators (WDI) 2012, environment: Carbon dioxide emissions by sector, p.179
[3] GECOL, Annual Reports 2012, 2010 and 2009, electricity production technology, p.4, p.13 and p.10 respectively (reports of 2010 and 2009 are in Arabic version).
[4] International Monetary Fund, Libya selected issues country report 13/151, May 2013, p.2

efficiency. The Renewable Energy Policy Network for the 21st Century (REN21) concluded that, "Since 2004, the number of countries promoting renewable energy with direct policy support has nearly tripled, from 48 to over 140, and an ever-increasing number of developing and emerging countries are setting renewable energy targets and enacting support policies. Policy targets have become increasingly ambitious, and their focus is expanding beyond electricity to include heating, cooling, and transport" (2014, p.6).

Beside this global aspect Libya is fighting with home made problems. Even the installed electricity capacity is growing in Libya still the supply is behind demand. Libya is experiencing with unscheduled and scheduled power outages. Outages are most common in peak demand periods in summer, when demand for electric cooling is highest. This situation became critical after the Libyan revolution in 2011, during which energy infrastructure, including power plants and transmission lines, were damaged and destroyed[5]. Representative international media coverage describes the current situation of electricity supply in Libya as follows[6]:

"In the past few days the capital Tripoli has had power cuts lasting up to 15 hours a day and in Benghazi in the east as much as 20 hours. Libyan Iron and Steel Company (Lisco), which has struggled with electricity shortages for two years, is one of the only foreign currency earners outside the oil and gas industry" (Routes, 2015)[7]

"Libya plans to import electricity from neighboring Egypt and Tunisia and to rent power generators to avoid power outages" (Enerdata, 2015)[8]

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[5] The revolution was from February 2011 to October 2011.
[6] In order to give evidence and argumentation to support the rationales behind conducting this study, international press reports have been used due to lack of other literature.
[7] Reuters Africa news: UPDATE 2-Power shortages shut production at Libya's biggest steel firm, Routes, report by Ahmed Elumami, August 4, 2015, available at: http://af.reuters.com/article/libyaNews/idAFL5N10F45Z20150804 [Accessed: 15th October 2015]
[8] Recent energy news Enerdata inelegance &consulting 10 August 2015 - Libya will import electricity from Egypt and Tunisia to avoid shortage http://www.enerdata.net/enerdatauk/press-and-publication/energy-news-001/libya-will-import-electricty-egypt-and-tunisia-avoid-shortage_33701. html [Accessed: 15th October 2015].

“Engineers and technicians from General Electric Company of Libya (GECOL) have been fighting a losing battle to maintain power supply throughout the country during the summer peak. With almost no budget for operations and maintenance, a massive deficit in generation capacity, and frequent grid failures caused both by accident and sabotage, large-scale outages have become a daily occurrence. According to one Tripoli resident "If there are just ten hours of power cuts, we are happy. Some days it is worse. Everyone who can get one has bought a generator” (African Energy, 2015)[9]

A further major problem is that Libya is facing desertification and lack of freshwater resources. For this reason, the Libyan government has prioritised planning to construct desalination plants, especially in the coastal cities where demand is highest. Priority has also been given to a large water development project, named Man-Made River Project (MMRP), which transports freshwater from the Sahara Desert to these coastal cities (TinMore Institute, 2012, p.5)[10]. This also increased electricity demand. Moreover, the population is growing, new development projects including houses, building complexes, industries and agricultural projects which are currently undertaken make the need to increase the energy production capacity as a priority for development.

In general can be concluded that Libya is facing many problems with its electricity production and supply system in both levels national and global. The national problems are represented in not meeting the energy demand of the society, harm is given the environment due to conventional electricity generating and there is no sharing to RET. Shortage and outage of the electricity hinders the economic progress. Regarding the global level, Libya has to stand with other communities to fight against global warming and climate change to reduce emissions resulting from power generation and the development of the energy sector towards sustainable development.

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[9] African Energy, Libya – archive news issue 306, 6 August, 2015 http://www.africa-energy.com/libya?type=articles accessed date [16th October 2015]

[10] Water security and interconnected challenges in Libya, TinMore institute research report WS121027, November 2012, p. 5-9.

Accordingly, this thesis is focused on utilising the advantages that RET can deliver for the Libyan energy supply system, and on overcoming the problems facing the energy sector on the national and global levels. This is tied to achieve with the case study method for designing a hybrid renewable energy system (HRES) in Brak City, and by applying the results of this case study to other regions of Libya. The solutions gained from this study can enable Libya to overcome its electricity capacity shortage, and to optimize the energy supply system in Libya through sustainable use of RET. The expected effects of the use of RET as well as the causes and effects of the main problem are shown in Figure 1.1. This Figure represents the research problem analysis and the target to be achieved in the study as a solution to the problem.

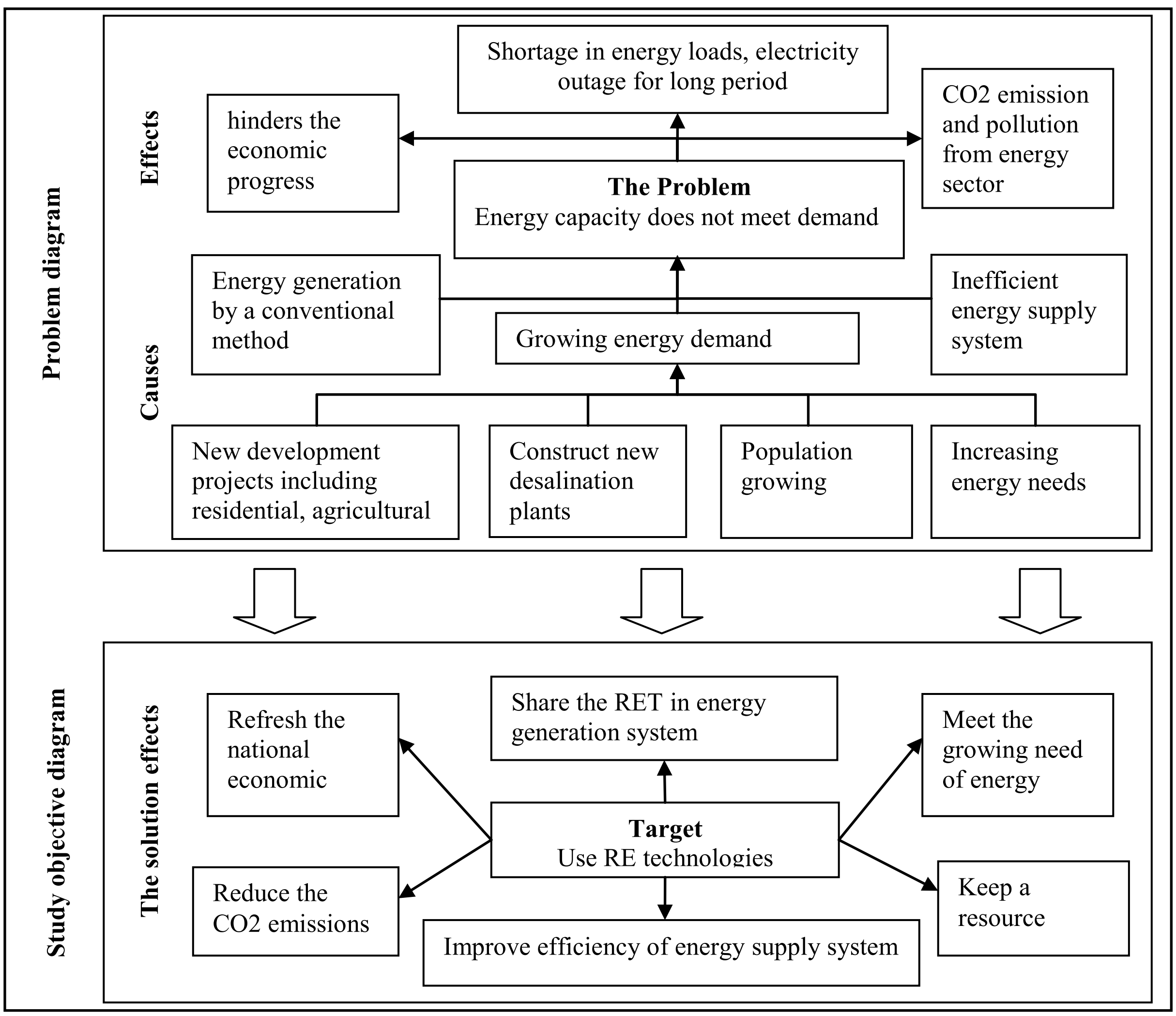

Figure 1.1: Research problem analysis and objective to be achieved (Source: author)

1.2. Research Objectives

Main research focuses is given to design a HRES for energy supply in order to overcome the obstacles facing the current energy system in Libya. It determines the advantages and potential of using RE technologies in this field.

Further aims and tasks covered in the study are:

- Assessing the existing energy supply system (Presented in chapter 2)
- Describing Libyan government policy for use and development of RET (Presented in chapter 2)
- Identifying the challenges and opportunities (Presented in chapter 2)
- Determining the potential of RE technologies in Libya (Presented in chapter 3)
- Determining the viability of RE technologies in the Libyan energy system (Presented in chapter 6)
- What is the outlook in Libya related to use of these technologies at both national and global level? (Presented in chapter 7)
- Which RE technologies are most optimal to implement in Libya districts? (Presented in chapter 7)

1.3. Thesis Structure

The thesis comprises eight chapters, each covering a defined area related to the main subject of research. The ***first chapter*** introduces the research, including discussion of the main objective of the study, the problem analysis methodology in order to specify the causes and effects of the problem, as well as the research methodology and work strategy procedure. The limitations of the study are within this chapter. Literature reviews of the research start in ***chapter two***, which includes a country overview and study of the current situation of the energy system in Libya and the existing energy operating model. Additionally, the present use of RE technologies and their contribution in energy generating as well as challenges and opportunities for development of the energy sector in Libya are described.

In ***chapter three*** the potential of RET in Libya is presented in order to assess their feasibility and viability. In this context, an overview is presented the RE resources and technologies. The resources and technology for each type of RET have been covered separately with its potential for Libya.

The practical part of the thesis constitutes chapters four, five, and six. The form used is a case study of electricity supply using HRES in the Brak City region focusing on implementation of scenarios to use solar and wind energy technologies in the system design. ***Chapter four*** includes assessment of the case study region, selection of the project site, description of the energy demand of the selected region (i.e. Brak City region) and determining primary electricity loads required in the system design. ***Chapter five*** presents Brak City HRES model inputs in order to build and configure the required energy system, which includes specifying the basic system components, system parameters, energy resources used in the system as well as specifying the cost assumed for system components and input parameter.

The results analysis and discussion of the case study are presented in ***chapter six,*** which includes key findings of the scenarios. Each scenario is analysed separately, but have the same methodology in order to ensure comparability.

With ***Chapter seven*** is given an outlook for the energy supply system focusing on prospects for implementing RE technologies in Libya. Moreover, the outlook for implementing solar and wind energy in the other regions of Libya based on the key findings of the study on the Brak City region is presented in this chapter. ***Chapter eight*** is the conclusion of this thesis.

1.4. Research Methodology and Workflow Strategy

For solving the research problem and its statements (section 1.1), the case study method has been selected as the practical research method. Yin describes that if research questions focus on "how" and "why" it is preferred to use the case study as a research method since “"how" and "why" questions are more explanatory and likely to lead to the use of case studies, histories, and experiments as the preferred research methods” (2009, p.9). Denscombe provides further perspective on when to use the case study approach as a research method as “the case study approach works best when the researcher wants to investigate an issue in depth and provide an explanation that can cope with the complexity and subtlety of real life situations” (Denscombe, 2007 p.38).

In accordance with the case study concepts described by Yin and Denscombe, the research questions and problem addressed within focus on the "how" and the "why"; and the research deal with real-life problem facing Libyan currently installed energy capacity, which does not meet present and future development demands of Libyan society. The workflow and the research strategy is illustrated in Figure 1.2, showing the research outlines, arrangement and sequence of the literature review and practical part as well as the working strategy in order to achieve the objectives of the thesis.

Specifically, the case study is designed and conducted here in several scenarios in order to investigate the problem in depth. The scenarios therefore targeting the same objective and dealing with the same tasks, but differing in the type of the RE technology used in the design. For example where in the first scenario the solar energy technology has been used, and the wind energy technology in the second scenario, both solar and wind energy technologies have been used in the third scenario (see, the case study protocol and the scenario, concept details in paragraph 5.1.3, as well as the illustration in Figure 5.1). Each scenario is designed individually and conducted commensurate with the respective RE technology. Each scenario has results analysis, discussion, and conclusion presented individually.

To achieve the case study target, as well as the main objective of this thesis, simulation software has been used in the design of Brak City HRES, and to configure the energy systems in each scenario. The software concept and reasons behind selecting this simulation tool in preference to other tools is discussed and presented in chapter 4. In conclusion, comparison of the scenario results and key findings gained from this study leads to determining feasible and viable solutions which can implemented to solving the problem and to overcome the obstacles and challenges currently facing Libya's energy system.

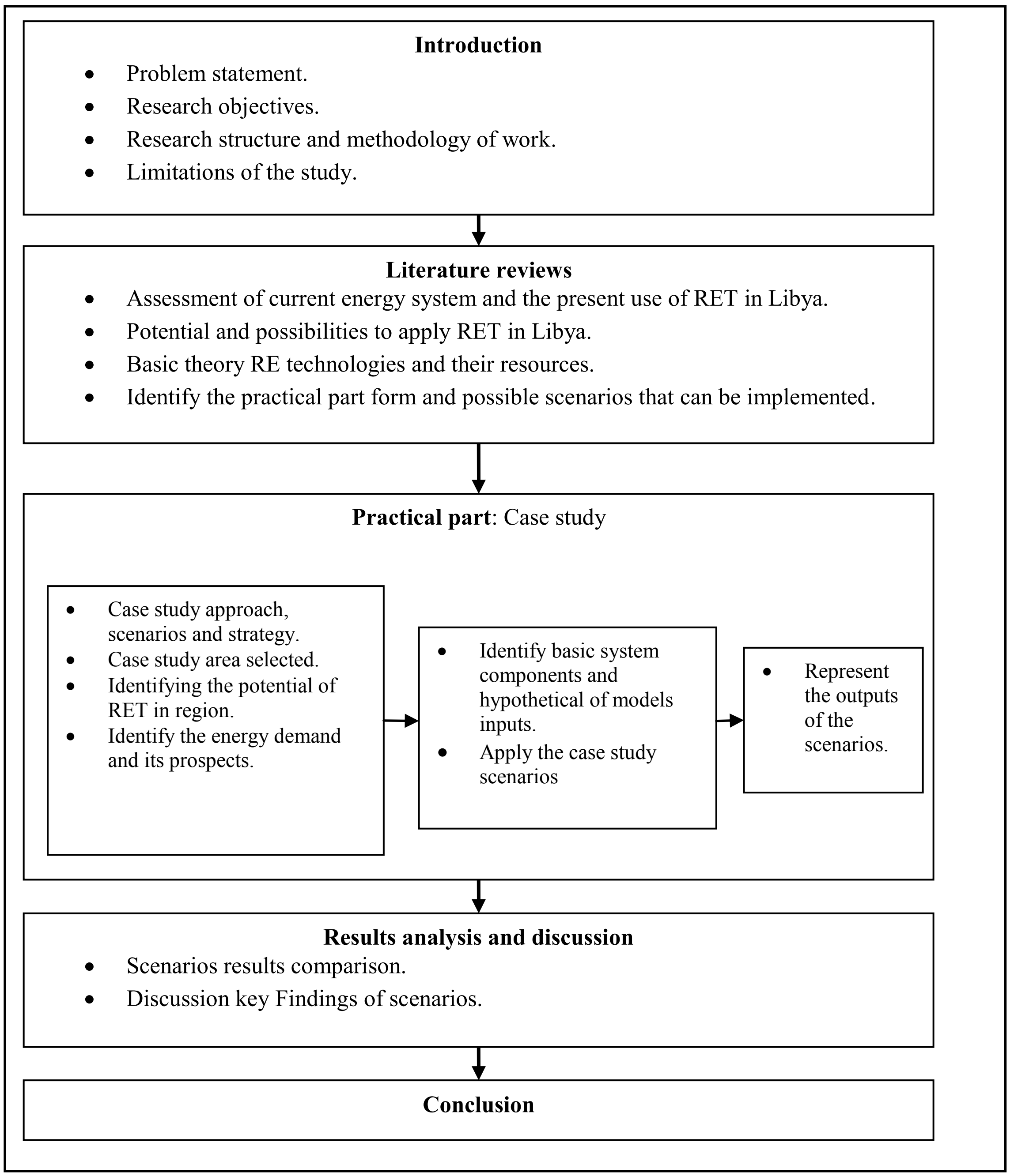

Figure 1.2: Research methodology and workflow strategy framework (Source: author)

1.5. Limitations of the Study

This study is specifically limited in scope to RE technologies application that can be feasibly implemented in Libya's energy supply system, which may meet the Libyan society's demands, and may sustainably develop this sector. Therefore, the research scope is limited as follows:

- Electricity supply, resources and generations technology in energy system of Libya.
- Potential of RE resources and technologies in Libya.
- The case study is limited in design of HRES in selected area (Brak City region).
- The case study scenarios are limited to use of solar and wind energy technologies in order to design the HRES in Bark City region.
- The HRES is designed to satisfy a minimum energy demand in Brak City only.
- The energy demand is identified in prospect of HRES project started in 2017, where the energy load designed with consideration of growth rate of both population and energy consumption in Brak City region only.
- The basic theory of the simulation tool that has been used in the design and the knowledge related to this tool (i.e. software tool).

2. Present Status of Energy Sector in Libya

2.1. Libya - Country Overview

2.1.1. General Overview

Libya or "State of Libya", as it is officially named[11], is located in North Africa and bordered by the Mediterranean Sea from the north, Chad and Niger to the south, Egypt and Sudan to the east, and Tunisia and Algeria to the west, as shown in Figure 2.1, representing the geographical location of the country. Libya covers an area of 1,759,540 square kilometers (km^2) and is the fourth largest country in Africa by area; additionally, it has 1,770 km of coastline along the Mediterranean Sea (Library of Congress, Federal Research Division, 2005, p.4).

The capital of Libya is Tripoli, which is the largest city and most important commercial and industrial center in Libya. The population of Libya is 6.3 million where most of populous live in cities along the Mediterranean coastal areas. Tribal character and culture drowns out the influence of the other demographics in most of the cities and regions of Libya; some cities are known for certain tribes because these tribes have inhabited these areas for a long time.

The climate in Libya is dry with most regions of the country being desert, especially in the south of Libya where the temperature can reach more than 45 degree Celsius (°C) in the summer season. In the coastal areas, the climate is characteristic of a Mediterranean climate, like many other countries located on the Mediterranean Sea. The terrain in Libya is mostly desert with plains and hills, and mountain chains crossing the county from east to west. The green mountain chain is in the eastern part of the country, and the other mountain chain which is known as the western mountain area is in the western part; in the central and southern regions the landform is almost flat.

[11] The current official name of Libya named by the General National Congress (GNC) in January 2013.

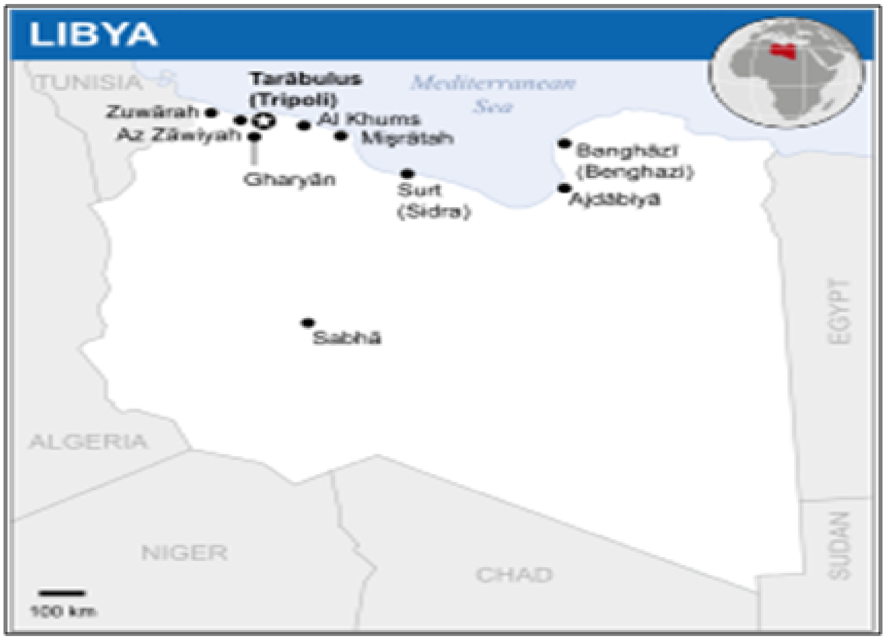

Figure 2.1: Geographical location of Libya (Source: Wikipedia)[12]

Libya's economy is dependent mainly on oil and natural gas reserves, which contribute to 95% of export earnings and 70% of GDP (African Economic Outlook, 2012, p.4). Furthermore, on a global scale, the Libyan economy is classified by WB as an upper middle income economy. The small population and the strength of petroleum revenues give Libya one of the highest per capita GDP in Africa. This demonstrates high satisfaction and indicates that the Libyan government has many economic benefits from this sector, which can contribute to the implementation of sustainable development that can further contribute to economic, environment and society improvements. The other sectors, which include the agricultural sector, commercial sector, industrial sector, contribute little to the country's economy (a mere 3%) and do not meet local demands, thus causing Libya to import 75% to 80% of its food demand (World Food Programme (WFP), 2011, p.12).

Unfortunately, these days the Libyan economy has been affected due to conflicts and civil war, with the main source of income (i.e., petroleum sector) as well as oil industries being closed and under control of rebels.

[12] Wikipedia website available at: https://en.wikipedia.org/wiki/Libya

2.1.2. Political and Administrative System

The political system impacts development in many developing countries like Libya. Consequently, it is important to understanding the decision-making relationship and the government policy towards development, especially since the subject of this thesis deals with a development project that contributes to the national economy. In fact, political decisions and the policy of the State of Libya related to development projects have had a significant impact, especially during the last four decades in the absence of participation of the private sector and activities being limited to the public sector.

Libya has experienced several different political regimes and was previously ruled by Turkey and Italy for long periods. In 1911, under Italian occupation, the country was divided into three provinces, Cyrenaica, Tripolitania and Fezzan; it continued its rule until independence was achieved on 24 December 1951 (WFP, 2011, p.2). Following its independence, Libya was formed into a monarchical political system under rule of Idris Al Senosy until 1969 when a military group overthrew the monarchy to declare the beginning of a new government system that lasted until the 2011, led by Muammar Al Gaddafi. As the Arab Spring arose in 2011, popular revolution broke out, receiving international support to topple a dictator who ruled the country for 42 years. Regrettably, this revolution did not reap the fruit it had hoped, and fighting and civil war still overwhelm some areas in Libya[13]. During those years many development projects were hindered due to the unstable political system as well as the centralization in decision-making related to the development and investment at both local and international levels.

These days, there are two governments in Libya, a government in the east, which is seated in Tobruk City and represents the General of the National Parliament (GNP). The government in the west represents the General National Congress (GNC), situated in Tripoli city. These circumstances have complicated the situation and Libyan cities have been divided between supporters of the east government in some cities and supporters of

[13] The civil war still present in some area of Libya up to date of published this thesis on December 2016.

the west government in other cities, especially in the absence of a constitution that defines the regime and the structure of the government.

Administratively, the country is divided into 22 municipalities[14] (known as Shabiyyat or Baladiyat in Libya), which in turn are subdivided into zones. Figure 2.2 shows the administration districts or municipalities of Libya according to 2007 subdivision, which was issued by General People Congress (GPC)[15] (Wikipedia, 2015). At the moment Libyans are actively seeking to establish a constitution to unite the country and the system of democratic governance which will lead them to better.

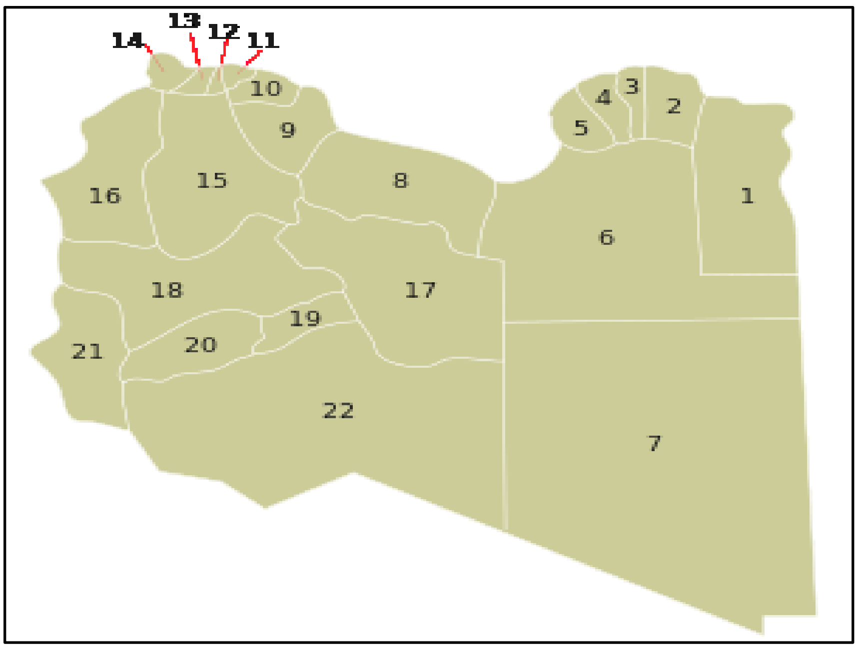

Figure 2.2: The administrative districts system in Libya (Source: Wikipedia)[16]

[14] In this study all assessments and the studies conducted are based on this division because it is the last legal and official administrative division before the civil war; nowadays there are many other administrative divisions which are not legally recognized, so, some references mention 32 municipalities and others 35 municipalities.

[15] GPC was the legislative government structure in Libya before the revolution of February and the civil war in 2011.

[16] Wikipedia website available at: https://en.wikipedia.org/wiki/Districts_of_Libya accessed on [accessed 4th January 2015].

2.1.3. Energy Sector

The energy sector of Libya is state-owned and under full supervision of the Council of Ministers[17], which in turn follows the Libyan government. This sector is run by several different institutions, each of them specializing in a certain jurisdiction and specific tasks, as detailed below:

- National Oil Corporation: Specializing in the field of oil and gas from extraction to the production, as well as all construction for the petroleum sector including ports, airports, buildings and institutions related to this sector.

- The Ministry of Electricity and Renewable Energy, which comprises the GECOL and Renewable Energy Authority of Libya (REAOL). The GECOL was established in 1984 and is responsible for the country's entire power sector, supplying electrical energy needs to the total population in Libya. Also, it oversees operation and maintenance of power grids, power plants, distribution and transmission stations and power lines as well as maintenance and built constructions of electricity (GECOL, 2015)[18]. The REAOL was established in 2007 in order to promote RE use as well as to integrate those technologies so as to share in the energy supply system of Libya. In fact, there is no publications indicate to the achievements of this institute related to RE technologies, only study indicate to the future strategy to implementations and share of the RE in Libya and there is no any project established in reality[19] (REAOL, 2009, p.9).

[17] In the current division in the government system, as discussed in the previous paragraph, the energy sector not influenced by civil war in administrative, and is still running with the equity of all Libyan society demands for all regions of the country.
[18] GECOL website in Arabic version, available at: https://www.gecol.ly/GECOL_LY/about.aspx [Accessed 6th April 2015].
[19] Also, the author was participant in the International Renewable Energy Conference and Exhibition that planed to take place in 8-10.12.2013 at Dati Elimad: Tripoli – Libya. The paper submitted at 11.07.2013 and accepted at 11.10.2013, and the conference cancelled on 24.11.2013 due to circumstances out of its control. The conference paper title: Energy Efficiency and Renewable Energy Technologies in Buildings in Libya.

2.2. Current Situation of Energy System

2.2.1. Electricity Supply System

Libya, like other countries, has its own power supply system, trying to be commensurate with its society's demands. Currently, the electricity supply system covers most regions of the country, where electricity access is 99% (WB, 2014, p.244). Furthermore, the electricity network connects and covers all cities and villages in the country, even those that are located in desert regions or away from power plants. Most of the power plants are located along coastal areas where a majority of the population lives (Ekhlat, Salah, and Kreama, 2007, p.4).

Electricity transfer to the regions that are located away from the power plants is conducted through High-Voltage Direct-Current (HVDC) technology over long distances, which increases electricity losses in national electric network. However, the process of converting Direct Current (DC) to Alternating Current (AC), to supply to customers as well as centralizing the distribution energy system, makes the losses in electricity even greater. In 2014, the losses of electricity in Libya's network were 12% of the total output, as compared to global levels in that year (WB, p.204). This is considered as one of several problems facing the national electric network of Libya at present time.

Figure 2.3 shows the historical data for electricity losses from 2003 to 2013, where Libya improves its energy efficiency in order to decrease the losses in electricity due to distribution and transmission inefficiency, especially in 2006, but the losses in electricity is increased in 2007 to reach the maximum losses rate in 2009. Still this has impact on its energy portfolio where it is considered to have currently the highest losses in Africa, according to the study published by WB (2014, p.165), as well as by comparison with world losses level, as shown in the Figure below.

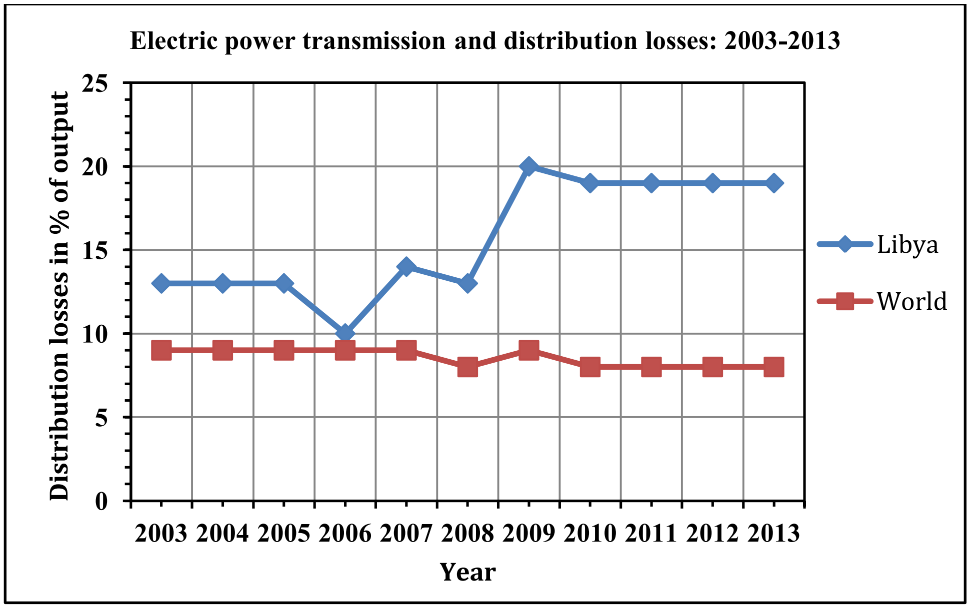

Figure 2.3: Electric power transmission and distribution losses in Libya in 2003-2013 (Source: WB)[20]

On international scale, Libya's electricity network is connected to its neighbors' sharing electricity with Egypt and Tunisia in order to meet the peak load demands in the border region, as well as to export excess loads, but this was not enough to satisfy the needs in these regions as well as to avoid the electricity outages. However, Libya has agreements to participant with international countries in a share power supply system known as DESERTEC. This project aims to establishing a global power system in order to share energy between Middle East and North Africa countries (MENA) and European countries, especially in promoting to the share of RE. Unfortunately, this project, like many other international agreements, has not yet been implemented and has no any of implementations at present in Libya (the project still planned to implement, but in the reality there is no any kind of activities related that in Libya, especially with non-stability of political situation and civil war in Libya in present time, which seems to be canceled to implement).

In summary, the electric network of Libya has vast electricity losses as an effect of the centralization of energy distribution, especially as it relates to supplying electricity to the

[20] WB website. Available at: http://data.worldbank.org/indicator/EG.ELC.LOSS.ZS?end=2013&locations=LY-1W&name_desc=false&start=2003 [Accessed: 29th June 2016].

region located at a distance from power plants. The positive thing is that most of the people have access to electricity.

2.2.2. Energy Sources and Production Technology

At present, most power plants use natural gas their as main source of energy, as shown in Figure 2.4, which presents the electricity produced source by fuel categories. Electric power generation in Libya operates through three technologies, gas technology, combined cycle technology and steam technology, as shown in Figure 2.5, where a majority of power plants are operated with gas technology that account for 53% of the plants (GECOL, 2012, p.4). By studying Figure 2.4 and 2.5, which reflect the current sources and technologies for energy production in Libya it is evident that RE resources have no share in current electric power generation. Furthermore, there is no consideration to use RE technologies, and the electricity is produced through non-sustainable sources.

The study issued by WB classified CO_2 emissions into four categories in order to assess the main sources of CO_2 emission, including electricity and heat production, manufacturing industries and constructions, residential and commercial buildings, and transport. In Libya, the electrical and heat production represented the highest CO_2 emissions (i.e., in the energy sector), which accounts for 62.1% of total pollution, as shown in Figure 2.6 (2014, p.70).

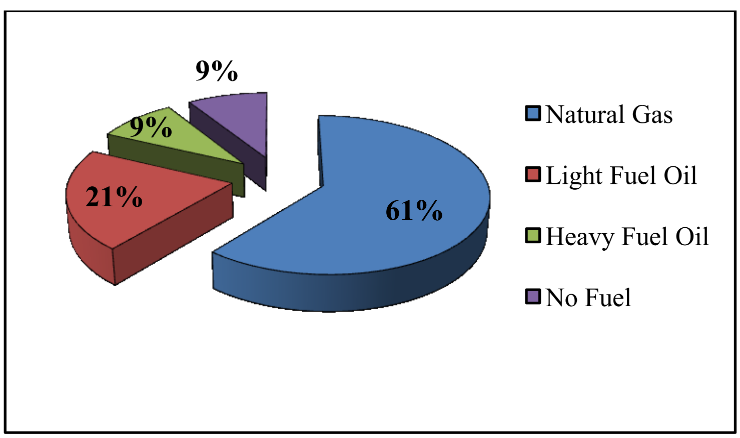

Figure 2.4: Energy production sources of Libya in 2012 (Source: GECOL, 2012, p.4)

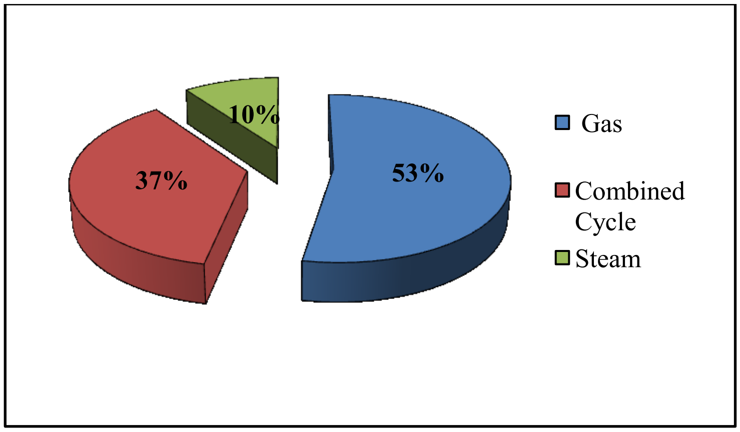

Figure 2.5: Energy production technologies of Libya in 2012 (Source: GECOL, 2012, p.4)

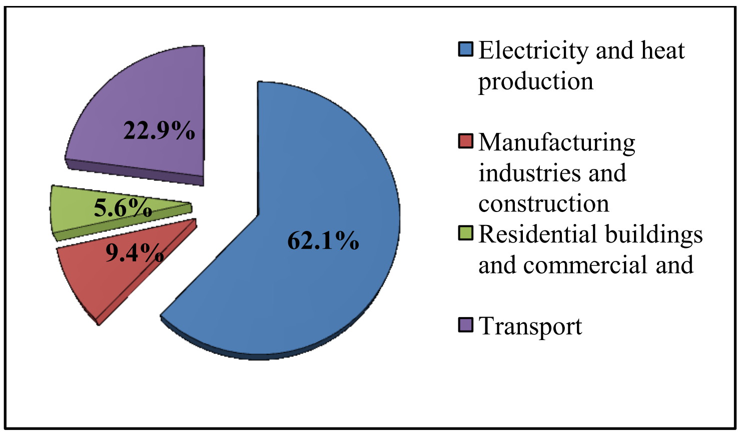

Figure 2.6: Carbon dioxide emission categories of Libya in 2012 (Source: WB, 2014, p.70)

2.2.3. Energy Consumption and Demand

The energy demand in Libya has rapidly increased with population growth, as well as development projects demands. Furthermore, electricity consumption in Libya is generally high, whereas the country is considered to be the largest consumer of power in Africa (WB, 2014, p.12). This because of several factors, such as cultural norms and social life practices, but the most significant reason is the subsidized electricity tariff, as indicated in the study published by IMF, which concluded that “Subsidies have led to high energy consumption compared to Libya’s GDP” (2013, p.8). Like other sectors in Libya, the energy sector is subsidized, where the electricity tariff is considered to be the second least expensive in the world, where it ranges from 0.015 $/kWh for residential consumers to

0.052 $/kWh for public services and commercial consumers, while the generating cost is equal to 0.20 $/kWh (IMF, 2013, p.7). Therefore, the gaps between the generating cost and tariff price represents a high subsidy. On the other hand the here intended HRES development is targeted to signification lower generation cost (see chapter 6).

Figure 2.7 represents the electric power consumption in Libya from 2003 to 2010, where the energy consumption growth rate increased annually. This Figure is provided to extract the growth rate from those years, which has been used to specify the increasing demand for electricity in coming years in Brak City (see, the case study, presented in paragraph 4.3.3).

In summary, the increased demand for energy has led increases in peak loads and black outs in some cities for several hours, and even several days. This is considered as one of the biggest challenges facing the energy sector in Libya at present, where a deficit in energy capacity is driving the Libyan government to take an active role to stem the problem and minimize the shortage in energy production commensurate with present and future society demands.

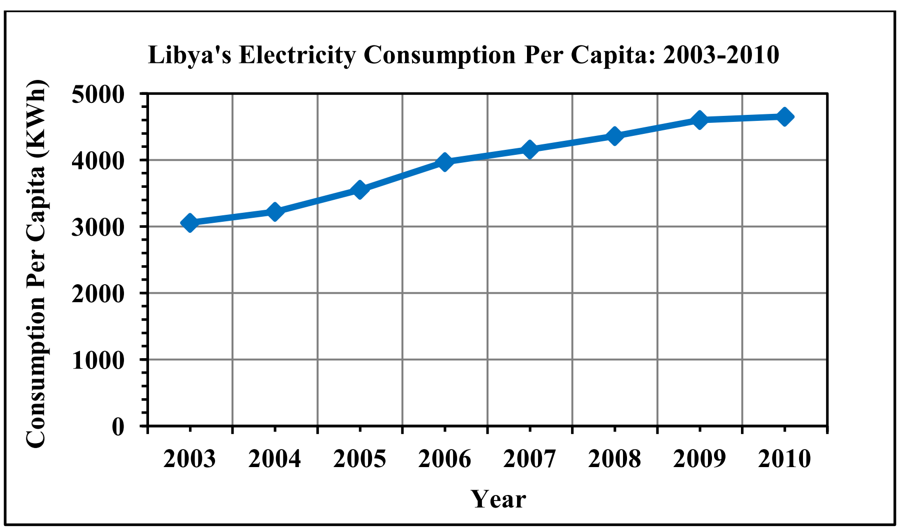

Figure 2.7: Electric energy consumption per capita of Libya for 8 years (2003-2010) (Source: GECOL and WB)[21]

[21] Data source for years 2003, 2004, 2005 are from WB database online website available at: http://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC/countries?display=graph [Accessed:17th June 2014]. Other data is from GECOL reports for 2006 to 2010, page, 3, 6, 2, 4, and 3 respectively.

2.3. Present Use of Renewable Energy Technologies in Libya

RE applications have been used in Libya since 1980, when photovoltaic (PV) system were introduced to provide electricity to microwave repeater stations near Zella City located at a distance from standard electricity access (Saleh, 2006, p.156). Following this, many PV technology stand-alone systems have been installed in different places around the country, especially in the field of communications in repeater stations that are far away from the connected power. Furthermore, it was used for the purpose of rural electrification, water pumping and cathodic protection, but the application of these PV stand-alone systems were only of very small capacity. The applications of this technology on a large-scale system basis has not been considered and have holds no practical purpose in the country at the moment.

Wind energy has also been installed in Libya, with capacity of 25 Megawatt (MW) in Derna City, which is known as the Derna wind farm. This project was not completed and does not operate or contribute to the electricity system (Saleh, 2006, p.160). The other RE technologies, such as biomass energy, hydropower energy and geothermal energy, have no application in Libya, whether on a small- or large-scale.

As a result, solar energy alone has been used in Libya and no consideration has been given to the use of other RE resources. The application of solar energy was in the form of a PV stand-alone system on a small-scale, and not on a large-scale of the application. One of the tasks conducted in the study was to focus on the use of those technologies on a large-scale basis, as illustrated in the case study in the next chapters. Table 2.1 summarizes the existing RET applications in Libya and their installed capacity at present time.

Table 2.1: Existing uses of RE technologies and their installed capacity in Libya[22]

RE technologies	Existing applications	Installed capacity
Biomass energy	No applications	Not installed

[22] Because of lack of bibliography, where is no data and publications present the RE technologies activities and the installations in Libya for the last 10 years. Thus, the study available is from 2006 in this area.

Geothermal energy	No applications	Not installed
Hydropower energy	No applications	Not installed
Solar energy	PV system stand-alone application in the field of communication, water pumping, ruler electrification	1525 kilowatt peak (kWp) (Saleh, 2006, p.158)
Wind energy	Horizontal Axis Wind Turbines (HAWTs) technology	Projected to provide 25 MW, but is not operational yet. (Saleh, 2006, p.160)

2.4. Development Challenges and Opportunities

2.4.1. Challenges

Libya lacks good electricity infrastructure and the existing electricity system does not meet the electricity demands for all sectors, industrial, agricultural, commercial or residential. The current problem for the energy sector is represented in the insufficiency of energy capacity, which has led to blackouts in most of country's regions, especially during the summer when electricity usage is higher triggering more frequent blackouts. To counter this problem and develop sustainable development of the energy system that is commensurate with Libya's demands at both local and international levels there are many challenges that need to be overcome. These challenges can be summarized as follows:

- One of the greatest challenges is the increased demand on electricity, due to population growth and the growth of demand for electricity to meet the subsequent developmental projects, including construction, agricultural and industrial projects, etc.
- The losses of electricity due to electricity transmission over long distances.
- The damages to the energy infrastructure during the period of the revolution[23], which has made some power plants incapable to withstand the electrical load, especially in the hot weather of summer, which has caused interruption to the electricity supply that can last for several days in some cities and villages.

[23] Again, the revolution period was from February 2011 to October 2011.

- Power generation in non-renewable manners and total dependence on the use of oil and gas, which create emissions causing environmental effect.
- Libya suffers from a lack of adequate water sources, whether groundwater or rainwater, especially as it relates to drinking water. This serves as a driver for GECOL to install the new energy capacities required for desalination plants. Consequently, the demand on energy has increased. In 2010, a total of 86,048 Megawatt-hour (MWh) was used to desalinate water in desalination plants (GECOL, 2010, p.15).

2.4.2. Opportunities

Presently, possible development opportunities for the energy sector in Libya are as follows:

- Upgrade the energy infrastructure and optimize the energy distribution system, especially in terms of electricity transmission in order to decrease the losses due to the transmission process of electricity.
- Use alternative sources of energy, apply RE technologies and share this technology to be participant in the energy production. Therefore, the use of such technologies can change the current situation for the better and lend to less negative environmental impacts which are being caused by the present energy sources used to generate energy; RE technology will guide the development of this sector toward sustainability.
- Share and partner with the private sector and optimize the investment law, and not limit energy activities exclusively to the public sector, as it currently is in Libya. Global experiences indicate that the joint participation of the private and public sectors has led to active development.

2.5. Conclusion

The literary reviews conducted on the energy sector in Libya in this chapter concluded that the energy generation method used in the current energy system is not environmentally friendly, whereas it depends on fossil fuel as its main source of power. Using those conventional sources has contributed to Libya having the highest CO_2 emission in the region. Alternative energy sources, such as RE technologies, have not been considered and there is no share to use any of these types of technologies in the current energy system; also, those technologies have not been considered for use in terms of large-scale application. The only existing application of those technologies represented in the PV stand-alone system at small capacity, which has been used in communication repeater stations.

Furthermore, the existing energy production capacity is insufficient to withstand the increasing peak loads, which continue to cause blackouts in most of the regions of the country, generally for several hours a day and sometimes for several days. The existing electricity system does not meet Libyan society's demand; there is a shortage at present in the energy capacity, and that shortage is likely to grow in the future.

Thus, this thesis takes an investigatory on the role of RE technologies and their application on the large-scale in order to contribute in share to overall power production and to optimize the current energy system of Libya toward sustainable development.

3. Potential of Renewable Energy Technologies in Libya

3.1. Potential of Biomass Energy

3.1.1. The Resources and Conversion Techniques

Biomass energy, or bioenergy, has several sources of energy compared to the other types of RET such as wind energy and solar energy, which are based on one source (i.e., the sun and wind respectively). This variety in sources of energy makes biomass energy one of the most frequently used in world, which equates to 1.8% of total global energy produced in 2014 (REN21, 2015a, p.31).

The resources for this kind of energy can defined by considering the meaning of ′biomass′, where Michaelides defines it as that which “encompasses all organic plant matter as well as organic waste derived from plants, humans, animals, and aquatic or marine life” (2012, p.288). Another definition clarifies that “Biomass energy is a general term that refers to the energy that can be derived from plant and animal materials, through a variety of conversion and end-use processes” (Hall, Barnard and Moss, 1982, p.1).

It may be concluded from these definitions that the biomass resources can be classified into three categories; plant, animal waste and human waste. These days a variety of feedstock is related to those categories considered as resources for biomass energy, such as wood, organic material, crops etc. Consequently, the conversion of these resources to useful energy may be conducted by many techniques that have been developed in this area. Wrixon summarizes the methods and conversion techniques of biomass energy resources into five categories, direct combustion, pyrolysis, gasification, fermentation and digestion (1980, p.144). These techniques are simplified in Figure 3.1, which represents the conversion methods for each source for biomass energy, as well as the outputs of the energy and its end-use. The aim of presenting this figure is to illustrate the process needed to convert the resource to energy whether in the form of electricity or heating energy.

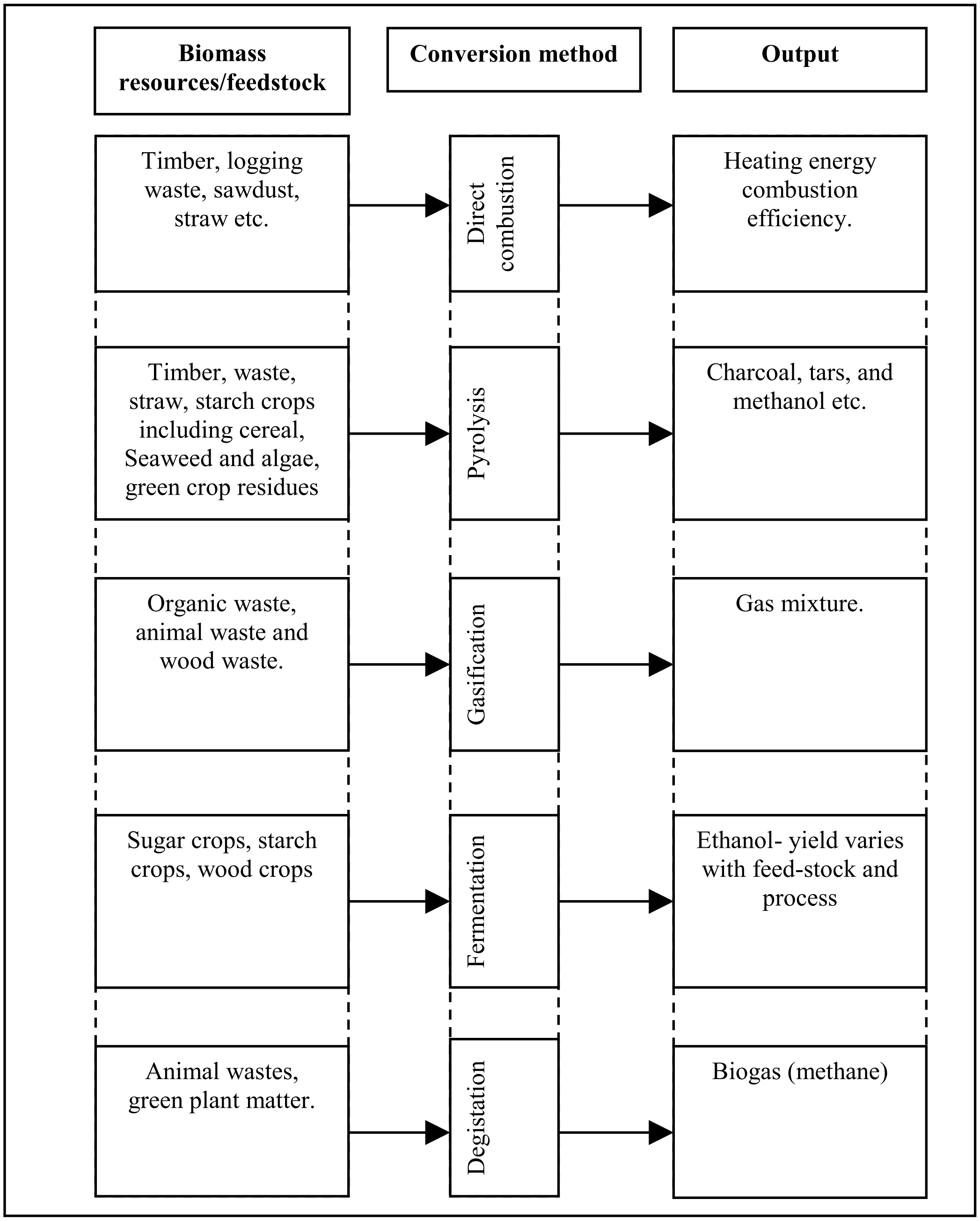

Figure 3.1: Biomass energy feedstocks with their conversion techniques (Source: adapted from Wrixon, 1980, p.144)

3.1.2. Potential in Libya

Biomass energy had been used in Libya since 1978; the study shows that 5% of the total energy was generated from the use of from biomass, which indicates that this kind of energy has been a part of energy use for several decades (Hall, Barnard and Moss, 1982, p.18). It was used as energy for cooking and heating, before the oil revolution emerged. Today there is no consideration for the use of this kind of energy in any area of social life, whether for individual use or general use; likewise it has no share in energy production within the country as previously mentioned (in chapter 2).

Another study issued by United Nations Environment Programme (UNEP) on the MENA region specifies the possibility of the biomass energy use in the area, showing that Libya has the potential to produce approximately 1.72% of its energy from biomass energy technologies, such as solid biomass technologies, which includes 0.2% from wood waste and 1.52% from municipal waste (2007, p.18). Additionally, another study estimated the possibility that 2% terawatt-hour per year (TWh/yr) could be produced from solid waste (Saleh, 2006, p.155).

From those studies it may be concluded that there is potential for biomass energy in Libya and that it is confined to municipal waste source, while other sources, such as wood and agricultural crops, have no possibility for use. This is related to the unavailability of sources for energy production, such as agricultural crops and woods; furthermore the current agriculture production of food does not meet from the primary population requirements and Libya needs to import about 90% of its food, especially wheat, barley and other agricultural crops. Furthermore, because Libya is mostly desert, it has less green land and forest, the less wood to provide as a sustainable source. In conclusion, there is potential to produce energy by biomass from waste where sources are available. Therefore biomass energy cannot really contribute to solve Libyans energy problems and will not included here in developing a HRES.

3.2. Potential of Geothermal Energy

3.2.1. The Resources and Technology

Geothermal energy has been used in different applications in human civilization since ancient times, and in 1904 the first large-scale application of this technology was set up in

Larderello, Italy, where natural steam was used to generate electricity (Berman, 1975, p.3). Geothermal energy is defined as " literally the heat of the earth" (Kruger, 2006, p.64).

Like biomass energy, geothermal energy has several sources, each having a specific technology to convert the sources to a useful form of energy. Bremen expressed that as "the means by which the geothermal resources are utilized will depend first on the nature of the resource, that is, whether the fluids obtained from the ground are dry steam or a mixture of steam and water" (1975, p.230). Another study classified geothermal energy resources into three categories: hydrothermal convention systems, hot igneous resources and conduction-dominated resources (Kutz, 2007, p.102). In the same context Kreith and Kreider argues that "geothermal energy can use the heat in the interior of the earth for electric power generation, heating of buildings, or as a source of thermal energy for heat pumps" (2011, p.33). Yet another study stated, "Geothermal energy is derived from the thermal energy stored within the rock fabric, several kilometers below the earth's surface" (Doherty and Harrison, 1995, p.5).

From the aforementioned studies, it may be summarized that geothermal energy sources include dry steam, heat from the ground, water springs, and hot and dry rocks. Currently, the technologies that is used to convert these resources into useful energy comprises geothermal heat pumps (GHPs), direct use applications and enhanced geothermal systems (EGS). In regards to the hot fluid resources Kruger similarity the technology used to convert the fossil fuel is the same that is used to convert the hot liquid of geothermal energy, where he argues that "the technology for the conversion of geothermal fluids into electric energy is the same as that for fossil fuels; the main difference is in the properties of the working fluids" (2006, p.165).

Presently, Asian countries, such as Indonesia, Japan and Thailand, utilize geothermal energy most, where the resources are active, and wherein steam water is considered most common source of geothermal energy. On a global scale, this technology is considered to have a small share in total energy produced by RET, which accounts for 0.4% of total use in 2014 (IRENA, 2015a, p.31). In addition, it is considered to have as expensive levelized cost of energy (LCOE) as compared to other RET, though it is still one of the forms of renewable and clean energy.

3.2.2. Potential in Libya

The potential for geothermal energy in Libya is theoretically viable, as the resource is available, where approximately 44 TW of heat power is transferred from the interior to the surface of the Earth" (Michaelides, 2012, p.257). Therefore, while it is theoretically possible, with consideration to the main resources of geothermal energy, such as hot or steam water, dry rock or heat rock and hot igneous resource, these sources are not available in Libya. The study conducted in that field shows the possibility of 2% geothermal energy in Libya from ground heat, related to the use of heat technology in buildings complexes or to heat water (i.e., GHPs technology) (Saleh, 2006, p.129). There are few hot water springs which are used in health services in Libya and which have not been considered as a source for RE.

In the same context, a study evaluated that the convective hydrothermal resources, whether steam or water-dominated, with temperatures ranging from 40 °C to over 60 °C in Libya (International Energy Agency (IEA), 2011, p.10). From this study it was concluded that the majority of land has hydrothermal resources that are at less than 50 °C, and a little portion ranging between 60 °C to 50 °C, which is considered to be less favorable resources as shown in Figure 3.2.

As a result, geothermal energy resources in Libya are not available, but there is the possibility to use this kind of energy from the interior heat of the earth theoretically. This entails the possible use of geothermal energy technology that depends on interior heat from the earth, such as GHPs, since the source is available. Other resources, such as hot or dry rocks, spring water and dry steam, have no potential for implementation in Libya because the lack of availability of such resources. Therefore also geothermal energy is excluded here for the intended HRES design.

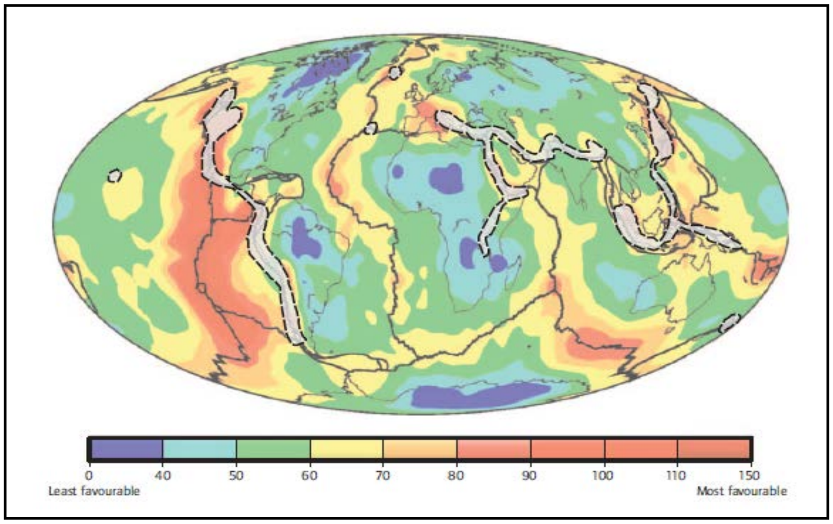

Figure 3.2: Libya with a world resource map of convective hydrothermal resources (Source: © OECD/IEA, 2011, p.10)[24]

3.3. Potential of Hydropower Energy

3.3.1. The Resources and Technology

The concept of using the movement of water as a source of energy has been known since ancient times (Michaelides, 2012, p.314). A simple definition of hydropower energy, or hydroenergy, is: "Hydroenergy is the energy in moving (falling) water" (Kruger, 2006, p.140). Like solar and wind energy, this kind of RE has only one resource, water, and depends on the movement of water to produce power.

Tidal energy and wave energy are forms of hydropower energy which depend on the movement of water to produce useful energy forms, mainly electricity. Therefore, the source is water and the convert technologies are different from one to other. Hydropower energy technologies include hydroelectric dams (known also as conventional hydroelectric) and run-of-the-river hydroelectricity, in general. Tidal energy technologies and applications have included tidal stream generator, tidal barrage, dynamic tidal power and tidal lagoon,

[24] The source noted in the evaluation Figure to "Convective hydrothermal reservoirs are shown as light grey areas, including heat flow and tectonic plates boundaries."

while the wave energy technologies are hydraulic ram, elastomeric hose pump, pump-to-shore, hydroelectric turbine, air turbine and linear electrical generator.

In summary, hydropower energy depends mainly on water as its energy source, whereas the common technologies and applications of this type of RE are dams, tidal and wave technologies. Currently, hydropower energy is considered to be the most cost effective form of energy, with LCOE for this energy reaching as low as 0.03 $/kWh in some places in the world (International Renewable Energy Agency (IRENA), 2015a, p.73). On the other hand, this type of RE represents 16.6 % of the current total RET production, which considered the most one procedure (REN21, 2015, p.31).

3.3.2. Potential in Libya

Hydropower energy, like other types of the RET, does not have a share in the power energy system of Libya; whether by small-scale application or large-scale. Libya has a long coastal strip along the Mediterranean Sea, which could be considered a resource for hydropower energy. This resource provides Libya an opportunity to apply hydropower energy technologies, including dams, tidal energy and wave energy along its Mediterranean coast. Otherwise, other resources, such as rivers or lakes, are not as readily available due to the lack of rainfall, to provide an adequate base storage of water in the form of dams. At present time there are 16 dams that have been constructed and are operational in Libya; they are operated for irrigation purposes, as well as to supply fresh water to some regions and there is no consideration to use them for generating electricity (Aqueil, Tindall and Moran, 2012, p.4).

In term of the potential for tidal and wave energy, the study conducted in that area shows the average wave energy flux estimated in Libya is from 3.5 to 11 kilowatt meter (kWm)[25], which indicates the great potential for applying wave energy technology (Martinelli, Pezzutto and Ruol, 2013, p.4499). Furthermore, there is potential to implement tidal energy; based on the study of the direction and movement of the tide toward beach

[25] The wave energy is measured in kilowatt-meter (kWm).

(Karathanasi, Soukissian and Sifnioti, 2015, p.4)[26]. Figure 3.3 represents the potential of tidal and wave energy that was concluded from this study.

In summary, the resources needed for hydropower energy are available in Libya, along its Mediterranean coastline. It is considered to be the only resource for this technology and it can be concluded that there is a good possibility to apply such technology, whether tidal and wave energy, or in dam applications, for example in combination with desalination plants. But in general hydropower energy is limited to local solutions (coast line).

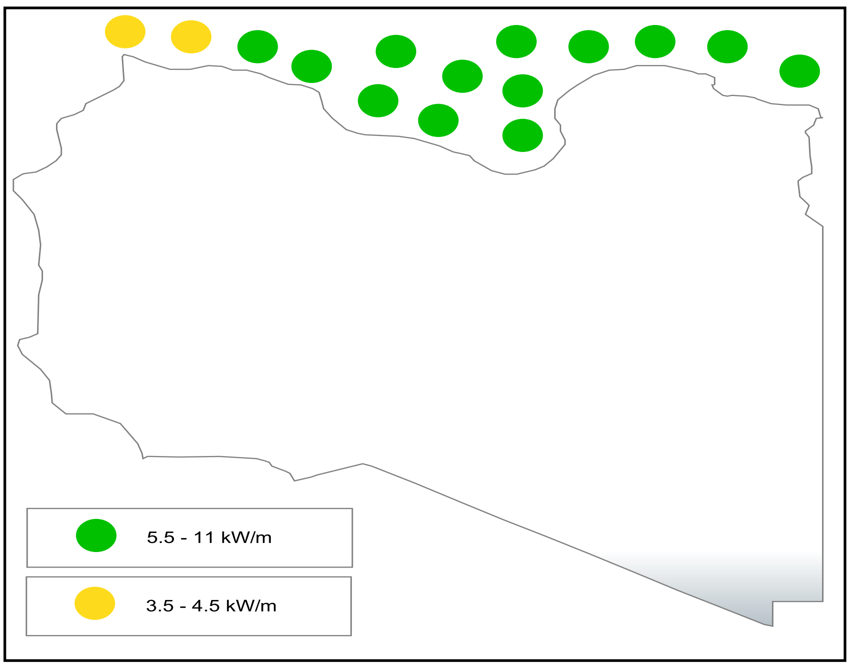

Figure 3.3: Average wave energy flux spent and tidal direction of Libya (Source: author's design adapted from Martinelli, Pezzutto and Ruol, 2013, p.4499)

3.4. Potential of Solar Energy

3.4.1. The Resources and Technology

Solar energy has been used for thousands of years, for all sorts of different purposes in the life. Williams argues that, "sunlight matching the earth can provide our needs for energy

[26] The study evaluated the direction of the tidal from 1970 to 2000.

without pollution" (1974, p.1). Other simple perspectives state that "solar energy is defined as that radiant energy transmitted by the sun and intercepted by Earth" (Kutz, 2007, p.13). Consequently, this type of RE depends on sunlight as its main source of energy, but like other RET, several types of technologies may be used in order to convert sunlight into useful energy.

Today there are several technologies that have been developed to take advantage of solar energy, including PV system, Concentrating Solar Power (CSP) and Solar Water Heating (SWH). The most widely used in the world are PV systems, which are used in a variety of applications whether in small systems like in residential uses or in large-scale uses like in solar farms, which provide for more efficient use of energy. Currently, world-use comprises 0.9% of the total RET output, with average typical LCOE costing 0.20 $/kWh in utility-scale of application (IRENA, 2015a, p.31). This is comparable to the energy generating costs typical for Libya (see paragraph 2.2.3).

3.4.2. Potential in Libya

Not surprisingly is solar energy use in Libya strong, and there is the possibility to implement such technology and their respective applications. The study issued by Solar Geographical Information System (Solargis) determined that Global Horizontal Irradiation (GHI) varies from 1950 kWh/m^2/yr. in the coastal region to 2550 kWh/m^2/yr. in the south of Libya, as shown in Figure 3.4. The sunshine averages 6.5 hours a day, and considering the large area of the country and the simplicity of the landform, it can be concluded that the factors give Libya a promising opportunity to apply and take advantage of the use of this technology. In more detail this will be analyzed in the case study (see chapter 6 and 7).

As discussed previously, this type of RET has been used in Libya in small application, and has not been implemented in large systems. The studies indicates there is a possibility for 140 TWh/yr. that can be produced from the use of solar energy, which is enough to fill the shortage in Libya's energy portfolio at the present time (Saleh, 2006, p.155; and also Martinelli, 2010, p.60).

In summary, the potential is high and implementation of solar energy can lead to taking a role toward sustainable energy and contribute to filling the gap in energy capacity shortage that Libya faces at present time, and more to be analyzed here in detail.

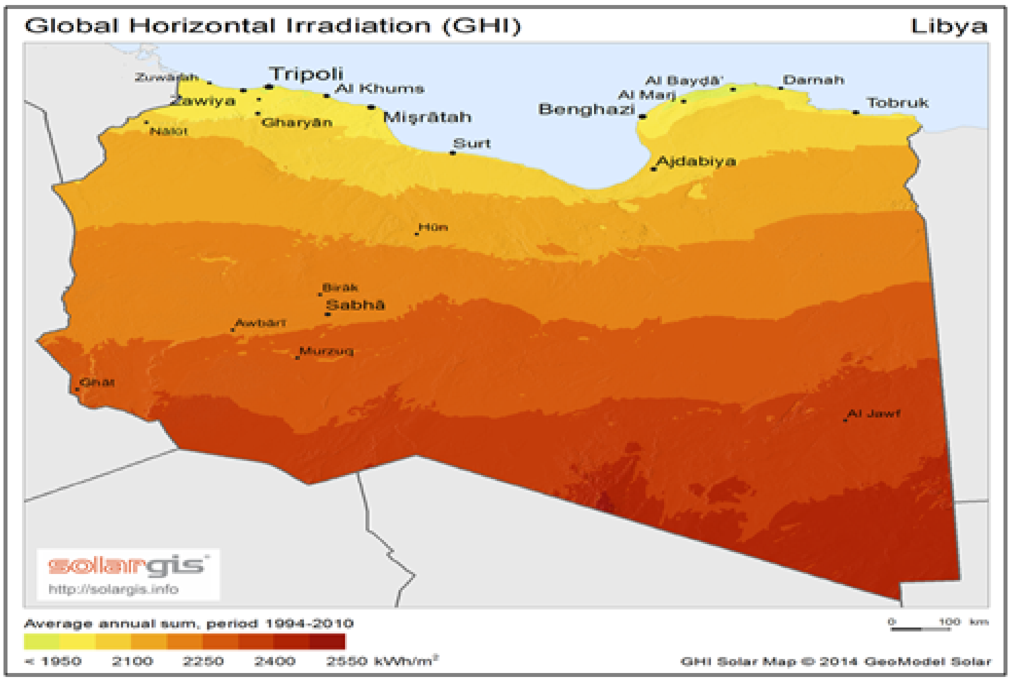

Figure 3.4: Global horizontal irradiation map of Libya (Source: GHI Solar Map © Solargis)[27]

3.5. Potential of Wind Energy

3.5.1. The Resources and Technology

Since the earliest ages, wind energy been to sail ships and power windmills to grind grain or pump water from wells (Michaelides, 2012, p.233). Like solar energy, this type of RE has only one resource, which is wind. Nowadays, wind energy technology has developed and there are several applications in use, though wind turbine technology is considered the most common. Current wind turbines are subcategorized as "modern wind turbines are classified into two configurations: horizontal-axis wind turbines (HAWTs) and vertical-

[27] The solar GIS logo and the titles are retained on the map as requested from the source copyright property for GeoModel Solar. Solargis website: maps available under Creative Commons Attribution-Share Alike 3.0 Unported License. Available at: http://solargis.info/doc/_pics/freemaps/1000px/ghi/SolarGIS-Solar-map-Libya-en.png [Accessed:12th May 2015].

axis wind turbines (VAWTs) depending on rotor operation principals" (Jha, 2011, p.2). These are considered to be the most common technology used at present related to wind energy.

Wind energy technology has two kinds of the applications, onshore systems and offshore systems, which are mostly implemented in large-scale applications (i.e., wind farms). Also, this type of RET has low LCOE, which typically range between 0.045 and 0.14 $/kWh in onshore wind system and from 0.12 to 0.20 $/kWh in offshore wind system in world-scale usage (IRENA, 2015a, p.74) and much lower than current energy production costs. Therefore wind energy owns the potential to avoid energy price subsidies. The present global production measures 3.1% of total RET output, which is considered small compared to other RE technologies.

3.5.2. Potential in Libya

Wind energy has considerable potential in Libya, and there is sufficient potentiality to implement such technology. Moreover, this technology can be use in both onshore and offshore systems since the Mediterranean Sea provides consistent enough high wind speeds to support wind offshore energy. Also, there is good potentiality to apply this technology in onshore system in all regions of the country. Here, see chapter 5 and 6 only onshore solutions will be analyzed more detailed.

The study shows that average wind speed in Libya is 5 m/s (Kristofferson and Bokalders, 1996, p.273). A subsequent study evaluated the most attractive location to implement wind energy technology is along the coastal area, in Derna City and Sirt City region in particular, where wind speeds varying from 6 m/s and 7.5 m/s respectively (Saleh, 2006, p.159).

In this study the average wind speed for all districts of Libya are represented in Figure 3.5[28] based on data from the surface meteorology and solar energy website provided by National

[28] The data obtained online, which are presented the average wind speed of districts for 22 years (1993 - 2005) as provided and supported by NASA. The website of the data is available at: https://eosweb.larc.nasa.gov/cgibin/sse/homer.cgi?email=skip@larc.nasa.gov [Accessed: 22nd March 2014].

Aeronautics and Space Administration (NASA). This data was obtained based on the latitude and longitude of the district, and determined the average wind speed at height of 10 m, as provided by NASA (see the detailed data in Appendix 1). Because of that, and despite the different of data from these sources (i.e. Kristofferson and Bokalders, Saleh and NASA), the data presented in Figure 3.5 has been used in the study, that show the wind energy potential in each districts of Libya, as well as the region used in the case study presented in the next chapters.

Nr.	Name of Districts	Average Wind speed (m/s)
1	Butnan	3.9
2	Derna	4.2
3	Jabal al Akhdar	4
4	Marj	5.2
5	Benghazi	5.2
6	Al Wahat	4.0
7	Kufra	4.6
8	Sirte	4.4
9	Misrata	4.2
10	Murqub	4.2
11	Tripoli	4.2
12	Jafara	4.2
13	Zawiya	4.2
14	Nuqat al Khams	4.1
15	Jabal al Gharbi	4.1
16	Nalut	4.1
17	Jufra	4.1
18	Wadi al Shatii	4.2
19	Sabha	4.3
20	Wadi al Hayaa	4.5
21	Ghat	4.4
22	Murzuq	4.5

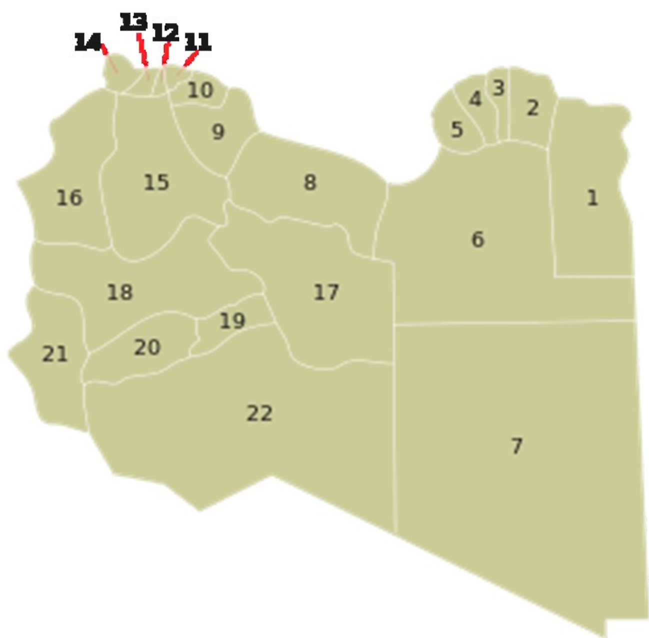

Figure 3.5: Wind energy potential in Libyan districts

3.6. Conclusion

The study conducted in this chapter shows that Libya has considerable potential for RE technologies. The implementation of those technologies can lead to greater outputs from the existing energy system and develop the energy sector in a more sustainable manner. The key findings for the potentiality of RE technologies are summarized in Table 3.1. As a result, it can be concluded that in first line solar and wind energy technology offer the greatest possibilities because of the strength of these resources in Libya.

Table 3.1 Potential of RE technologies in Libya

Type of RE	Potential of resources	Potential of technology implementation
Biomass energy	Waste whether human and solid	Any technology related to waste includes, gasification, combustion and pyrolysis technology
Geothermal energy	Heat from the earth (interior heat of the earth)	GHPs, which depend on interior heat of the earth
Hydropower energy	Mediterranean Sea is considered the main resource of hydropower energy in Libya, with coastal length of approximately to 1800 km	Dams technology, tidal technology and wave technology
Solar energy	The average annual GHI in Libya ranges from 1950 to 2550 kWh/m^2, considered a strong resource for solar energy technology	PV CSP SHW
Wind energy	The average annual wind speed in Libya ranges from 3.9 to 5.2 m/s, considered good for wind technology	HAWTs VAWTs

4. Case Study Methodology and Area

4.1. Case Study Approach

4.1.1. Case Study Objectives

For reasons given in section 4.2 case study focused on design HRES for Brak City to meet electricity demands in the region and decrease the losses in electricity as well as satisfy the shortage in electricity that causes for outages that facing the existing electricity supply system. Libya has no RE technologies in use to generate electricity and there is not any kind of RE contribution in electricity production in the current system. Therefore, the study covered Brak City and set out first to explore the possibilities of RET that can be used in this region. Secondly, the insights gained in the study of implementing RE technologies in Libya will be scaled to provide recommendations on both local and international levels.

Furthermore, the basic objective of this study is to discern the optimal HRES to satisfy the energy demands of the study region with consideration to the increasing demand of electricity, as well as population growth. More clearly, the optimal HRES in the study entails determining the minimum cost of energy (COE) and most cost-effective system as well as optimal system type (OST) configuration of each system design to meet electricity demand in region. To make this determination simulation software has been used in order to specify the system configuration, components and COE in each design; this software is illustrated in the next paragraph. With this being the main goal, the delineated objectives covered in the study were as following:

- Finding out the potential of RE technologies in the study region (Presented in this paragraph 4.2.3).
- Determining if this optimal HRES is cost-effective, environmentally-friendly and meets the electricity demand in region than the currently used fossil fuel based generation of electricity (Presented in paragraphs 6.1.5, 6.2.5 and 6.3.5).
- Conducting a feasibility study on the optimal HRES with different components and applications, for example, in the case for using solar energy technology in which

components and conditions for the system can be optimal (Presented in paragraphs 6.1, 6.2 and 6.3).

- Making a comparison between a stand-alone system with a grid extension as it relates to cost (Presented in paragraphs 6.1.4, 6.2.4 and 6.3.4).
- Conducting a comparison of COE gained from the scenarios (Presented in paragraphs 6.4).
- Determining which RET is optimal to use in the region: solar, wind or both in one system (Presented in paragraphs 6.5).

This chapter gives also the regional overview, case study methodology as well as the estimation of the electric load demand for Brak City HRES. It continues with a short description of the selected HRES designed software.

4.1.2. Selected Software

There are many software models and tools that have been developed to assess RE and energy efficiency technologies in a variety of applications. In the study the Hybrid Optimization of Multiple Energy Resources (HOMER), developed by NREL, was used to design Brak City HRES (Lambert, Gilman and Lilienthal, 2006, p.379). HOMER was chosen for the study because it has a variety of components allowing for a number of combinations to configure the design of a hybrid energy system (HES) in both off-grid and grid-connected power systems. In addition, the software has several applications of technologies and technical parameters that make allow it to design energy systems more accurately as other modeling tools. Furthermore, its resource database, available from NASA, provide measurements based on site coordinates and climate data such as solar radiation, wind speed and air temperature which are required in design.

Moreover, HOMER simulates energy consumption and production for each hour of the year and matches the RE production that is possible based on the available renewable sources in the site.

Software is categorized in three processes: simulation, optimization and sensitivity analysis. In the simulation process, HOMER simulates and calculates for selected system configuration (sensitivities) in each time step of the year in order to determine technical feasibility as well as their net present cost (NPC). NPC are the total life cycle costs of the HRES for investment, operation, maintenance, replacement and included salvage values. Regarding the optimization process, HOMER simulates the entire energy system design with different system configurations in order to determine the optimal system that satisfies the technical constraints at the NPC. In the sensitivity analysis process, HOMER considers optimizations based on the variables that are assumed in the design and measures the effect of these variables on system configurations, as well as the changes that occur due to inputs of these variables. Figure 4.1 shows the concept of the software processes and the their relationship, while the license for using this software is presented in Appendix 5 [30]. Lambert, Gilman and Lilienthal explained the relationship between HOMER processes based on this Figure as "the optimization oval encloses the simulation oval to represent the fact that a single optimization consists of multiple simulations. Similarly, the sensitivity analysis oval encompasses the optimization oval because a single sensitivity analysis consists of multiple optimizations" (2006, p.380).

It's a pity that beside this advantages must be mentioned that HOMER software system is not able to calculate and determine the real cost optimal system. The size of all HRES components must be pre-selected. HOMER is than calculating only for all possible combinations of these pre-selected components, the energy generation costs. Identified is than only the cost optimal solution of these component sizes and not in which way derivations of these pre-selected component sizes lead to further cost reductions.

[30] The license is for legal use as well as property right from HOMER Energy.

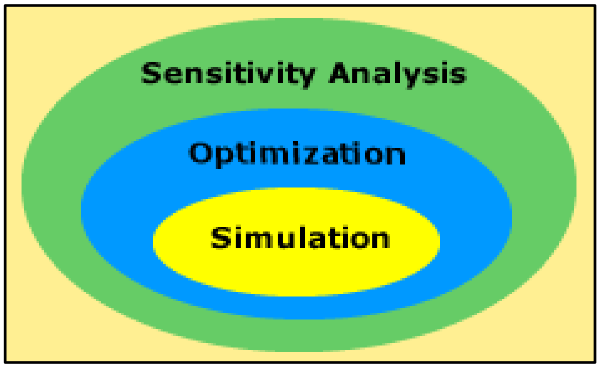

Figure 4.1: Conceptual representation of the software process (Source: HOMER energy)[31]

4.1.3. Case Study Scenarios

This case study was considered within three scenarios; each scenario deals with a certain type of RET with different components and combinations. The first scenario focused on design HES with solar energy technology based on the solar resource in the project site. For the second scenario, the wind energy technology in the design was used based on wind resource in the project site. In third scenario, both solar and wind technologies are used in the design of system. All scenarios examine the feasibility of build and created stand-alone system and grid-connected system, as well as compare the stand-alone system to grid extension. Thus, each scenario will be considered in three categories of design in order to determine lower COE to allow for a clear comparison between those categories in COE, electricity losses, electricity shortage and RE share percentage in the project. Therefore, the scenarios are different in the RE type that is used as well as configuration system, but are similar in methodology of design. For this reason, the same equipment is used in all scenarios related to systems configuration and their components, such as diesel generator (DG), battery, inverter and grid utilities; they are consistent in sizes and cost in order to make the study more accuracy (for more details see chapter 5). Yin develops roles of case study processes which are known as case study protocol to support the idea that “the protocol is a major way of increasing the reliability of case study research and is intended to guide the investigator in carrying out the data collection from a single case (again, even if the single case is one of several in a multiple-case study)” (2009, p.79). Consequently,

[31] HOMER energy website, online available at: http://www.homerenergy.com/software.html [Accessed:12th April 214].

the case study has been conducted using specific protocol in order to simplify the workflow methodology and clarify the stages as well as the scenarios concept as shown in Figure 4.2 below.

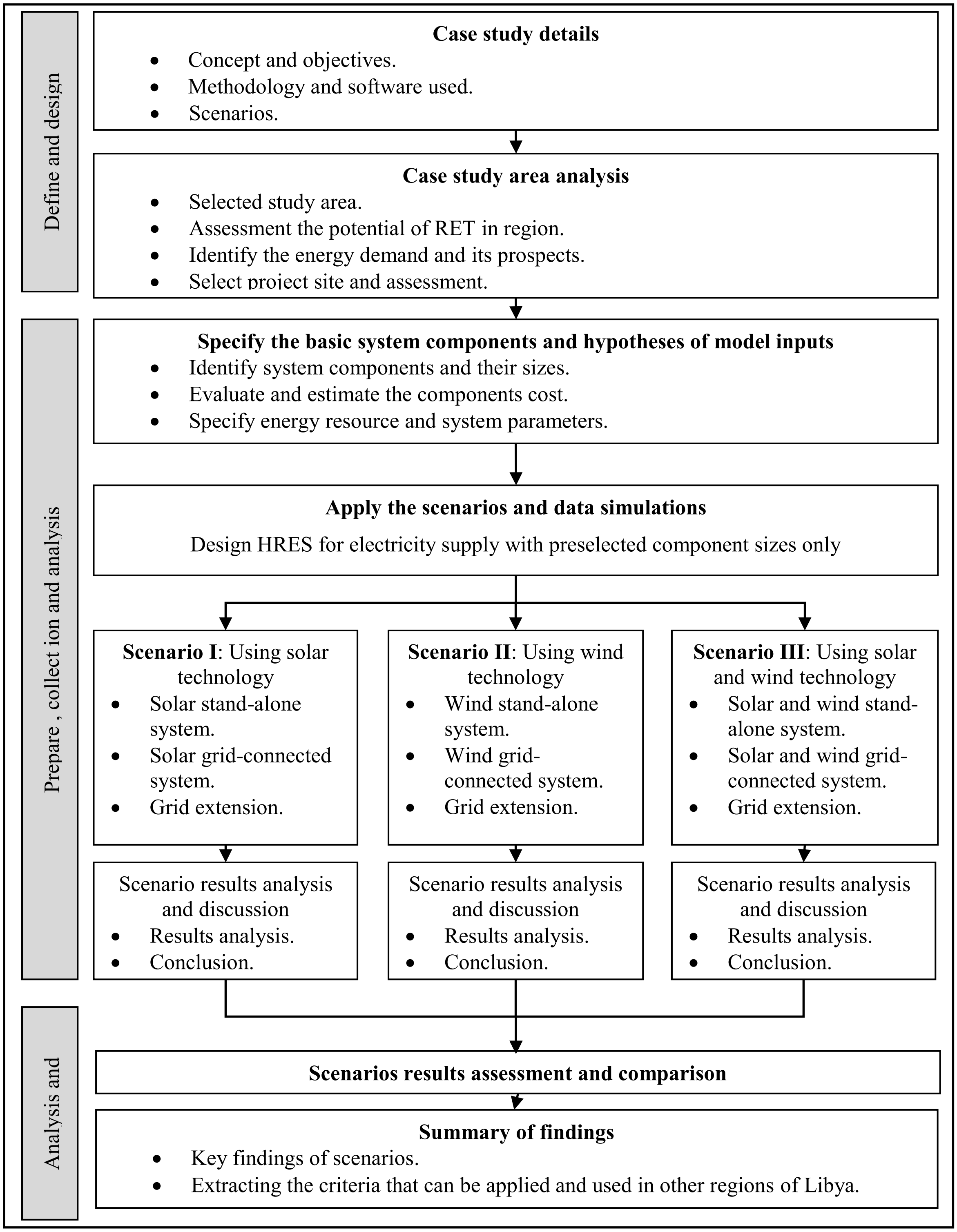

Figure 4.2: Case study protocol and methodology (Source: author)

4.2. Case Study Area

4.2.1. Brak City Overview

The Wadi Al Shatii or Ash Shati is a municipality consisting of a chain of villages, which is home to a population of 82,505. These villages are located beside the main road within the region, where Brak is the biggest town in both population and area, and serves as the administrative city in the municipality, hence earning the designation as Brak City. For this reason the study area is referred to as Brak City instead of Wadi Al Shati municipality.

Brak City is located in the south west of Libya, as shown in the map in Figure 4.3 below, bordered on the north by the municipalities Nalut and Jabal Al Gharbi, in the south by the municipalities of Sabha, Wadi Al Hayaat and Ghat, while the Illizi Province of Algeria is to the west and the municipality of Jufrah is to the east. The area of the municipality is 97,160 km^2 (Wikipedia, 2013)[32], and once was within the province of Fezzan during the Italian referee (1911-1964). The region consists of semi-desert with desert and is very hot in summer and cold in winter; temperatures reach 45°C in the summer and 3°C in winter; on very rare occasions there is snowfall.

The Brak City area is characterized by an abundance of fresh groundwater, which encouraged the Libyan government to develop grand agricultural projects for the production of wheat and barley in the region in order to satisfy the needs. In addition, the area is home to the largest industrial project to supply Libya's coastal areas and cities with fresh water for drinking, known as MMRP, in order to alleviate the shortage in those regions. As the area is rich in iron ore and magnesium, the Libyan government has considered making it one of the major industrial zones in Libya in the future, but this is still in planning phases and has yet developed to this day.

[32] Wikipedia website, online available at: https://en.wikipedia.org/wiki/Wadi_al_Shatii_District#cite_ref-1 [Accessed: 7th December, 2013].

All these elements were factors for considering and selecting Brak City to conduct a case study on the design of an electricity supply system for using RE technologies as a way to create a potential project that meets future needs of region.

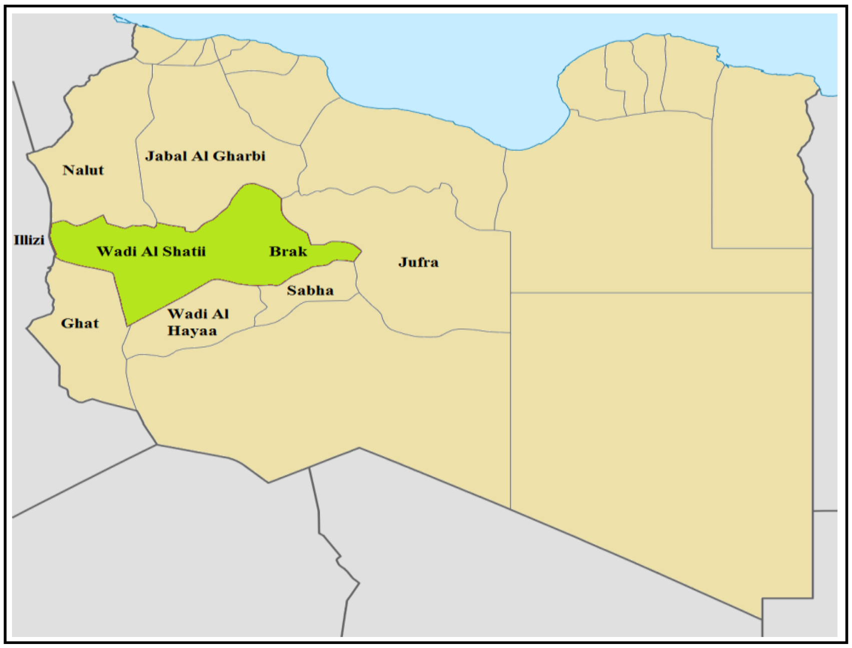

Figure 4.3: Libya map with Wadi Al Shati district and Brak city location (Source: author's design adapted from Wikipedia: https://en.wikipedia.org/wiki/Brak,_Libya)

4.2.2. Current Situation of Electricity System

Another consideration is a fundamental and important reason represented in the constant power outages during the summer period and the region's dependence on power plants of west Tripoli. In other words, the lack of a local power plant in the region creates a perpetual dependency on the electricity coming from the main stations in the west of Tripoli. Furthermore, the shortage in Libya's electricity capacity in present time makes this situation more critical since the blackouts can remain for days.

The current electricity system of Brak City is dependent on imported electricity from Tripoli west station through high voltage electricity lines, which transmit the current to the main electric station of the region. Besides that, the diesel turbines generator is used to generate the electricity to satisfy the region demands by supplying electricity to substations in the region where it is further disseminated to customers. This means Brak City depends on conventional electricity turbines, as well the electricity produced from the central station that coming from coastal area, which entails a currency transfer that is long in distance. But this is not only the sole problem facing the current electricity system in area and not the only this reason behind establishing the RE system in Brak City; there are many problems with the current electrical system and impediments to its development, which can be indicated as follows:

- High losses in electricity due to long distance transmission, as well as losses due to converting the electricity from high voltage to alternating current several times from main station to sub-station to end use.
- Shortage in the demands due to peak loads, especially in summer when the climate is warm and temperatures high.
- The current generating system is environmentally unfriendly, wherein electricity is generation by traditional methods using fuel, which creates high pollution (i.e., the use of diesel turbines to generate the electricity).
- To know the advantage of use RET instead the conventional system in region to overcome the current system problems as well meeting the future demands of electricity.

4.2.3. Potential of Renewable Energy in Region

From the discussion presented in chapter 3, that illustrated the potential of RE resources and technologies as well as the possibilities to implemented in Libya in general. This section concentrated on discovering the RE technologies potential and possible use in Brak City region as illustrated in Table 4.1.

Table 4.1: Possibilities of RE in Brak City region

Type of RE	Possibilities in region and discussion	Finding
Biomass energy	There are no forests in the region since the climate is typical desert, in addition to the lack of annual rainfall. While there are several agricultural projects to produce	There is no possibility to use biomass because the energy resource is

	grains, such as corn, wheat and barley, to cover part of the needs of the region and Libya in general. Thus, this type of RE cannot be used because the resource is unavailable and lacks potential.	unavailable.
Geothermal energy	There are no hot water springs in the area nor any volcanic activity, which is considered the main source of energy; also, studies on geothermal in the region do not exist. However, as indicated by international studies, scientifically the heat in the ground and increases with depth and the region's environment offers a possibility for making use of this type of RE, still there is a main obstacle facing this source is cost.	The energy resource is available but the possibility to use this type of RE is very low because of cost. Thus, this kind is not considered for use in the area.
Hydropower energy	There is no possibility to use this kind of RE because the region is located in the Sahara area, where there are no rivers or water lakes, which are considered as the main source to hydropower.	There is no possibility to use hydropower because the energy resource is unavailable.
Solar energy	The potential for solar energy is considered to be high in the area, where the average annual solar radiation varying from 2175 kWh/m^2 to 2250 kWh/m^2 in the region as shown previously in chapter 3 (see Figure 3.4). Therefore, applying this kind of RE in the region is very possible and offers high potentials.	There are a high potential for using this type where solar resources are available with high capacity.
Wind energy	The average wind speed in the region is 4.2 m/s, which is considered mid-level. Therefore, the wind energy in the area is available as a source and type of RE.	There is possibility to use this type of RE, where wind resource is available.

4.3. Design Electricity Demands for Brak City

4.3.1. Methodology of Design the Demand Load

Figure 4.4 shows the calculation methodology and steps that were applied in order to determine the electricity demand load required to design the Brak City HRES.

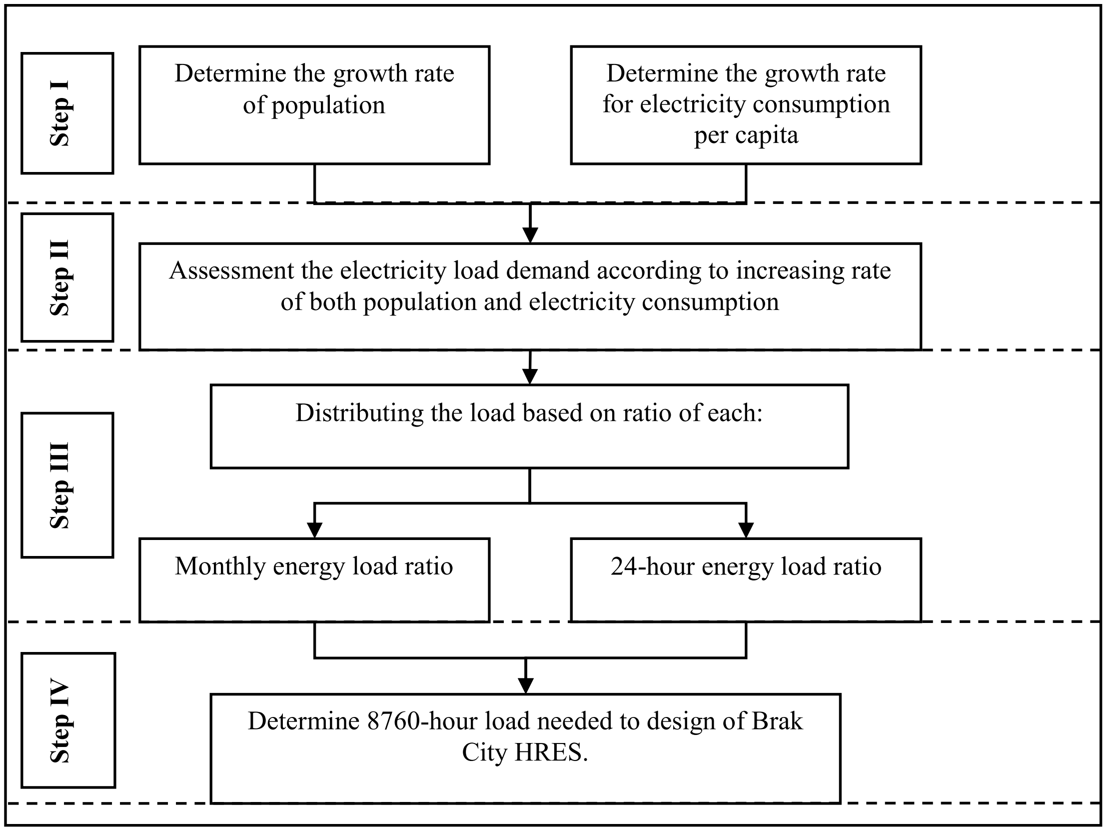

Figure 4.4: Calculate steps for the primary electrical load of Brak City HRES need (Source: author)

4.3.2. Determine the Growth Rate of Population

The population growth rate was calculated in order to assess the increasing population in the region and find out the system electrical load capacity for the next years as devised in the future plan of the project.

According to findings[33], the average population growth rate in Libya for 10 years (2003-2012) was calculated and illustrated in more detail in Appendix 2 paragraph 1. The result of this calculation is represented in Figure 4.5, showing that population growth increased through those years in general, while the growth rate decreases as a percentage. As a result the value 1.4%, which represents the average growth rate in these 10 years, has been used to determine the future of electricity loads commensurate with the population increase.

[33] No values available for Brak City region.

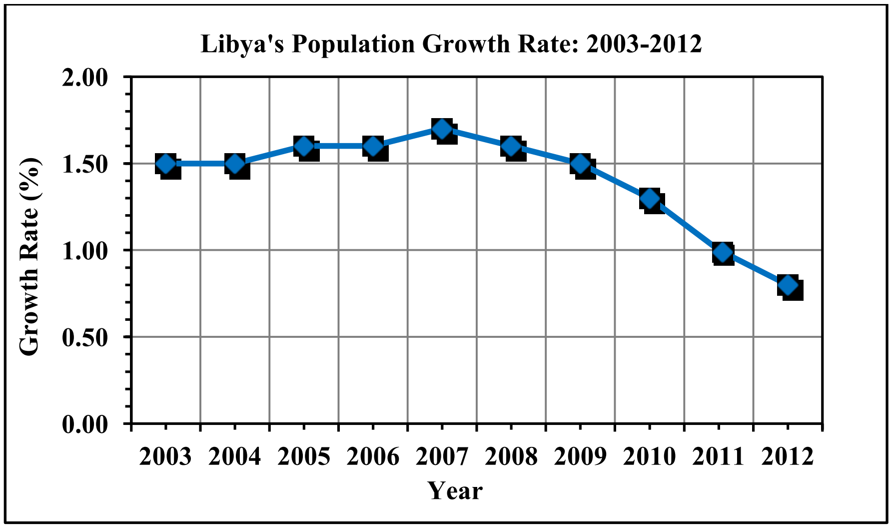

Figure 4.5: Population growth rate of Libya from 2003-2012 that been used to assess the growing population in Brak City in order to specify the increasing electricity demand in coming years in the region (Source: WB)[34]

4.3.3. Determine the Growth Rate for Electricity Consumption

The electricity consumption per capita in Libya is increasing annually compared to neighboring countries where it is the highest consumption per capita in electricity within MENA countries. As discussed previously in Chapter 2, where the study on electricity consumption per capita for 8 years was represented (see Figure 2.7, electricity consumption in Libya from 2003-2010) in order to assess the prospect of energy demand in Libya. In this context, the growth rate in electricity consumption per capita was considered in the design of Brak City HRES, where the average growth rate for those 8 years was calculated. The reason this value was calculated was to determine the yearly electricity consumption per capita in the next years with consideration to the growth rate of consumption in order to specify the system power capacity, or output capacity.

The result is represented in Figure 4.6, which shows that the growth rate rises up and down with varying of years, where the average growth rate is 6.3% as detailed in Appendix 2,

[34] WB website, online available at: http://data.worldbank.org/indicator/SP.POP.GROW/countries/LY?display=graph [Accessed: 28th November, 2012].

paragraph 2. In the study, a growth rate value of 2% was used in the design of Brak City HRES because Brak City is located in a rural region and energy consumption can be less there than in urban regions. Also other argument for the selection of this rate value is that the typical growth rate in developing countries ranges from 2% to 4% (Berrie, 1992, p.7), which can exemplify the reduced consumption in Libya when there are no subsidies for the energy sector, and COE becomes expensive compared to the current situation.

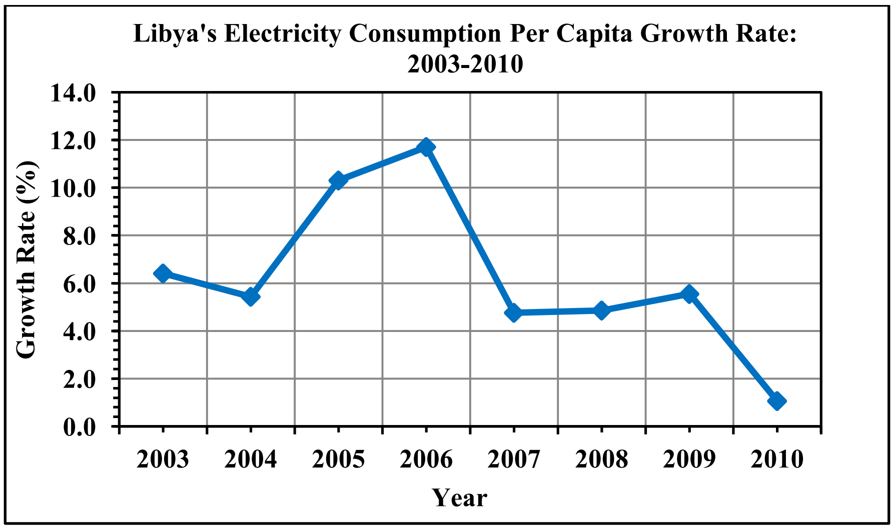

Figure 4.6: Electricity consumption per capita growth rate of Libya from 2003 to 2010 that been used to specify the increasing electricity rate required in the design of Brak City HRES (Source: author)

Table 4.2 shows the result of estimating the electricity load system and the expected loads and estimated a minimum load Brak City HRES that has been used in a software simulation process, while the calculation details for expected loads in 2017 year are discussed in Appendix 2 (paragraph 3, 4 and 5). The estimated load is determined with consideration of the growth rate of both population and electricity consumption of Libya only (represented in Figure 4.5 and Figure 5.5). The other considerations such as losses ratio as well as expected growth rate in electricity shortage not included in the study, because the load designed to satisfy the minimum requirements of Brak City HRES.

Table 4.2: Estimation of minimum load in design of Brak City HRES[35]

Descriptions	Values
The expected populations for Brak city in 2017, the first operational year (beginning of the project) of the Brak city HRES.	88,444 in population
The expected annual average of electricity consumption per capita at the start of the project in 2017 (see Appendix2, paragraph 3)[36]	5,355 kWh/ann./capita
The annual energy demand to meet the electricity needs of Brak city in 2017 required by the system (the load for the system design).	473,617,620 kWh/year
The average monthly energy demand of Brak city HRES that needs to satisfy the monthly electricity demand for Brak City.	39,468,135 kWh/monthly
The average daily energy demand of Brak City HRES.	1,297,583 kWh/day
The average hourly load demand of Brak City HRES.	54,066 kW

4.3.4. Determine the Electricity Load Ratio

4.3.4.1. Monthly Load Ratio

Several studies were conducted on monthly electricity loads in Libya by GECOL in order to define the peak load as well as loads consumption in each month (GECOL report in 2007, 2008, 2009, 2010 and 2012). By studying these reports and comparing the electrical load curves in those years, when the study was conducted, concluded that the load curve and load demands are semi equal in these years. For example, by comparing between load demand curves in January of 2007 with the load demand curve in 2008 find that the loads look to be in the same frequency and only different in electricity consumption amount, which is increased yearly by increasing the demands on electricity.

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[35] The load values represented in this table are in kW because the software (i.e. HOMER) supports only the load in unit of kW, which means it must load values entered in this unit.

[36] This is in the step II (see Figure 4.4) assessment load, which is still based on the consumption value of 2010 take from Figure 2.7. This 2010 consumption is influenced by subsidies and because of shortages and blackouts it is know as being not enough. Therefore these 5,355 kWh per annum and capita is not the “real” demand. It is seen here as a minimum requirement only, as requirements level people of Libya used. Therefore the intention to design a HRES is to scene a minimal demand level only.

Therefore, in this study the monthly load curve of 2012 has been used, which corresponds to the last study issued by GECOL with consideration to the load increase demand on electricity as well as population growth. The monthly load curve in Figure 4.7 represents the electricity consumption for the Libyan network for all consumer sectors, including the industrial sector, commercial sector, agricultural sector, public utilities and residential sector. In this context, the calculations in the study for monthly load curve and the load frequency in each month were taken based on the average load curve for all these sectors (i.e. all network loads).

It can be seen from the average load curve that the load in the beginning of January started to decrease and continuously decrease until April when the lowest load was registered in the year. Thereafter, the load increased at the end of April and continued rising until August when there is peak load, which shows that the highest electricity consumption were in August and July respectively. At the end of August, the load starts to decline in September and October, being further cut down in November and continue to rise again in December.

But can the energy load ratio vary in the coming years? And can the energy demand intensity of each month change from the current situation? Also one cannot take the values of these monthly energy loads because they represent the monthly energy loads for the year 2012, which cannot be similar in the coming years because energy demands are increasing annually. Because of that, the solution was in determining the monthly energy ratio based on the value of the average energy load recorded in that year (i.e. 2012) in order to extract energy ratio of each month to distribution the energy as ratios as illustrated in detailed calculations in Appendix 2 (Table paragraph 4). Accordingly, these energy ratios were used in the study to find energy demand expected in the coming years and that are required in the design for Brak City HRES as represented in Figure 4.8.

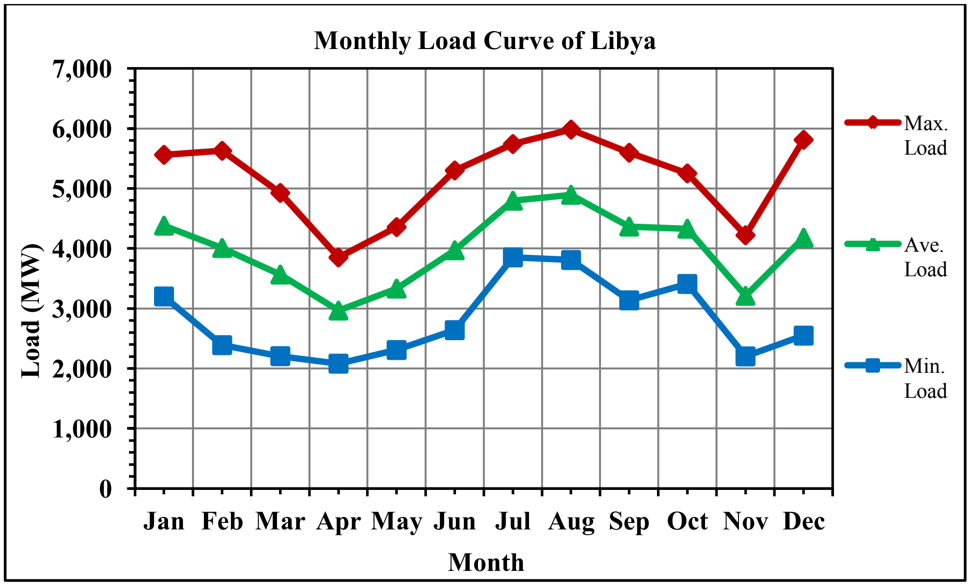


Figure 4.7: Monthly load curve of Libya's electricity network 2012 that used in design in order to determine the load ratio in each month for Brak City HRES, where the load ratio extracted is based on the average load values. (Source: GECOL, 2012, p.4)

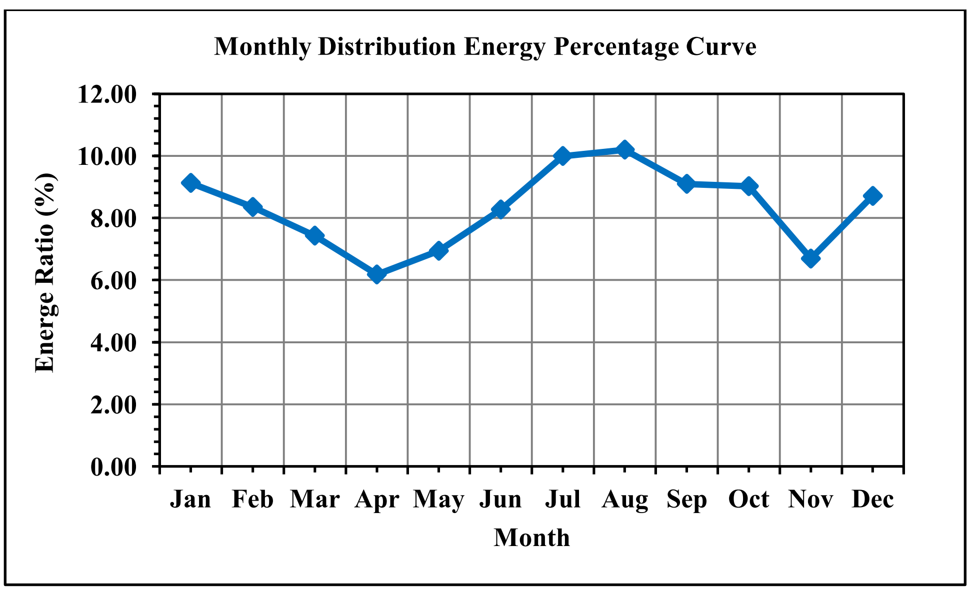


Figure 4.8: Monthly energy ratio used in the design of Brak City HRES, which is determined based on average monthly load values of Libya's electricity network in 2012 (Source: author)

4.3.4.2. Daily Load Ratio

The daily loads are important elements to build any energy system so as to identify the load frequency during a 24-hour period. In Libya, there are very few studies published about the hourly measured load and from which can be assess the daily load frequency and hourly peak load (to know the loads variation from hour to hour due to different demanded day-time activities). The study issued by GECOL in 2008 on the daily load curve shows that, in general, there are high differences in a 24-hour load curve in that specific year.

Therefore, in the study the average daily load curve for Libya's 2008 electricity network used in the design of Brak City HRES is represented in Figure 4.9, where the calculations of load ratio were based on the values of average curve. Thus, the method used to determine the daily energy ratio that is based on the average load value registered in that day is the same as the method used to determine the monthly energy ratio as illustrated in detail in Appendix 2, paragraph 5. Consequently, these energy ratios were used in the study to find daily loads expected in the subsequent years and as required in the design of Brak City HRES. The results of this calculation are represented in Figure 4.10, where as shown the loads begin to decline gradually due to decrease of electricity consumption between one o'clock and five o'clock 1:00 and 5:00, the period for the lowest load during day. Thereafter, the loads start to climb at 6:00 when the demand for electricity increases until 21:00, when the maximum load occurs in the day and then declines during the remaining hours of the day.

Therefore, these are the daily energy ratios used in the study, but these loads are constant daily for each day in the month, which means that the load ratio in the first day of month is similar to last day in the month in value. For example, the 24-hour load value on the 1st of January is the same load value in the 24-hour period on the 31st of January, as with other months of the year.

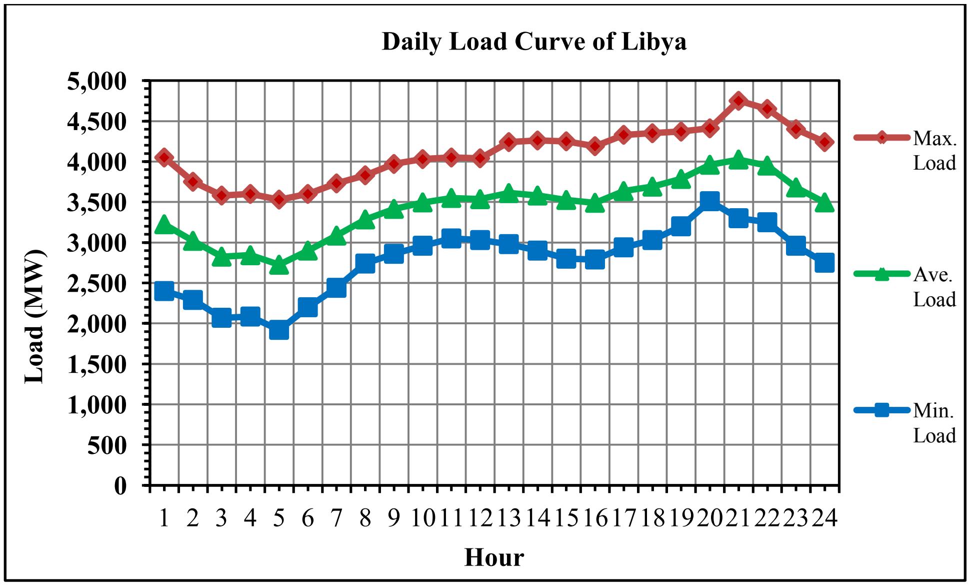


Figure 4.9: Daily load curve of Libya's electricity network in 2008 that was used in the design in order to determine the load ratio in each hour of the day for Brak City HRES, where the load ratio was extracted based on average daily load values (Source: GECOL 2008, p.6)

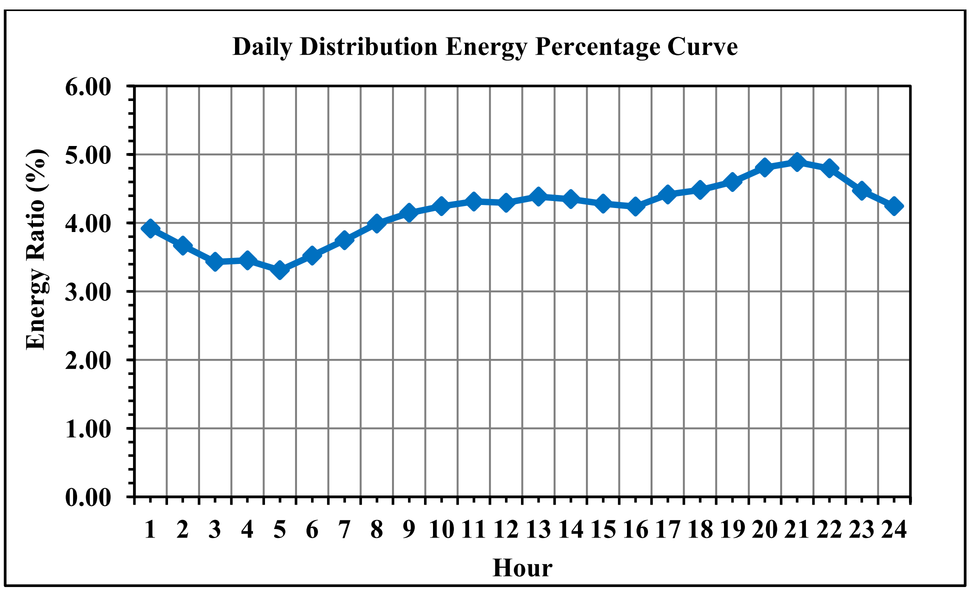


Figure 4.10: Daily energy ratio used in the design of Brak City HRES, which is determined based on average daily load values of Libya's electricity network in 2008 (Source: author)

4.3.5. Distributing the Load Based on Ratio

Furthermore, in this study the daily load is assumed to be equal for all month days, which means that the load in 1st day of January is the same load value in last day of January, as it is in other months, while the monthly load is different in January than it is in December. This assumption is necessary because no data about seasonal profiles a day-to-day variations are available. Figure 4.11 represents the near assumed monthly loads requirements, while Figure 4.12 depicts the daily load curve for each month according to hourly energy ratios.

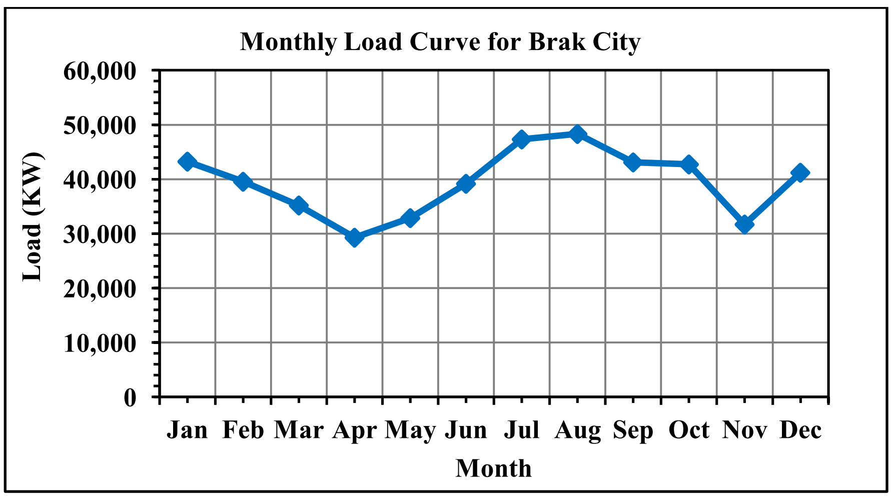


Figure 4.11: Monthly load outlook of Brak City in 2017 used in the design of Brak City HRES that was designed based on Libya’s monthly electricity load ratio network in 2012 with consideration of expected monthly energy demand in the region (Source: author)

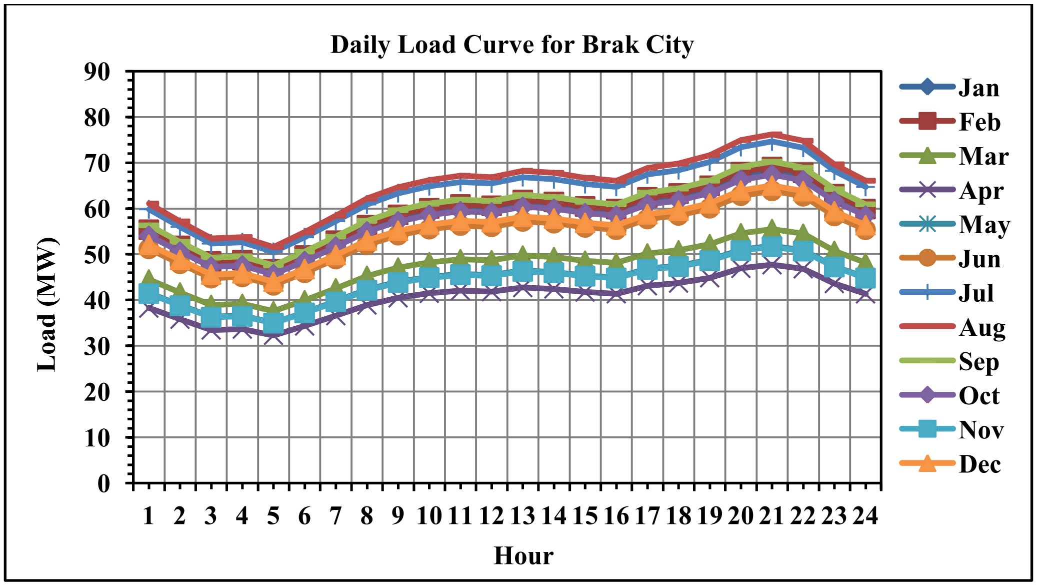


Figure 4.12: Daily load outlooks in each month for Brak City in 2017 used in the design of Brak City HRES that was designed based on daily load ratios of Libya's electricity network in 2008 with consideration to expected daily energy demand in the region (Source: author)

4.4. Project Site Selection

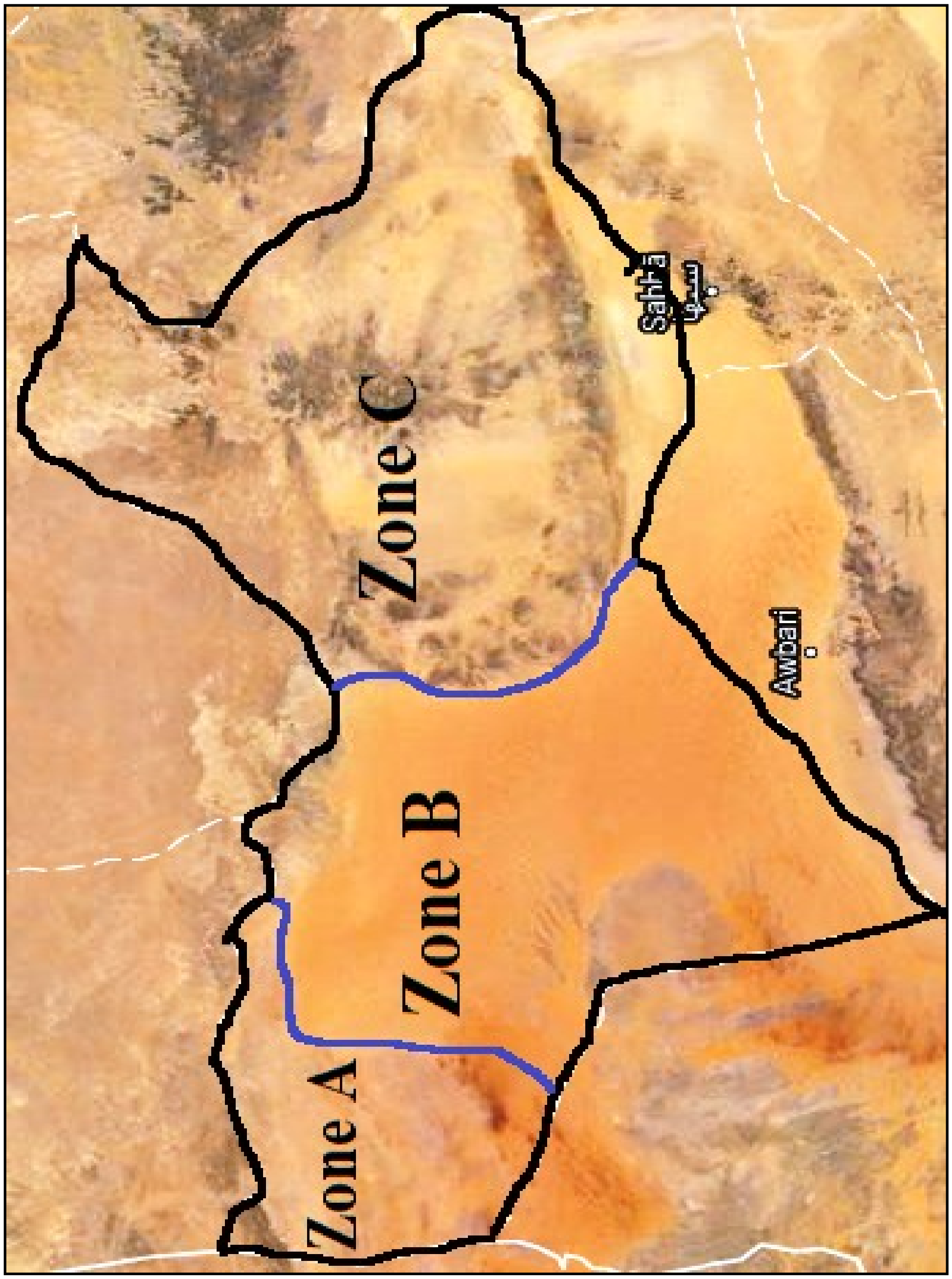
Site selection for establishing the RE system must be based on various fundamental factors, such as natural resource, climate, type of RET, accessibility to public utilities and surrounding area of potential sites. These elements are complementary to each other, for example, RE sources may be available at a site, but the nature of the climate shift between implementation of these technologies. In particular, a desert climate where dust is prevalent, like in the Brak City region, can be a hindrance. Therefore, in the study these elements have been considered in order to specify a suitable place to construct the Brak City HRES.

To achieve that, the project site was selected based on selections criteria, which are related to region requirements needed to select a suitable project location appropriate for current and future demands of the region. At first, the Brak City area was portioned into three zones to explore all areas and make carefully decisions related to the selection of an appropriate site on which to build the Brak City HRES, as shown in Figure 4.13a. For this reason, zone A is located away from building complexes, the national electricity network as well as difficult landforms, thus is not beneficial to establish the project in this zone. With respect to zone B, it is also semi-useful because the landform mostly consists of sand and sand dunes which makes construction of an RE system difficult, if not almost impossible, and uneconomically sound because of the impact the sand and dust will have on RE technologies, whether solar or wind energy. Zone C is more suitable for building the Brak City HRES because it consists of villages and residential areas, as well as local and national electricity grid and roads located inside this zone, that are developing economically and socially in comparison to other regions. Consequently, zone C was selected for the construction of the Brak City HRES project because it is more suitable than the other zones.

To conducting the study with widely feasibility, seven locations were selected to establish the project upon, which cover zone C as shown in Figure 4.13b. Thus, the selections criteria were applied to assess a suitable project location.

The selections criteria and a discussion of their assessment are represented in Table 4.3, where location 2 (i.e., L2 on the map) was identified as the final selected location because it satisfied the criteria more suitably compared to the other locations. The assessment score was between 1 and 5, whereas 1 was considered as the most satisfactory and 5 was the least satisfactory. In regards to solar radiation and wind speed data, they are approximately equal in the locations, as defined by a RE website developed by NASA (2013)[37], where the measurement was based on 22 years of historical data between 1983-2005 (the RE resources of the locations are represented in Appendix 3)

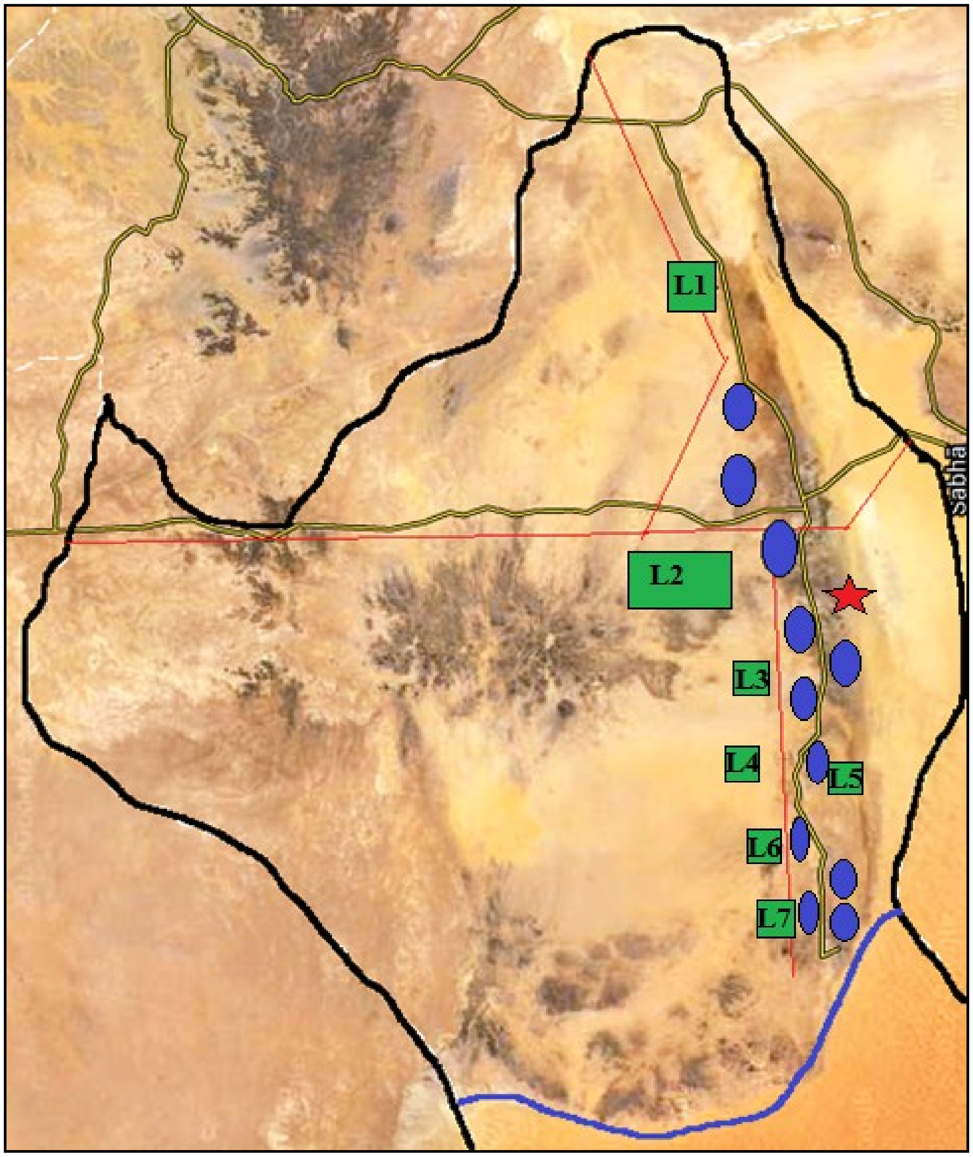
[37] NASA Surface Meteorology and Solar Energy website, online. Available at: https://eosweb.larc.nasa.gov/sse/RETScreen/ [Accessed: 05th August 2013].



Map keys	
(black line)	The administrative division border of the Wadi Al Shatii municipality according to Libya government division in 2007.
(blue line)	The zones border for the Wadi Al Shatii municipality made by the author in order to discover the RE technologies that were possible in the region in detail.

Figure 4.13a: Satellite map of Wadi Al Shatii municipality and Brak City region with detailed zones (Source: Google)[38]

[38] Google website, online. Available at:



Map keys	
	High voltage transmission lines
	The main electricity station of Wadi Al Shati municipality
	Selected locations to construct the Brak city HRES
	Location of the villages and residential complexes of Wadi Al Shatii municipality.

Figure 4.13b: Satellite detailed map of zone C with selected project locations

https://www.google.de/maps/search/Wadi+Al+Shati+municipality/ [Accessed: 26th February 2015].

Table 4.3: Locations assessments and selection of the project site

Selections criteria / indicators	Discussion	Locations assessment.							Location winner
		L1	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	
Access to electricity lines grid.	To what extent after power lines, both local and national, where the cost will be less, and the distance less between the station and the electricity distribution lines.	3	2	3	3	4	4	3	L2
Access to energy station in region.	To what extent after power lines, both local and national, where the cost will be less, and the distance less between the station and the electricity distribution lines.	3	1	3	3	4	4	4	L2
Surrounding area activities.	What are the other actors that can provide electricity in case there is a surplus in production, and are intended to other sectors such as agriculture and industry.	3	1	3	4	3	4	4	L2
Population density	Where is the most densely populated areas in the region.	4	1	3	4	4	3	3	L2
Solar radiation.	Annual average solar radiation in the location, as irradiation is high the productivity will increase.	1 5.7	1 5.7	1 5.7	1 5.7	1 5.86	1 5.86	1 5.86	All
Wind speed.	Annual wind speed in the location that refers to production capacity, whereas high speed yields productivity increases.	1 4.3	1 4.3	1 4.3	1 4.3	1 4.3	1 4.3	1 4.3	All
Landform.	Landform type consists of mounts, sand dune or rocks, which are important in terms of construction and installation of the system components.	2	2	3	3	4	4	3	L1 & L2

Temperature.	Ambient temperature in the location, where the high temperature will have an effect on production efficiency, especially in solar energy.	1 22.3	1 22.3	1 22.3	1 22.3	1 22.2	1 22.2	1 22.2	All

In summary, location 2 has been choose to establish the Brak City HRES, which is shown in Figure 4.14 represented by the satellite map of the selected location. The other parameters, which are considered in the design of Brak City HRES, such as the natural resource data, site coordinates and climate required to simulate HOMER are shown in Table 4.4.

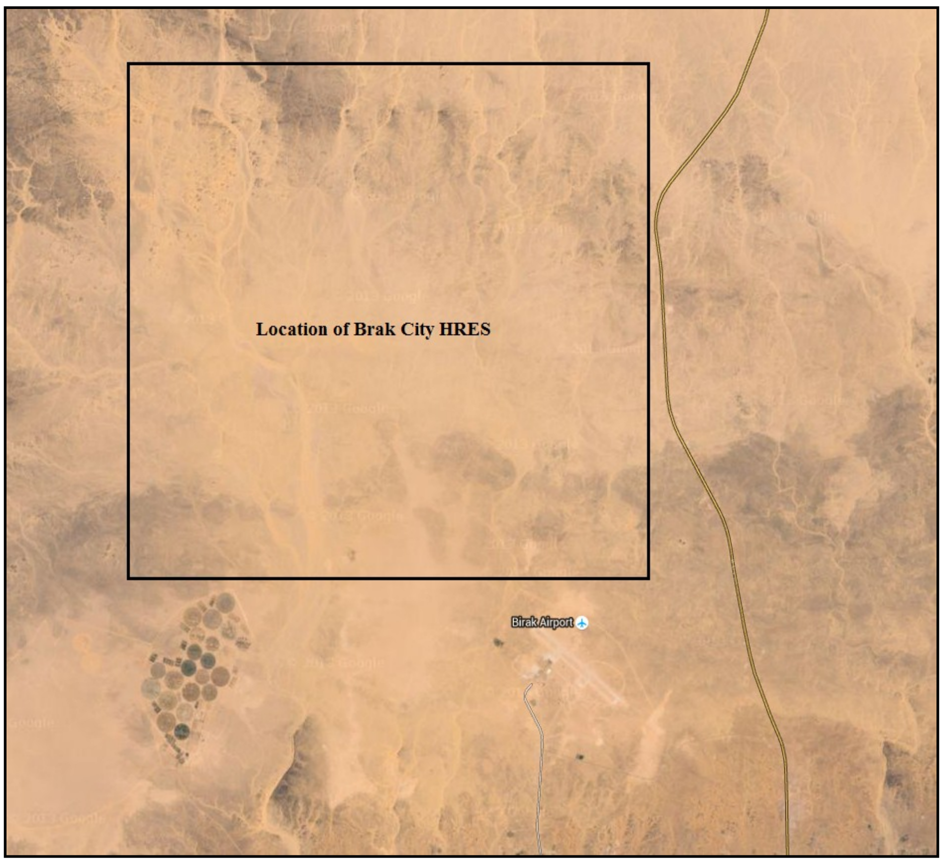


Figure 4.14: Satellite map for the selected location (L2) of the Brak City HRES[39] (Source: Google map)[40]

[39] Note that all details on the map of Figures 4.14 and 14.15 are not to scale, where the project locations, villages locations and the national electricity line network are presented on the map in approximation to their real location, as estimated by Google Earth.

Table 4.4: Details and characteristics of the site for the Brak City HRES

Item	Description
Place of project	North of Brak City (30 km from town center)
Measurement date	05.08.2013
Coordinates of the place	Latitude 27°41'13" North, Longitude 14°16'22" East.
Landform	Land almost flat
Annual average daily radiation	5.7 $kWh/m^2/d$
Annual average daily wind speed	4.3 m/s

4.5. Conclusion

The study conducted in this chapter and upon the selected case study area shows that there is considerable potential for solar and wind energy in the region. The other RE technologies, such as biomass energy, geothermal energy and hydropower energy, are not readily available in the region, despite that geothermal energy can be implemented theoretically in technologies based on the interior heat of the earth, such as GHPs technology. Also, like other districts of Libya, RET has not been used in the region and presents an energy system that depends entirely on fossil fuel to generate electricity.

Consequently, solar energy represented in PV technology and wind energy represented in HAWTs technology will be used in the design for Brak City HRES. Brak City was selected as a case study area in order to design HRES specifically for this region and to discover the advantages and roles for using RET in this region, as well as to consider and scale the key findings of this study for other regions of Libya. As discussed earlier in this chapter, there were many reasons for selecting Brak City for HRES design (see paragraph 4.2.1.).

[40] Satellite map for Brak City HRES taken by Google Earth, online. Available at: https://www.google.de/maps/search/Wadi+Al+Shati+municipality/@27.708171,14.3140971,12z/ [Accessed: 3rd March 2015].

5. Brak City Hybrid Renewable Energy System Components and Assumptions of Models Inputs

5.1. Primary Electrical Load of System

Figure 5.1a gives an impression which general system data input is necessary. The load demands for the Brak City HRES have been entered, as previously designed and determined (in paragraph 4.3). The load type specified as AC load. The designed loads are set identical for all days of a month (as illustrated in paragraph 4.3.6). The reason for the decision to indicate the all as weekdays and set the random variability to zero, is the as mentioned in paragraph 4.3.6, the missing of a database from which seriously such difference between weekday and weekend day respectively such variation percentages can be estimated.

After entering these values, the system is calculating load curves and monthly load curve (see Figures 5.1b and 5.1c). It can be seen that these calculated load profiles are identical with the in chapter 4 (see Figure 4.11 and 4.12) developed load profiles.

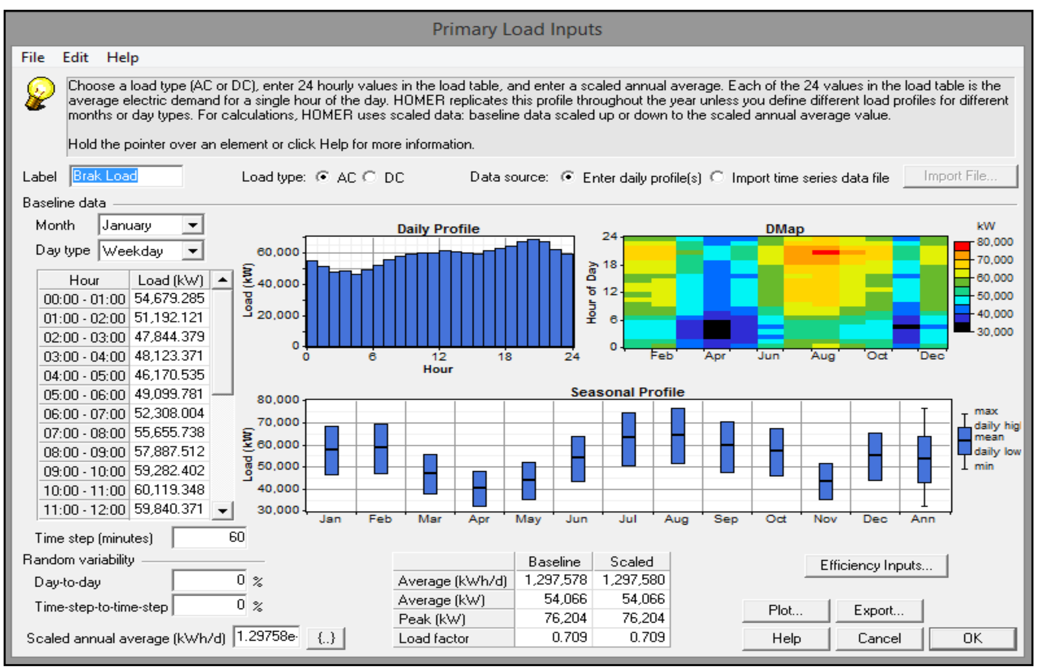


Figure 5.1a: Primary electrical load for Brak City HRES

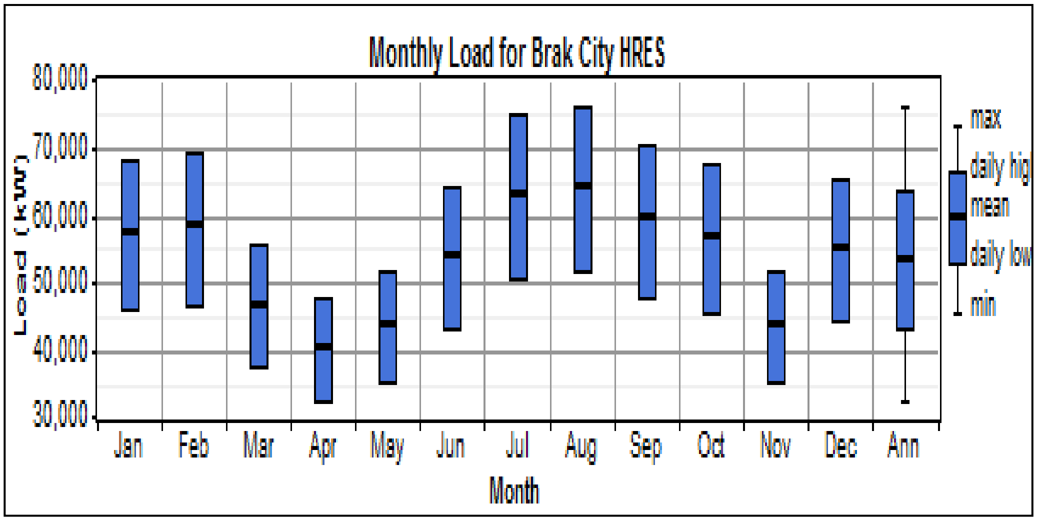


Figure 5.1b: Monthly load profile for the Brak City HRES (indicated as sessional profile in Figure 5.1a)

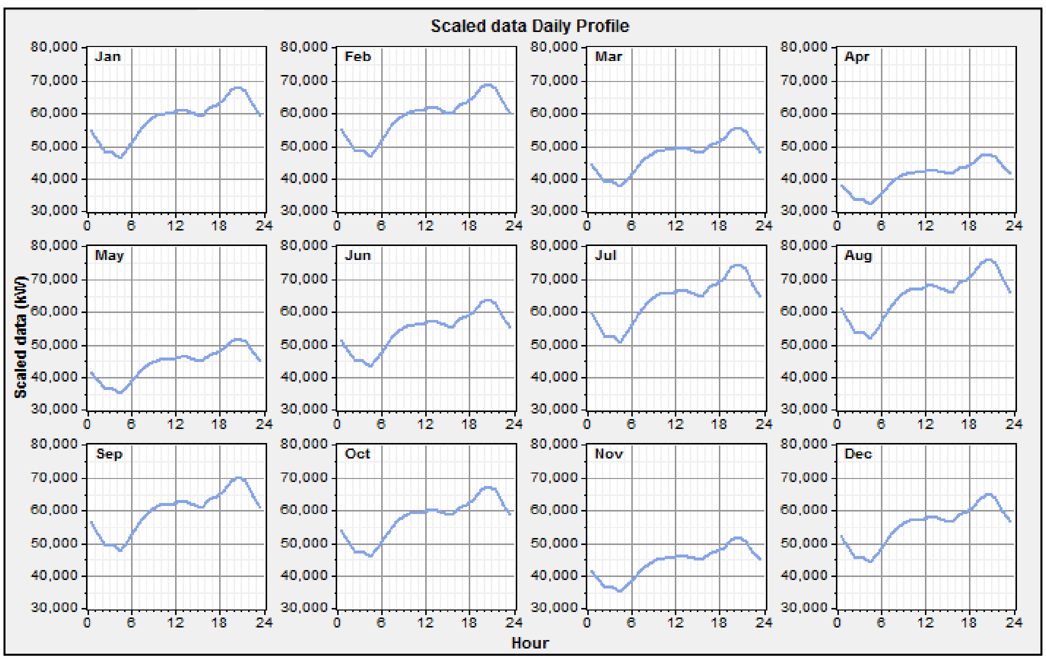


Figure 5.1c: Daily load profile of each month for the Brak City HRES calculated by the software

5.2. Data Selection for the Major Components of the Hybrid Renewable Energy System

5.2.1. Photovoltaic Panel

The price of PV modules and their installation cost is expensive compared to conventional electricity devices such as diesel generators. Especially additional components such as a tracking system, monitoring and controlling system which must be adjusted to the kind of PV panels and their efficiency, make the installation of PV solar panel expensive (IRENA, 2012d, p.19-20). Based on that, the selection of the appropriate technologies of the PV module is a key element managing the cost of the solar energy system.

The study issued by IRENA on installed PV system shows an impressive decline of their installation costs. From 2010 to 2015, it varied from 3600-5000 $/kW (in 2010) to 2500-3400 $/kW (in 2015) for amorphous silicon (a-Si) thin film, while the installed cost for cadmium telluride CdTe and copper indium gallium selenide (CIGS) was between 3600-5000 $/kW (in 2010) and from 2500-3500 $/kW (in 2015) (IRENA, 2012d, p.41). On other hand the study shows that the PV panel efficiency increased and developed: from 8-11% in 2010 to 11-12% in 2015 for a-Si thin film, and from 11-12% in 2010 to 13-17% in 2015 for CdTe thin film and CIGS thin film. As a result, the cost decline by 30% during those 5 years and efficiency increased (IRENA, 2012d, p.41).

Libya does not have an industry association or solar technology market, or any kind of related activities in this area; for that reason the PV module costs were taken based on these studies with consideration of the project site character, region climate and suitable technologies. Therefore, in the study, the CdTe thin film PV panel module was specified to use with capital cost of 3000 $/kW, which represented the average installed cost estimated by IRENA (2012d, p.41). The cost includes the PV subsystem, which including shipping, mounting hardware, wiring, tracking system, transportation to the project site and installation requirements. If the current trends continue for cost reduction the replacement cost after 20 years will be 720.3 $/kW, but there can be no guarantee cost reductions will be continuous or that solar panels will maintain a life of 20 years. Based on these assumptions, the replacement cost assumed to capital cost decreased by 30% which equal to 2100 $/kW. The operation and maintenance (O&M) cost for PV panel is very little and not required for the panels, despite that 60 $/kW is assumed as the cost yearly for cleaning, changing the required wiring and checking system connections.

The detailed overview of PV system cost and the parameters considered in the study are illustrated in Table 5.1, while Figure 5.2 shows all these parameter inputs by HOMER. The tracking system applied is indicated along the horizontal axis with daily adjustment and tilted to the south, at an angle equal to the latitude of the site, with the intention of choosing this kind of tracking so as to capture the sun as efficiently as possible, which will give more energy output as well as to avoid the accumulation of sands and dusts in the case of using fixed track system. The derating factor is assumed to be 90%; this factor reduces the PV panel production by 10% taking into consideration the effect of temperature and dust on the PV panel (HOMER energy, 2014)[41]. Consideration to the effect of temperature on cell PV panels has been taken into account too, to measure the real production of the PV panel.

Related to the PV sizes system, Kreith and Kreider indicated that "PV systems are usually sized based on the average values of energy and power needed, available solar radiation, and component efficiencies" (2011, p.400). In the study, the PV sizes assumed based on this concept, and considered based on power needed in the system, are assumed and adjusted to the energy demand after the HOMER simulation and several tests in order to meet the required load.

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[41] HOMER energy website, online Knowledge database support portal. Available at: http://usersupport.homerenergy.com/customer/en/portal/[Accessed: 19th May 2014].

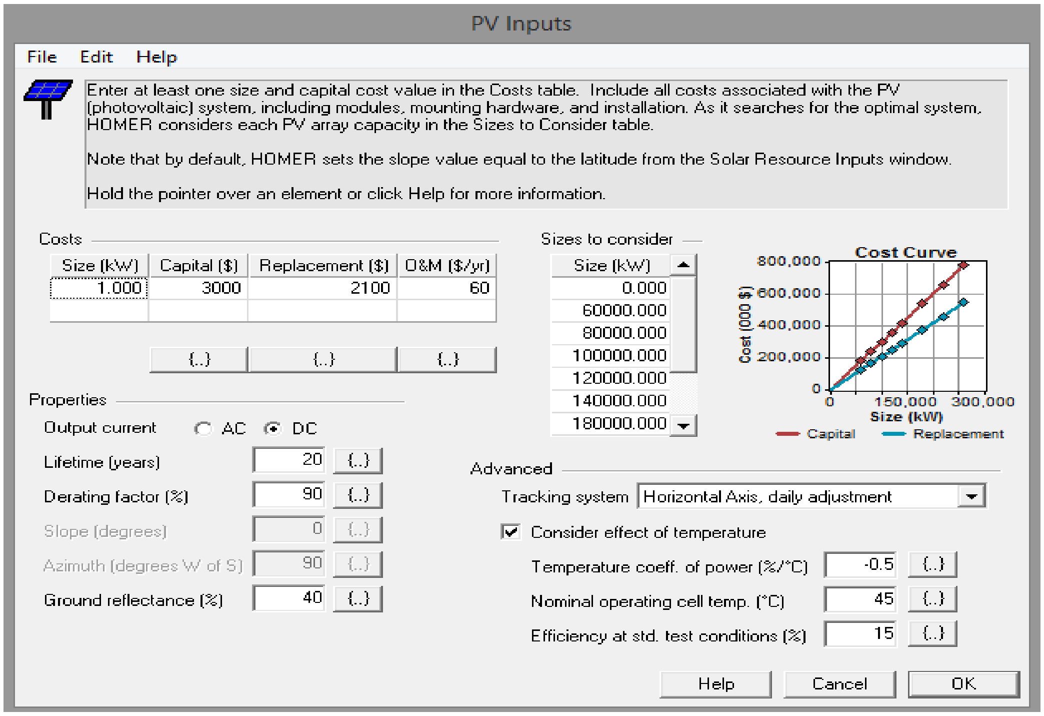


Figure 5.2: PV system input values used to design the Brak City HRES

Table 5.1: Input values summary of the PV system and parameters assumption details

Parameters	Value	Assumption discussion/ references
Capital cost	3000 $/kW	The cost assumed in average cost of estimated installed cost for utility-scale PV system, where it is assumed based on the study conducted on the international market assumption for utility-scale PV system in 2015 (IRENA, 2012d p.41).
Replacement cost	2100 $/kW	The replacement cost in the study assumed as reduction of 30% of capital cost for PV system, which considered the decline in price by 30%.
O&M cost	60 $/kW/yr.	The cost assumed based on the O&M cost estimation in the desert such as in the Brak City HRES location (Electric Power Research Institute (EPRI), 2010, p.9).
Life time	20 years	The majority of the manufacturers provides the lifetime of PV panel as 25 years. In the study assumed in 20 years because can affect through area climate where project located in the desert area.
Derating factor	90%	This value is assumed to consider the effect of temperature on the PV array, typically around 90% (HOMER energy, 2014).
Ground reflection	40%	This is a typical value for the desert area such as in the Brak City region, estimated as 20% in grass-covered areas and varied between

		0.07-0.10 in ocean areas (Coakley, 2003, p.21).
Tracking system	Horizontal axis daily adjusted	This kind of tracking system has been assumed in the study to capture the sun as much as possible during day time, as well to avoid the accumulation of dust which can occur in cases where fixed tracking systems are used.
Temperature coefficient of power	-0.5 %/C	This value depends on the type of PV model; it commonly varies from -0.20 to -0.60 (%/C) and the assumption was based in that range (HOMER energy, 2014).
Nominal operation cell temperature (NOCT)	45°C	These values vary from 45°C to 48°C typically, as specified depending on technical data of the PV module, so the assumption was in this range (HOMER energy, 2014).
Efficiency at Std. test condition	15%	Also, the efficiency is different depending on the kind of panel and its technical data; it varies from 11-17% in current PV module types. Therefore the assumption was in average value of CdTe thin film PV panel module (in 2015) that has been specified to use in the design as illustrated above.
Size to consider	60,000 kW 80,000 kW 100,000 kW 120,000 kW 140,000 kW 180,000 kW 220,000kW 260,000kW	The PV sizes adjusted based on energy load required in the system, as discussed above.

5.2.2. Wind Turbine

Wind turbine is essential in determining the cost of HRES too, considering it is very cheaper technology compared to solar panel installation costs. For this reason, industry companies and international associations pay attention when choosing suitable wind turbine technology that is commensurate with the location characteristics and region demands. Nowadays, various markets of wind turbine industries offer the technology at different prices and qualities. The study conducted by IRENA classifies the typical installation cost of wind turbine into three international markets: China and India, Europe and North America (IRENA, 2012e, p.42). Also there is a big and growing industries market in the wind turbine sector, which are introducing many kinds of wind turbines with different classifications and technologies, such as output capacity and purpose of use; in general, all of them are equal in terms of producing energy which makes the selection of wind turbine technology more difficult.

Thus in this case study, the installation cost, based on the Europe market, for wind turbine was taken into consideration for the design. Costs vary from 1850 to 2100 $/kW for onshore wind farm, and the O&M cost varies from 0.013 to 0.025 $/kWh (IRENA, 2012e, p.43-44). The reason for choosing the Europe market price instead of others is due to the high quality of wind turbines as well as the big size of this sector in Europe, which offers wider options for selecting wind turbines. Furthermore, the wind turbines used in the design of Brak City HRES are European (German made) hence the relevant market price has been chosen. Other parameters must be taken into account, including wind farm capacity, wind speed and land property as well as investment policy, which can increase the cost. As an example, in terms of project land, in most cases, such land is rented in most of European countries, whereas in Libya, such land is state owned and there is no cost for renting it; conversely, Libya has no industries in the wind turbine field, which means it must be imported thus making the cost higher.

The wind turbine installation cost share is 65% to 84% of total cost for an onshore system, with construction cost, grid connection and miscellaneous costs making up the balance (IRENA, 2012e, p.19). Modern wind turbines have two or three blades, and the most widely used at present is that with three blades with horizontal axes (i.e., HAWTs). This was concluded from the study issued by Michaelides which states that "typically, the modern turbines have two or three-blades and their design and operation have been optimized to produce maximum energy from the prevailing local wind conditions" (2012, p.235). The other study shows that "The most popular configuration for power-generating wind turbines is the upwind three-bladed Horizontal Axis Wind Turbine (HAWT)" (Kutz, 2007, p.120). Consequently, in the design of the Brak City HRES the HAWT type with three blades has been selected.

Additionally, in the study two wind turbines ENERCON E-101 and E-82 E2 have been used in the design in order to identify the suitable wind turbine to use, where the cost and technical parameter values of selected wind turbines are represented in Table 5.2. The reasons for choosing this kind of wind turbines instead of other kinds are presented as follows:

- Based on the average wind speed in the project location (4.3 m/s), which can produce energy in excess of 82 kW.
- To know the advantages and disadvantage of using two types of wind turbine, and which one optimal to use.
- Using wind turbines with high output capacity, such as E-101, require less land use; since the Brak City HRES is considered as a large-scale system, it could be more logical to use large wind turbines instead of small ones which need more land, as a best practice lesson learned from developed countries in this field (IRENA, 2012e, p.34).

The HOMER input values for wind turbines that were used in the design as shown in Figure 5.3a, and 5.3b, while technical data and wind turbine detail for each one is represented in Appendix 4. Also, a sensitivity study in wind turbine hub height for each wind turbine type was included in the study in order to specify the suitable hub height for each wind turbine. This sensitivity study based on hub height for wind turbine E-82 and wind turbine E-101 as well as the system components sizes that have been used in the design of Brak City HRES. The result of this simulation presented in Table 5.3, where the system simulated in several times using one wind turbine hub height as recommended from manufacturer in each time (see technical data for wind turbines in Appendix 4). As shown that the COE is influenced due to wind turbine hub height values in wind turbine E-82, while does not influenced in wind turbine E-101. In result the hub height 138 m for wind turbine E-82 was chosen in design, because gives less value of COE, and the 99 m hub height for wind turbine E-101, where the COE does not changed by hub height for E-101 even in high values.

Table 5.2: Wind turbine cost and parameters assumption details

Parameters	Values		Assumption discussion / references
	Wind turbine E-82	Wind turbine E-101	
Rated power	2000 kW, AC	3050 kW, AC	The maximum power output by wind turbine as recommended from the manufacturer (ENERCON, 2015, p.12 & p.22).
Capital cost	1,642,500 USD	3,650,000 USD	By assuming the cost as 1825 $/kW, where this value represents the average installation cost in the Europe market as discussed above.
Replacement cost	1,511,100 USD	3,358,000 USD	By assuming the cost declined by 8% of capital cost, where typical price declined by 7-10% as mentioned in the study issued by IRENA, thus the cost is assumed in that range (2012e, p.35).
O&M cost	31207.5 USD	69350 USD	The O&M cost assumed by 0.019 ($/kwh/yr), where this value represents the average cost in the Europe market as discussed above.
Hub height	138 m	99 m	These values selected based sensitivity study as well as tested and simulate the design in several times and comparing the result with COE in each one as discussed in previous.
Lifetime	20 years	20 years	Majority of manufacturers attribute wind turbine lifetime as 20 years. The study assumes this as accurate.
Size to consider	50, 75, 100, 125, 150 and 175 quantity	50, 75, 100, 125, 150 and 175 quantity	The wind turbines sizes adjusted based on energy load required in the system.

Table 5.3: Sensitivity study on wind turbine hub height versus COE

Wind turbine E-82		Wind turbine E-101	
Hub height (m)	COE ($/kWh)	Hub height (m)	COE ($/kWh)
87	0.163	99	0.163
85	0.162	135	0.163
98	0.161	149	0.163
108	0.161	-	
138	0.159	-	

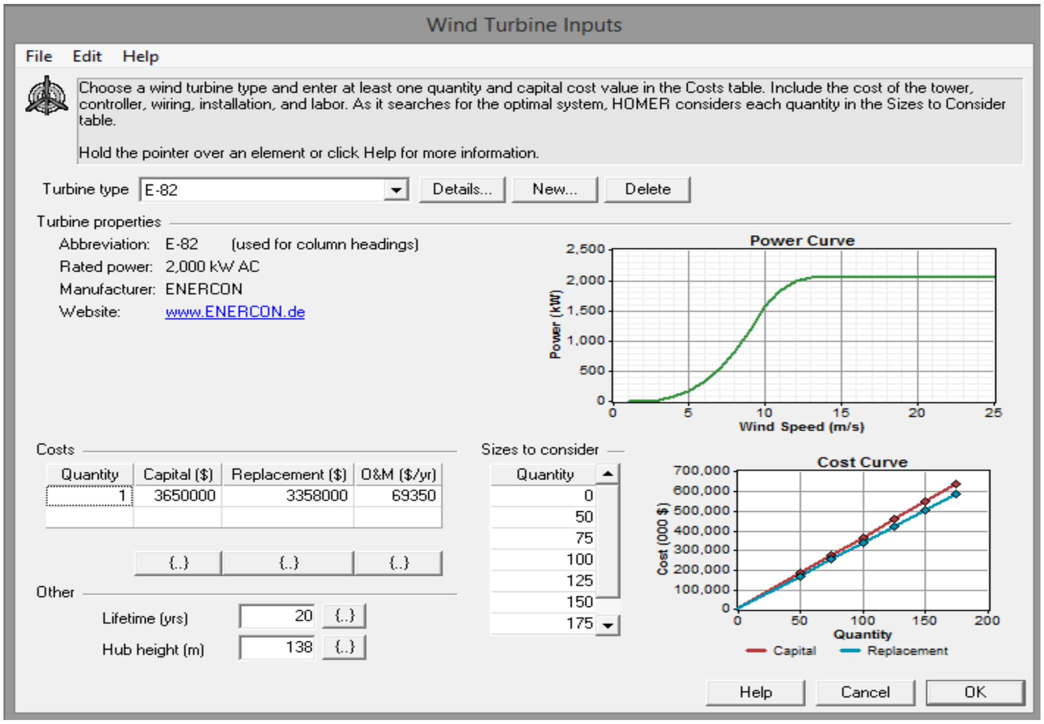


Figure 5.3a: Wind turbine E-82 input values used in the design of Brak City HRES

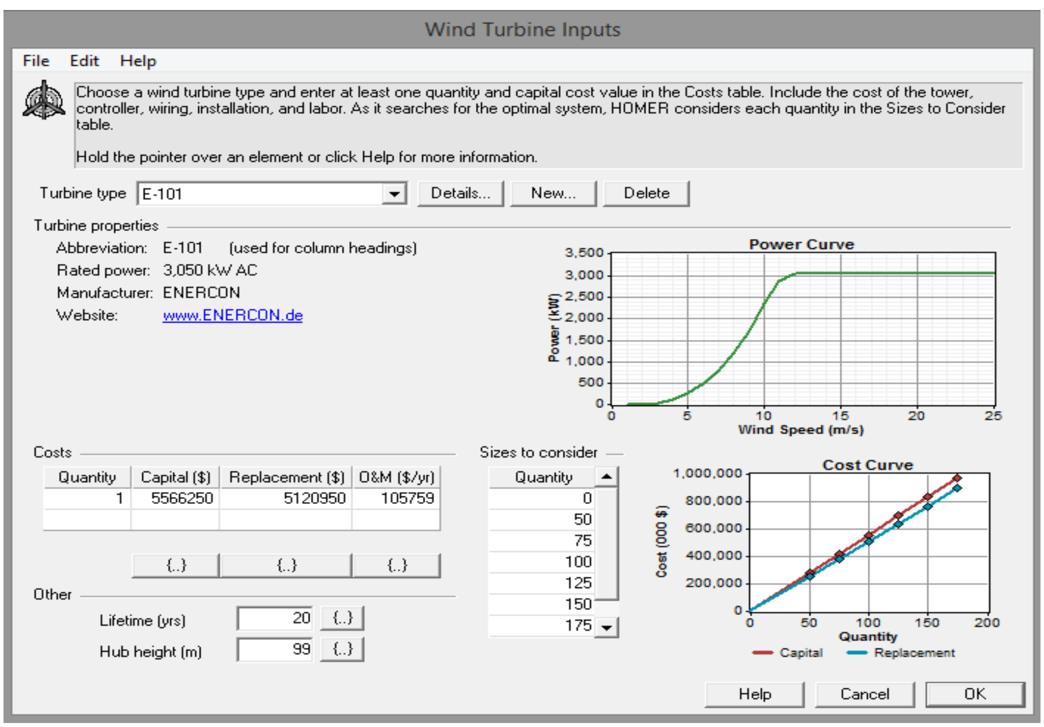


Figure 5.3b: Wind turbine E-101 inputs values used in the design of Brak City HRES

5.2.3. Generator

There are big industries and manufacturers that provide different kinds of electrical generators with different technologies; this makes it difficult to choose the proper technology. HOMER simplifies this by listing different types of fuel, which enables the designer to classify the kind of generator according to fuel type. In Libya, most electricity production is done by diesel generators such as in Brak City region; this was the rationale behind the decision to choose the use of DG in the design instead of other types of fuel, such as gasoline or gas. Figure 5.4 shows the generator inputs and some data that HOMER requires to simulate the system components, whereby the DG, specified as AC type, produced and minimum load ratio by 30%. The minimum load ratio used to avoid the run the generator at low load value, where has effect on corrosion and a shortening of lifetime or at least increased maintenance cost for DG, where running the generator below than 25% can occur that, for this reason assumed greater than this value (HOMER, 2016)[42].

The capital cost is assumed to be 800 $/kW including all the installation costs and requirements of the system, while the replacement cost is assumed to be 600 $/kW. The O&M cost is assumed as 0.03 $/kW/hour. The estimation of the cost and O&M of the generator was based on trend market, while load ratio and lifetime were derived from the HOMER online portal (2014; 2016), which supports the several capacities of the DG and their expected lifetime.

[42] HOMER energy, online support portal. Available at: http://usersupport.homerenergy.com/customer/en/portal/articles/2188635-generator-minimum-load-ratio [Accessed 15th September 2016].

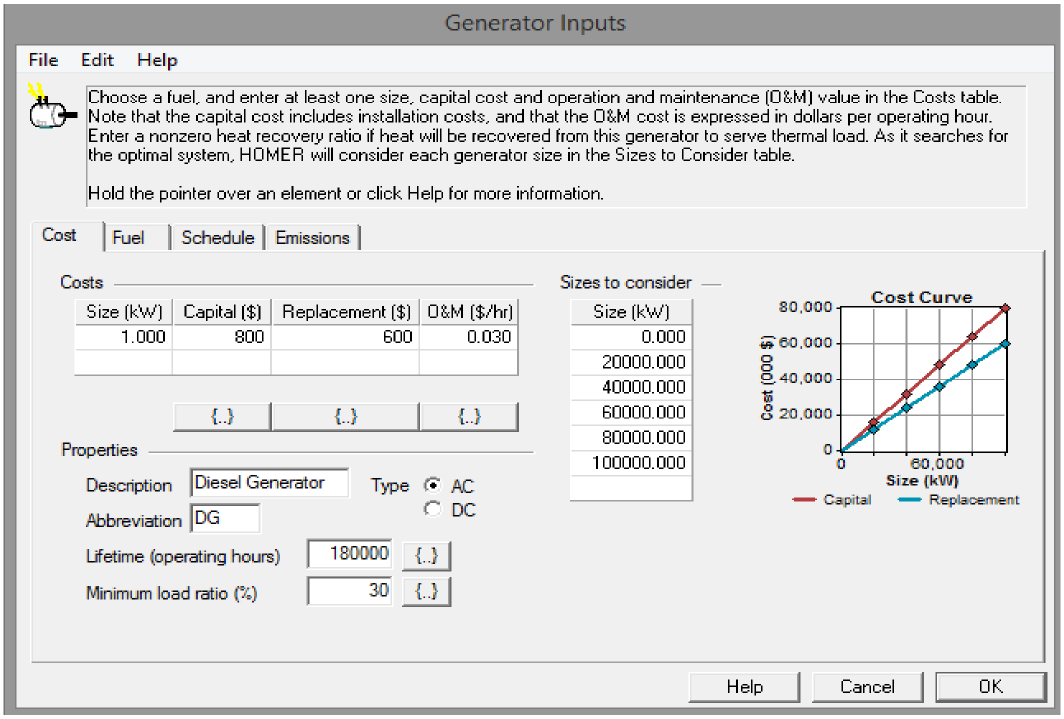


Figure 5.4: Generator inputs values used in the design of Brak city HRES

5.2.4. Converter

A converter, or inverter, is the device that converts electricity from DC to AC, which is one of the major components in HRES. The inverter typically accounts for 5% of the total installation cost in the system, where the cost range is between 0.27 $/W to 1.08 $/W, which differs depending on the system size. In a large-scale energy system, the inverter cost varies between 0.23 $/W and 0.57 $/W, while the cost ranges from 0.31 $/W to 1.03 $/W in small-scale system applications (IRENA, 2012d, p.20).

Therefore, in the study the cost converter was assumed in range of typical cost, where the capital cost is 700 $/kW, and the replacement cost was assumed by 550 $/kW. The O&M cost of an inverter is rare to require despite being assumed as 3 $/kW/yr.; these costs are taken according to international pricing estimates with consideration specific to the project site, such as transport to the location, shipping and installation requirements. The inverter efficiency and rectifier efficiency is assumed to be 90% and 85% respectively for all sizes considered in the system, and the inverter allowed operating simultaneously with the AC generator, as shown in Figure 5.5, which represented the converter inputs values that are need by HOMER to simulate the system components data and their parameters. Typically, the converter lifetime is 15 years, wherein the study assumed it as that (IRENA, 2011, p.55).

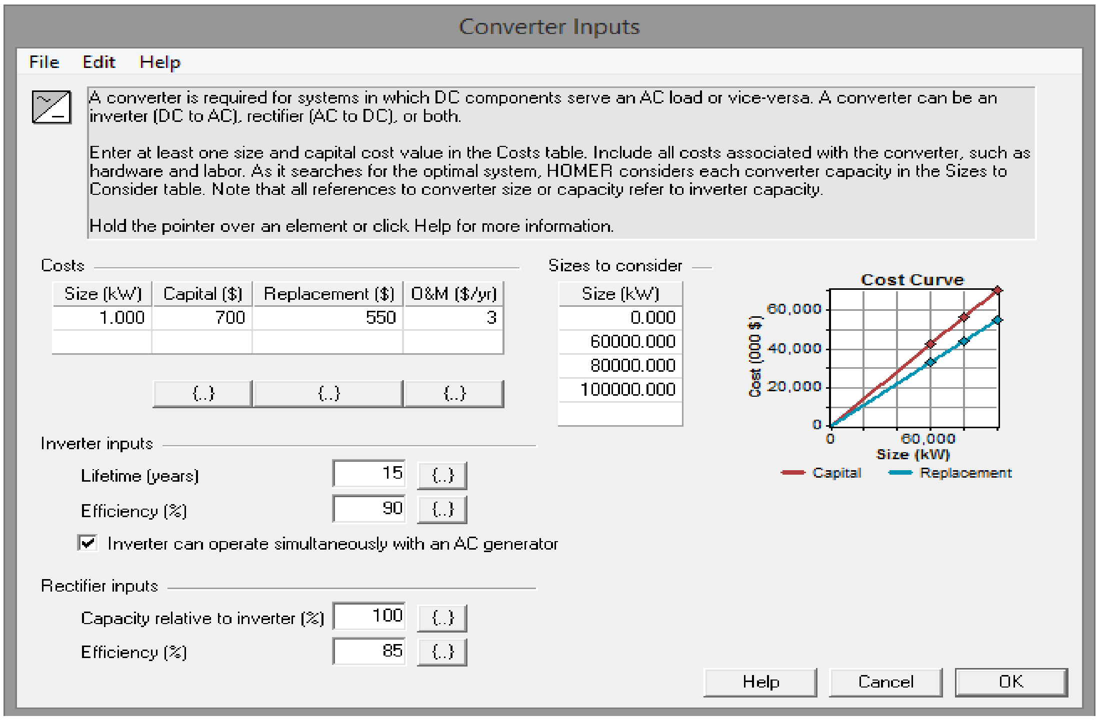


Figure 5.5: Converter inputs values used in the design of the Brak City HRES

5.2.5. Battery

The battery is responsible for storage of electricity, especially in a stand-alone system. In fact, the storage of electricity in a hybrid system is expensive because the system depends on the battery when there is not enough electricity produced from the system. The Surette 6CS25P have been chosen in the design of the Brak City HRES because they have a high storage capacity and can be store a large amount of electricity. It is a lead-acid type of battery, which is commonly used in RE systems, especially in PV systems as indicated by Foster, Ghassemi, and Cota "the most common types of batteries used with PV systems are lead-acid" (2010, p.145). Figure 5.6 shows the battery inputs that have been used and the battery's parameters.

The capital cost of the battery was $1200 and the replacement cost assumed to be $1000, while the O&M cost required to upkeep the battery is assumed to be 5 $/yr., where the price was based on the international market with consideration to shipping, transportation and installation requirements for the project location (the battery characteristics are detailed in Appendix 4, paragraph 6).

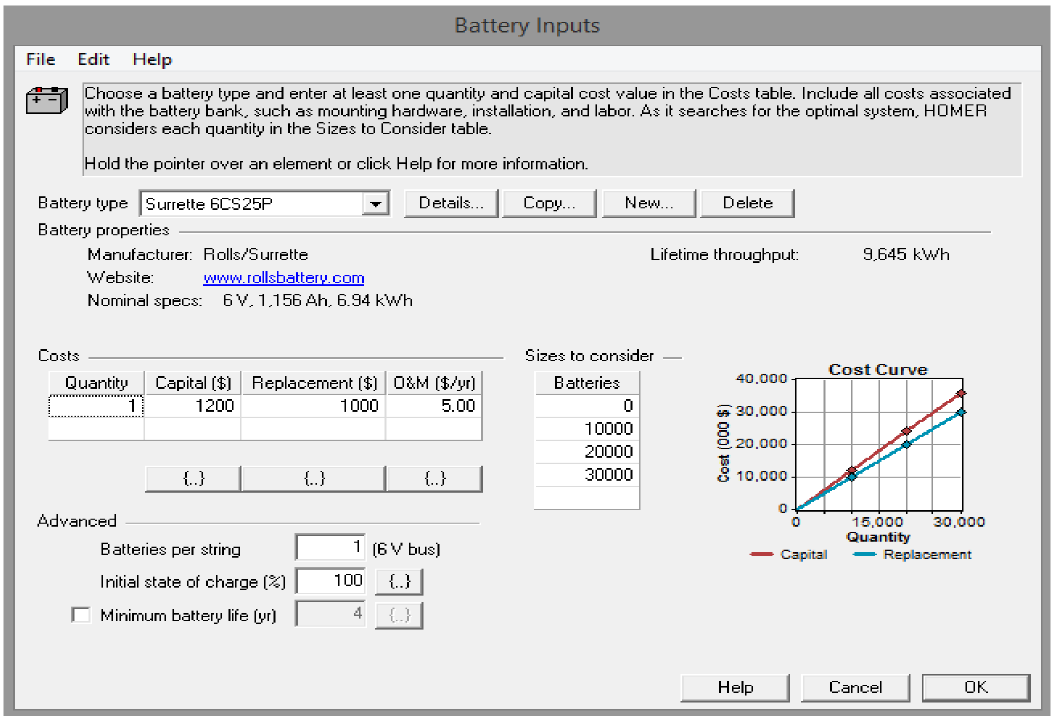


Figure 5.6: Battery inputs values used in the design of the Brak City HRES

5.3. Energy Resource

5.3.1. Solar Resource

The solar resource inputs are fundamental to calculate the PV array power output for each hour of the year. The essential performance of solar resource is based on solar radiation, which depends on location coordinates (i.e., longitude and latitude) and varies from one place to another. Williams explained, “to evaluate the economics and performance of systems for the utilization of solar energy in a particular location a knowledge of available solar radiation at that place is essential" (1974, p.3). The other study indicates the importance of solar radiation, as "detailed information about solar radiation availability at any location is essential for the design and economic evaluation of a solar energy system" (Kreith and Kreider, 2011, p.283).

The study input the daily solar average radiation and clearness average index for each month, which are measured previously (in chapter 4 paragraph 4.4, and with the solar source data of the selected location attached in Appendix 3) according to the latitude and longitude of the project location. Furthermore, the time zone was considered in the study to enable HOMER to simulate accuracy data based on local times for sunrise and sunset at the site in order to determine daily radiation.

As shown in Figure 5.7, there is high potential for solar horizontal radiation in the region, especially in July, June and August respectively when the average daily radiation is very high compared to January, February, November and December, when averages are very low. For the remaining months averages are close to the annual average value. In the design of HRES for Brak City is a sensitivity study included. In first line is the scattering of the clearness factor responsible for changes of the daily radiation. Unfortunately is the scattering of this clearness factors not known. Estimated are here that this clearness factor may be approximately 15% higher or lower than observed in average. This led on the one hand to 0.85*5.7= 4.85 kwh/m^2/d, which is nearly equal to the annual radiation average of Murqub district, therefore these Murqub district radiation values consideration here (see Appendix 1). On the other hand with 15% higher clearness approximately radiation values of Kufra district will be reached. This 6.37 kwh/m^2/d annual average of Kufra district value is therefore also clearness for this sensitivity analysis.

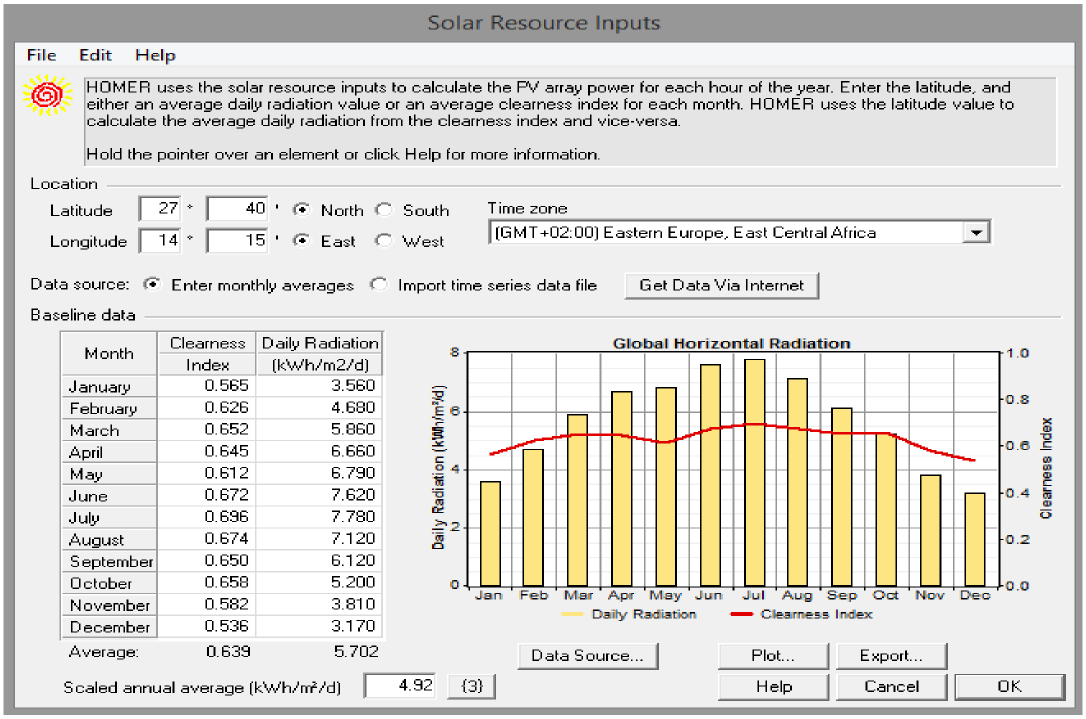


Figure 5.7: Solar resource inputs values for the site of the Brak City HRES

5.3.2. Wind Resource

The wind resource has been used in order to determine the wind turbine production capacity, which was determined by inputting the average wind speed for each month, which are measured as previously mentioned according to project site coordinates (again, in chapter 4, paragraph 4.4, with and the wind source data of the selected location attached in Appendix 3).

The wind speed potential in the site, represented in Figure 5.8, shows the wind speed varying from 3.9 m/s to 4.9 m/s due to difference of season, whereas the high wind speed values are in May, April, June, March and July respectively, while it is semi equal in remaining months. The annual average wind speed values were scaled into three values to conduct a sensitivity analysis similar as done for solar resource and as simplification for the real but unknown scattering of annual wind speed values, the wind conditions of other region of Libya considered here:

- Annual average wind speed of 4.3 m/s, which represents the real annual average value of year months in Brak City region.
- Annual average wind speed of 3.9 m/s, which represents the annual average wind speed in Butnan district, where considered the minimum wind speed of Libya districts (see Appendix 1).
- Annual average wind speed of 5.2 m/s, which represents the annual average wind speed in Marj and Benghazi districts, where considered the minimum wind speed of Libya districts (see Appendix 1).

The rationale for conducting a sensitivity study on wind speed with different values is to measure wind power production in the case that wind speed is lower or higher than the annual average value, and to determine if can meet the load demands in this scenario. The assumption parameters related to wind source are shown in Table 5.4 with discussion.

Furthermore, sensitivity study conducted on advanced parameters of wind turbine with comparing the results with COE in order to specify the suitable value to use in the design. This sensitivity study based on Weibull k value, 1-hr autocorrelation factor, diurnal pattern strength and hour of peak wind speed value as well as the system components sizes that have been used in the design of Brak City HRES. Likewise, other sensitivity study, here the system simulated in each one by using one value in the design. The results of this study for these parameters are represented in Figure 5.9a, Figure 5.9b, Figure 5.9c and Figure 5.9d respectively. As shown from these Figures the COE influenced by changing value of Weibull k, especially in case of using 2.5 in the design which given the lowest COE. The value of 2.5 Weibull k was selected to used in the design, because the frequency of this value unknown for wind data in Libya and there is no study indicated to that. Regarding the 1-hr autocorrelation factor, the system does not influenced by using 0.80, 0.85 and 0.90 and gives the same COE in these values, while influenced in case of use 0.95, where the COE increased as 0.010 more. May be this indicating to that the system components efficient to operate with autocorrelation factor value between 0.80 to 0.90. In this context, the 1-hr autocorrelation factor value assumed as 0.85 in the study, which represented the average of these values. For the diurnal pattern strength and hour of peak wind speed value the COE does not change and not influenced through changing the parameters values as shown, where in the design assumed as 0.20 for diurnal pattern strength and 15 hour of peak wind speed.

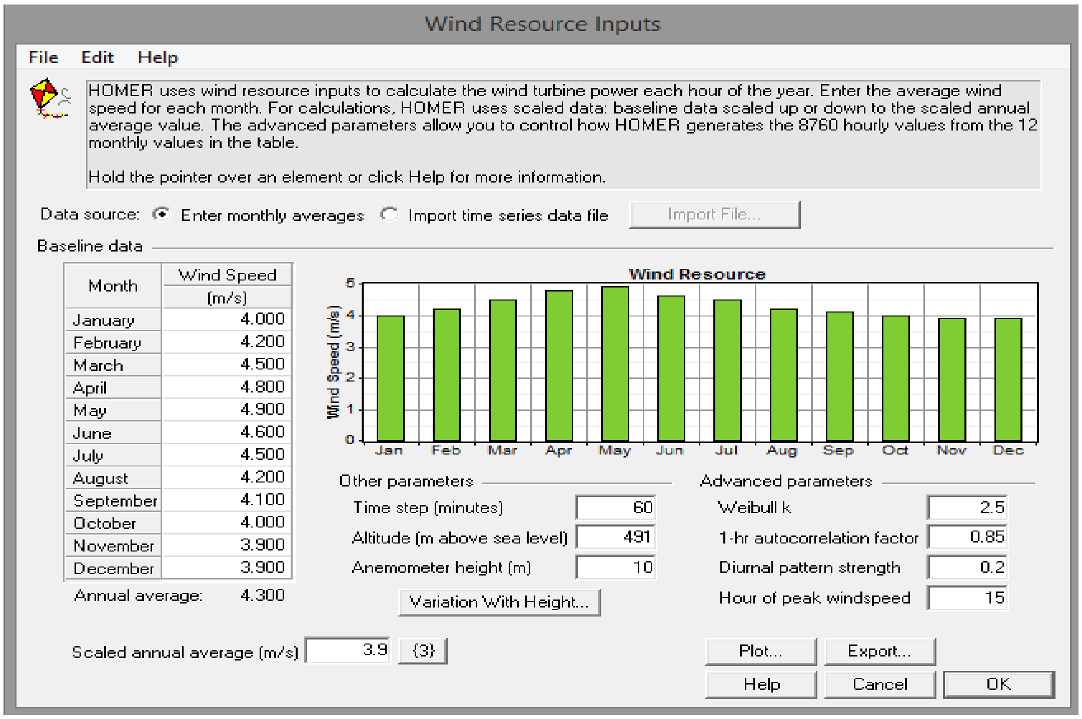


Figure 5.8: Wind resource inputs values for the site of the Brak City HRES

Table 5.4: Wind resource parameters assumption details

Parameters	Values	Discussion of assumption
Time step	60 minutes	Assumed as standard
Altitude	491 m	Determined based on the site coordinates, where measured by NASA (see Appendix 3, location 2).
Anemometer height	10 m	The height above ground at which the wind speed data is measured by NASA (see Appendix 3, location 2).
Weibull k	2.5	Typical values ranges from 1.5 to 2.5 (HOMER energy, 2015)[43]. In this study was selected based on a sensitivity study conducted on Weibull k value versus COE as shown in Figure 5.9a.

[43] HOMER energy, knowledge support portal of the software [Accessed: 23rd November 2015].

1-hr autocorrelation factor	0.85	This value typically ranges from 0.80 to 0.90, (HOMER energy, 2015). In this study was selected based on a sensitivity study conducted on 1-hr autocorrelation factor value versus COE as shown in Figure 5.9b.
diurnal pattern strength	0.2	This value varies between 0-0.4 typically (HOMER energy, 2015). In this study was selected based on a sensitivity study conducted on diurnal pattern strength value versus COE as shown in Figure 5.9c.
hour of peak wind speed	15	Typical range is 14-16 hours (HOMER energy, 2015). In this study was selected based on a sensitivity study conducted on diurnal pattern strength value versus COE as shown in Figure 5.9d.

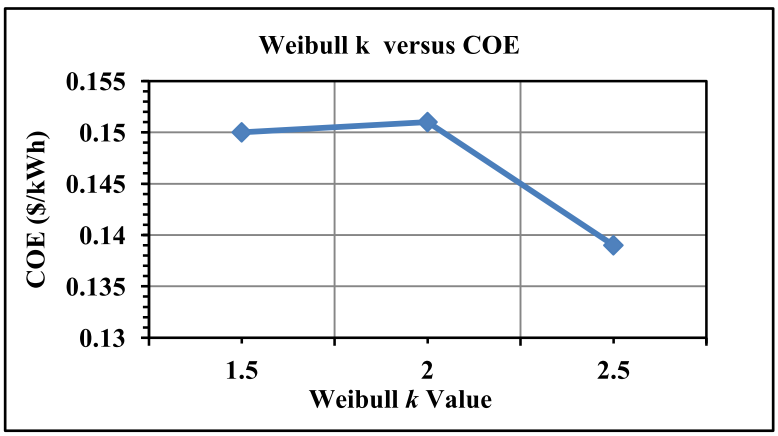


Figure 5.9a: Sensitivity study on Weibull k value versus COE

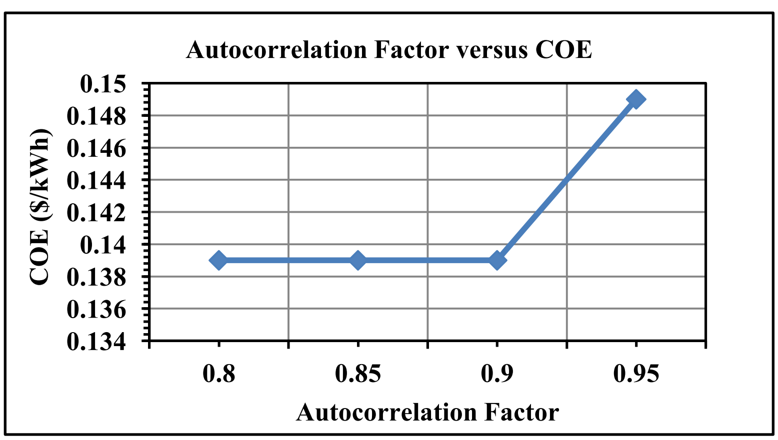


Figure 5.9b: Sensitivity study on autocorrelation factor value versus COE

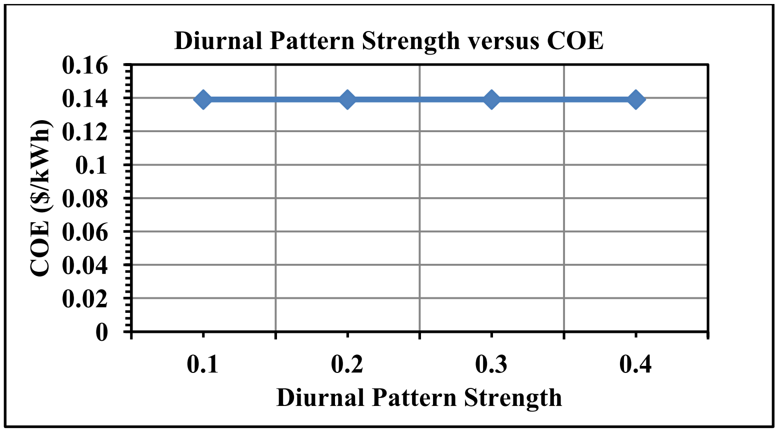


Figure 5.9c: Sensitivity study on diurnal pattern strength value versus COE

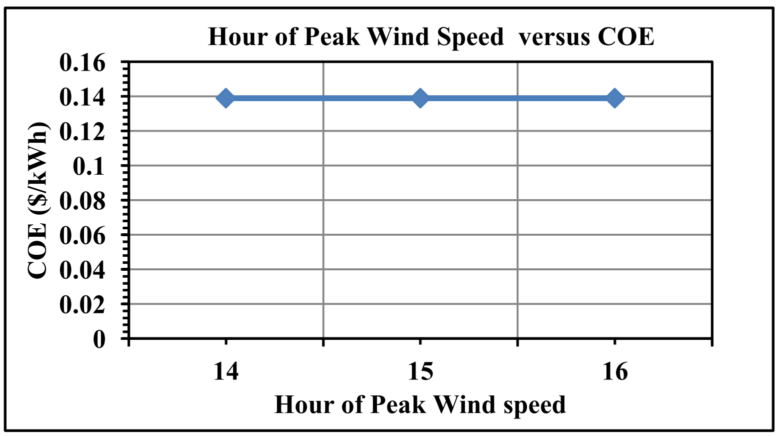


Figure 5.9d: Sensitivity study on hour of peak wind speed value versus COE

5.3.3. Diesel Fuel

The diesel fuel price in Libya is subsidized by the Libyan government by 60% of real cost at the equivalence of 7.6% of GDP representing a total of 13.8% of GDP subsidies in 2012, which indicated a high subsidy in fuel price (IMF, 2012, p.4). Presently, diesel price is equal to 0.10 $/L in the current oil market of Libya; this is very low in comparison to international average diesel prices, as well as real cost of production. Therefore, the diesel price in the study was taken as real price without subsidies and with consideration to transport cost because the project region is located far away from diesel suppliers. On the other hand, in the study a sensitivity study was conducted on the diesel price in order to examine the COE in terms of increases in diesel prices, where the price was assumed to be 0.20 $/L, 0.40 $/L, 0.60 $/L and 0.80 $/L in the study to find out, if dramatic diesel price increases would support RE systems.

5.4. System Parameters

5.4.1. Economic Inputs

Economic inputs values were used in HOMER to calculate the NPC, which are different based on macroeconomic and investment policy calculations. Therefore, in this study the macroeconomic condition and concessional financing, as well as investment policy in Libya, have been considered in order to specify the annual real interest rate and were assumed at 6%. Based on the technical definition, “real interest rate is equal to the nominal interest rate minus the inflation rate” (HOMER, 2014). On other hand, project lifetime must be taken into account so as to determine the NPC through the project lifetime, which used as 25 years in the study as shown in Figure 5.10. The select of project lifetime was based on a sensitivity study that conducted in order to specify the project lifetime by compared with COE by simulating the design in several times by using the project lifetime in each once. This sensitivity study based on some components lifetime that have been used in the design of Brak City HRES, such as converter, PV panel and wind turbine of, whether solar system, wind system, solar and wind system as shown in Figure 5.11. As shown that, whenever project lifetime increased, the COE decreased, for this reason the maximum project lifetime was selected in the design (i.e 25 years).

Considerations to other elements, such as system fixed capital cost, system fixed O&M cost and capacity shortage penalty were not take into account in the study because they are calculated by HOMER according to real components costs, which means converting real capital cost for each component throughout its lifetime using the real discount rate.

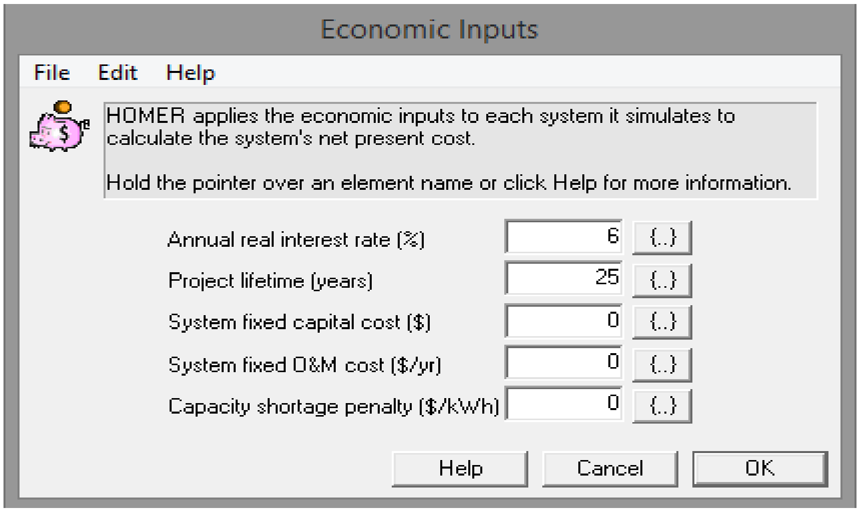


Figure 5.10: Economic inputs values used in the design of the Brak City HRES

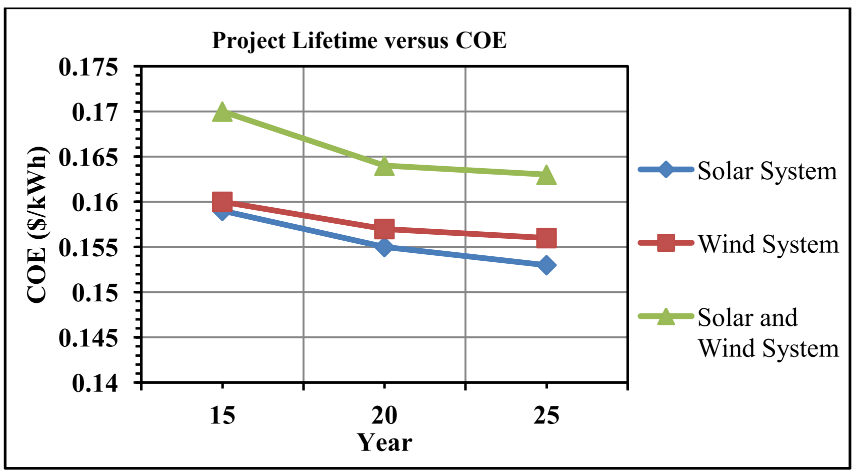


Figure 5.11: Sensitivity study on project lifetime versus COE

5.4.2. Constraint Inputs

Producing 100% energy via RE resources is difficult and even impossible, especially in a utility-scale system with large capacity such as in the Brak City HRES. Also, literature studies show that it is difficult to balance the energy production in a HES with certain productivity of loads, and some cases are not economically viable to serve the load required (HOMER, 2014). More pronounced is the example of the case of cloudy days when PV production will be less than the load demands, similarly is the case of atypical days with low wind speed during which wind energy production will decline. The system will have to use the electricity that is produced by other components, such as DG, to satisfy the needs in these cases. Consequently, to avoid these situations HOMER provides constrain inputs, which are used to calculate the feasible conditions of the system and the economic performance for each hour of operation to meet the demands.

Therefore, in the study the sensitivity study conducted on minimum renewable fraction in order to specify the suitable value to be used in the design. This sensitivity study based on minimum renewable fraction supported by HOMER as well as the system components sizes that have been used in the design of Brak City HRES, whether solar system, wind system, solar and wind system. As shown in Figure 5.12 the COE influenced due to changing value of minimum renewable fraction when is greater than 20% in solar system and when is greater than 30% in wind system, while the COE does not influenced in case of design solar and wind system even at 50%, the COE stay at same value. In this context, the result of this sensitivity study concluded to that a minimum renewable fraction by 20% have been used in the design, because it's the appropriate value for all design scenarios, which gives the lowest COE in all design scenarios, whether design solar energy system, wind energy system, solar and wind energy system. The maximum annual capacity shortage assumed by 0% to identify the real shortage percentage in each scenario according to energy resource situations. In addition to this, HOMER calculates renewable output percent in each scenario based on the system configuration components and resource capacities for each case. So, in this context the percent of renewable output for solar and wind have been taken as default values by HOMER as illustrated in Figure 5.13.

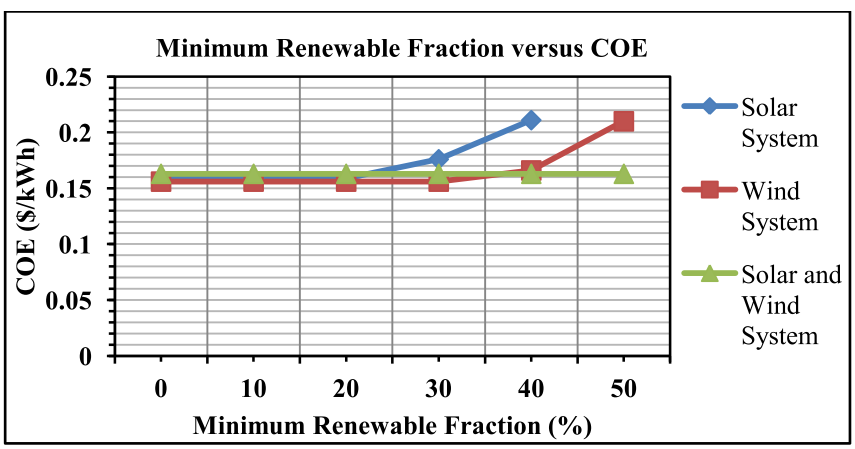


Figure 5.12: Sensitivity study on minimum renewable fraction value versus COE

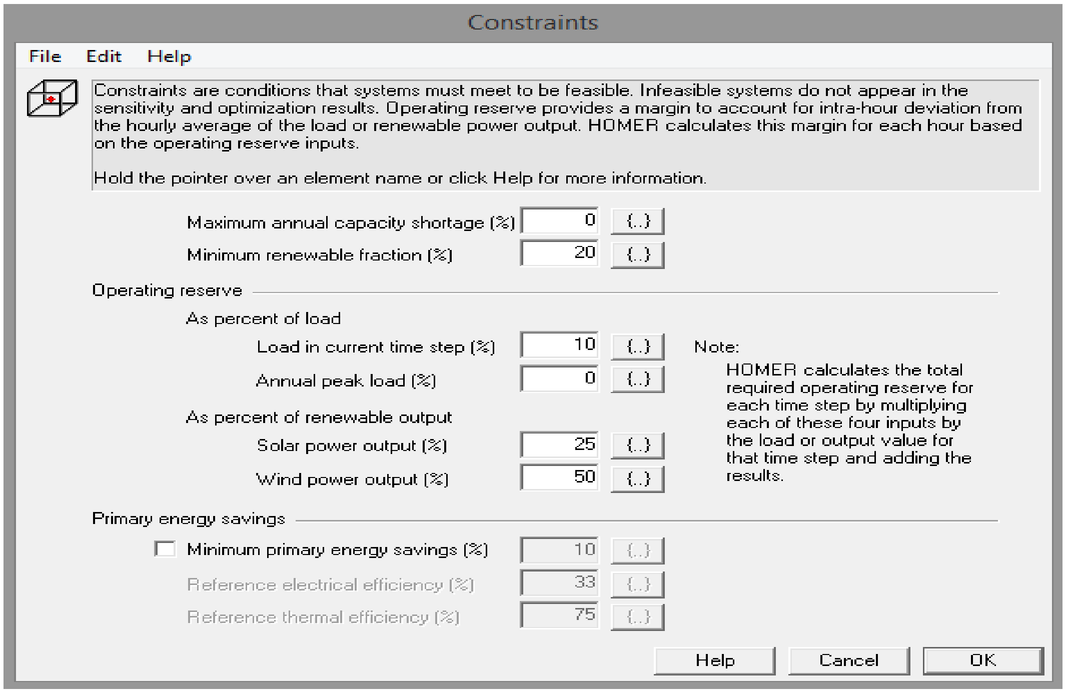


Figure 5.13: Constraints inputs values used in the design of the Brak City HRES

5.4.3. Ambient Temperature Inputs

Ambient temperature is very important to calculate and determine the effect of temperature on the PV panel and to calculate the production of the PV array in each time-step. The average temperature of each month is used in the study, which is determined according to the project site coordinates. The temperature is high in May, June, July, August and September indicating that the effect on the PV panel is high during these months, while it is neutral during the rest of the months of the year except in January, February and December (winter season) when it is relatively low. That means that as the temperature is higher the PV panel productivity will slightly decrease, which indicates to that the production of the PV panel is affected by ambient temperature. Thus, in the study the annual average temperature of 22.4°C is used in the design to measure the real power production of the PV panel as shown in Figure 5.14, which is determined based on the site coordinates (see Appendix 3, location 2).

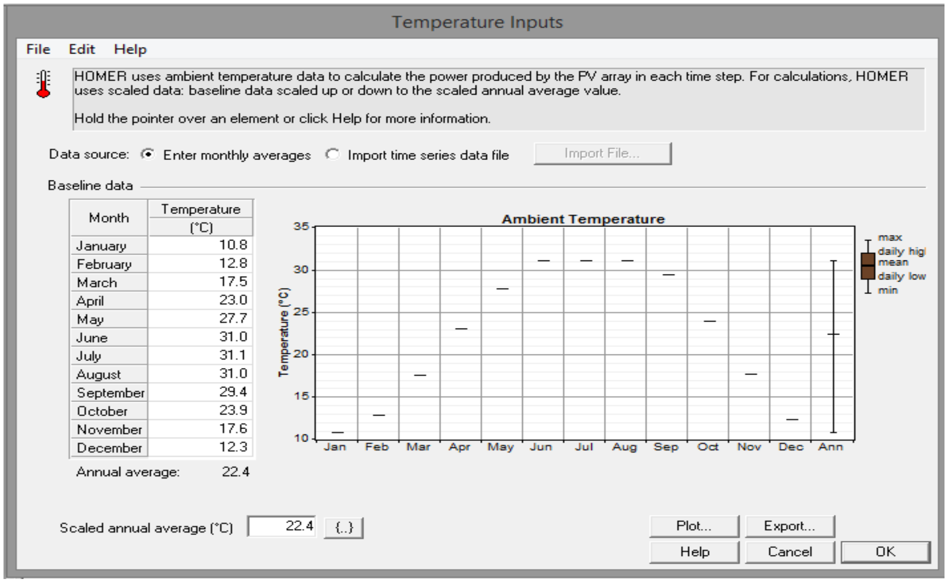


Figure 5.14: Temperature inputs values used in the design of the Brak City HRES

5.4.4. System Control Inputs

HOMER has two different types of dispatch strategies, load following strategy (LF) and cycle charging strategy (CC), which are used to control the system of battery charging. In the study, both strategies have been used, as shown in Figure 5.15, to let HOMER simulate and calculate the best strategy in each scenario based on system configurations, as well as to make the simulation process more widely usable, and not to force all systems to operate on one strategy. The difference between these strategies is that in the LF strategy the generator is operating to provide only the power necessary to meet the load demands at the time, while in the CC strategy the generator operates as much power as possible to charge the batteries in addition to meeting the load (HOMER, 2015). Concerning the generator control system, the system allows for multiple generator operation, with multiple generators running simultaneously and with generator running at less than peak load to make HOMER determine the possibilities in each system.

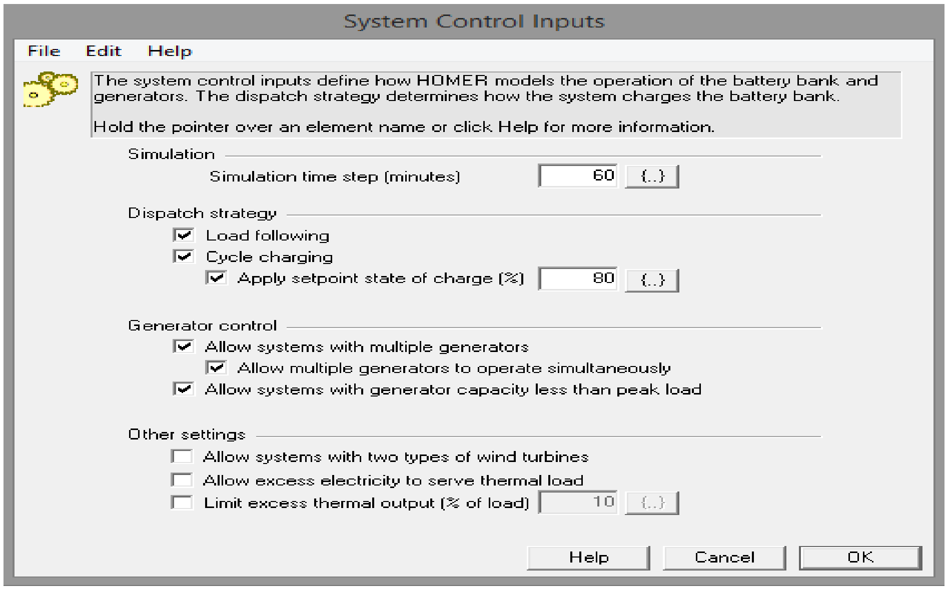


Figure 5.15: System control inputs values used in the design of the Brak City HRES

5.4.5. Grid Extension Inputs

The grid extension inputs in HOMER were used to calculate the minimum distance that make a stand-alone system cheaper than grid extension, which means comparing the cost between a stand-alone system and one that is grid extension; this was defined as breakeven in HOMER.

Thus, the capital cost for one kilometer (km) is assumed at a rate of 15000 $/km and the O&M at 160 $/km as shown in Figure 5.16, where the price assumed is based on the construction market price in Libya. Regarding to the grid power price, in the study was selected based on a sensitivity study conducted on electricity price produced in the grid versus diesel price in order to determine the grid price at each diesel price level, where 0.130 $/L, 0.203 $/L, 0.277 $/L and 0.351 $/L have been used in the design as clarified later in paragraph 6.1.3.3 (Figure 6.7).

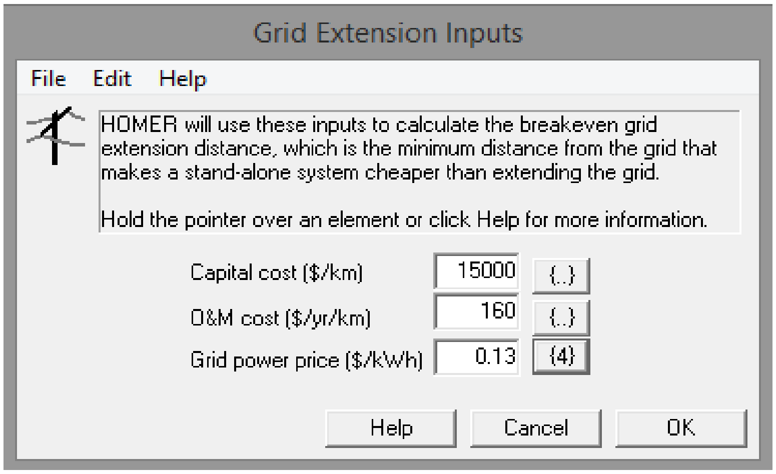


Figure 5.16: Grid extension inputs values used in the design of the Brak City HRES

5.5. Summary of Inputs and Selected values

The values in the study were selected and assumed with consideration to international studies that have been conducted in this area in order to specify the cost, components sizes and parameter values, whereas the assumptions are summarize as follows:

- The component sizes including PV panel, wind turbine, inverter, battery and DG are adjusted to the required load of system that has been previously designed (in paragraph 4.3.). The sizes were tested several times by simulation data in HOMER and the results were adjusted in order to specify the optimal sizes appropriate to each component as well as the load required by the system.
- The component sizes, parameters and cost for all scenarios are similar and identical in order to make the feasibility study and comparison of the scenarios results more consistent and feasible.
- The cost system components were estimated based on international studies as well as industry market price in this field, with consideration to the shipping cost, transportation and instillation cost at the project site.
- The cost of infrastructure such as needed buildings, roads, and diesel storage as well as site exploitation not considered in inputs data for design of Brak City HRES as well as not supported by HOMER processes in design. Also, the cost of electricity transmission

and connectivity grid infrastructure whether in stand-alone system or grid-connected system to the electricity station for Brak City region not considered in the study.

- The parameter values were assumed at average or within typical range values in most cases, which were provided by HOMER and global studies. In addition to, a sensitivity study conducted on some components parameters in order to specified the suitable value to be used in the design (as in paragraphs 5.3.2, 5.4.1 and 5.4.2).
- The sensitivity variable values considered future outlooks, such as diesel price to consider the effect of changes to these variables on the energy system in the case of increasing costs.

6. Results Analysis and Discussion of Design Brak City Hybrid Renewable Energy System

6.1. Scenario I: Design Solar Hybrid Energy System for Electricity Supply to Brak City

6.1.1. Scenario I: Concept Formulation

This scenario focused on the design of the HRES for Brak City that will operate with solar and diesel main sources of energy, thereby combining PV module and DG technology. Therefore, the design was considered in two Categories, wherein the first design concentrated on a solar stand-alone system, and the second one focused on a solar grid-connected system in order to meet the electricity demands in Brak City. The objectives of this scenario are to identify and discover the following:

- The feasibility of using of PV technology in case of increasing diesel prices in region.
- The solar energy shares in the system as well as the COE.
- Which most cost-effective system to use in the region, solar stand-alone system or solar grid-connected system?
- To compare the COE gained from the study with the COE of existing system.
- What is the OST configuration in a solar stand-alone system and solar grid-connected system?
- If the design meets the electricity demand for Brak City.

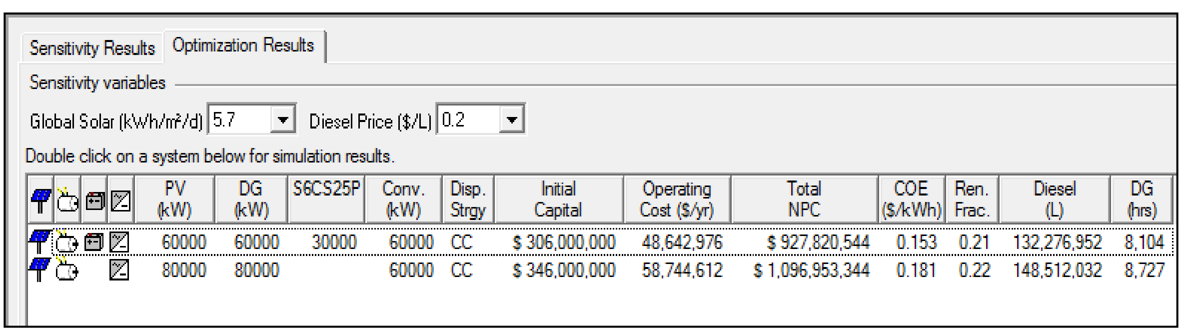
To achieve these targets, the result of 1728 systems designs (see Appendix 5, paragraph 16) was simulated and tested by HOMER, additionally 12 sensitivity cases have been used in the design representing four variables of diesel price and three variables of solar radiation density as previously specified in chapter 5 (in paragraph 5.3.1. and 5.3.3.). The detail of system categories and winning components related to the design of the solar HES are shown in Appendix 6, paragraph 1 (the objectives answer presented in paragraph 6.1.5).

6.1.2. Result Analysis of Solar Stand-Alone System

6.1.2.1. Optimization Results

HOMER presented the optimization results categorically, where each category reflects system configuration and size components with NPC and renewable fraction in the system. Because of huge data results, in the study, a particular case has been considered in order to compare the system categories for all systems of scenarios, not only in the case of solar energy technology usage in the design, but in other systems, as well, including wind energy systems, solar and wind energy systems. Consequently, the average of renewable sources in the site as well as the current cost of diesel in Libya without subsidies has been taken into account in the study in order to compare these systems in one identical case (i.e. average solar radiation 5.7 kWh/m^2/d, average wind speed 4.3 m/s, and with diesel price 0.20 $/L).

In the case of the design for a solar stand-alone HES for Brak City, the optimization results for the average renewable resource in the site and fuel price is shown in Figure 6.1. The most economically OST is PV/DG/battery/converter with a minimum COE of 0.153 $/kWh and with 21% share of RE in the system with CC of dispatch strategy, even without battery, because the generator need to operate at full output to serve the required load (see, the CC clarification in paragraph 5.4.4).



PV (kW)	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
60000	60000	30000	60000	CC	$ 306,000,000	48,642,976	$ 927,820,544	0.153	0.21	132,276,952	8,104
80000	80000		60000	CC	$ 346,000,000	58,744,612	$ 1,096,953,344	0.181	0.22	148,512,032	8,727

Figure 6.1: Optimization results for solar stand-alone HES for Brak City at sensitivity variables of solar radiation 5.7 kWh/m^2/d and diesel price 0.20 $/L

6.1.2.2. Simulation Results of Energy Production of the Optimal System

The simulation results presented in the study are at the same variables that have been considered in the optimization results, which refer to the average of renewable sources in the project location and the current diesel price in Libya. Consequently, the simulation results of the solar stand-alone HES design are represented in Figure 6.2, where the share of PV electric production is 24% in the system. The excess of electricity is 0.483%; this is the loss of electricity from system components such as inverter, battery and DG where this value goes to waste (HOMER does not account this value to calculate the COE). The system has shortage capacity of 0.048%, despite the small quantity of unmet electricity load, resulting in 0% total energy produced.

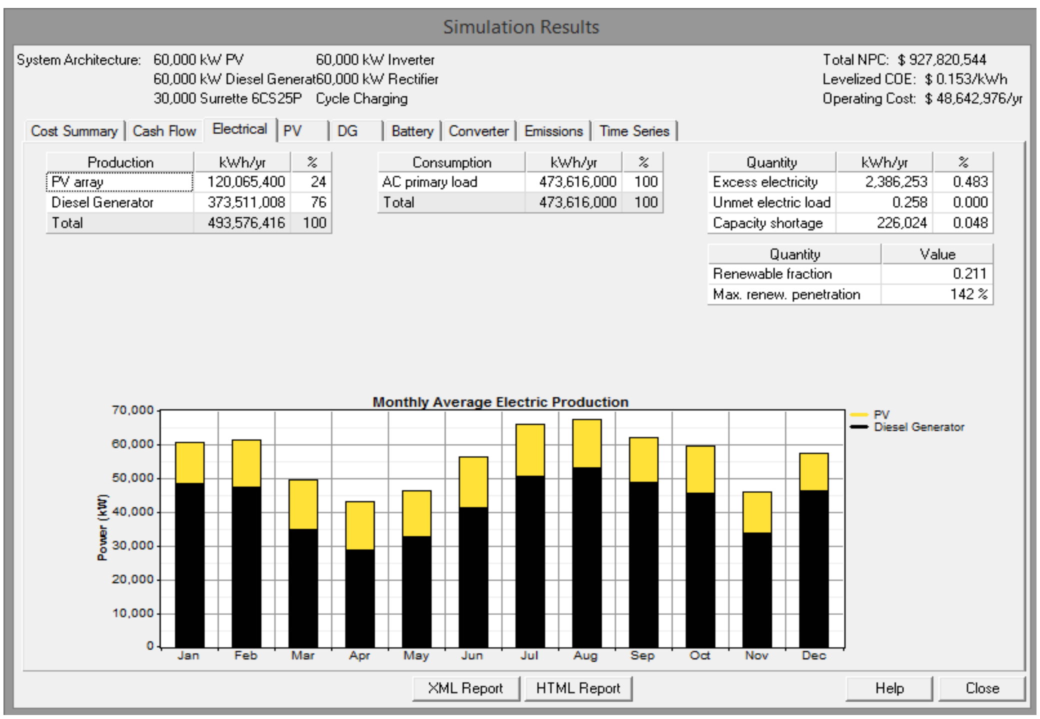


Figure 6.2: Simulation results for solar stand-alone HES for Brak City at solar radiation of 5.7 kWh/m^2/d and diesel price 0.20 $/L

6.1.2.3. Sensitivity Results

In this sensitivity study only the optimal system configuration is analyzed. It is analyzed how sensitive this OST is reaching on changes in diesel price and/or solar radiation values.

In all cases is PV/DG/battery[44] (as shown in Figure 6.3) the optimal solution. Therefore, The OST configuration does not influenced and not changed by increases in fuel price nor by solar radiation density at the site.

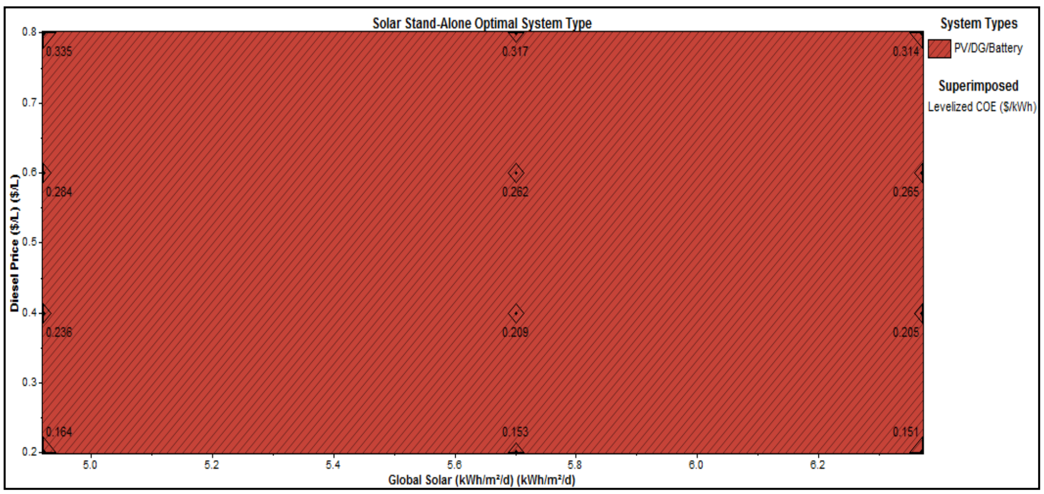


Figure 6.3: Sensitivity results and OST for solar stand-alone HES for Brak City with superimposed LCOE

The overall sensitivity results of all systems configuration related to the design for the solar stand-alone HES are represented in Figure 6.4, which show all the system components with each sensitivity variable as well as the value of future parameters. The cheapest COE is 0.151 \$/kWh at solar radiation 6.37 kWh/m^2/d and diesel price at 0.20 \$/L and with share of the RE set to 24%, which reflects the low diesel price and highest solar radiation. Therefore, the COE increasing whenever diesel price and solar radiation increased. As shown that CC is optimal dispatch strategy overall system components sizes as well as the sensitivity variables used in the design.

[44] This configuration of the OST includes converter too, where HOMER did not displayed this when representing sensitivity results graphically, thought it was displayed in overall sensitivity result categories as well as in the schematic of the system, as well as in other design systems of scenarios.

Further will be mentioned and discussed only some reasonable results of this sensitivity. For example: Even the sensitivity variables changing (i.e. solar radiation and diesel price), system components size not changing in DG, battery and converter. A changing in PV size occurs in case of diesel price lower or higher as 0.40 $/L (except for solar radiation of 4.92 kWh/m^2/d and diesel price at 0.40 $/L). This may be referred to, that these components sizes are the optimal in system configuration not in general but due to the chosen input values.

The renewable fraction in the system increases as solar radiation and diesel price increased, but, surprising not in case of diesel price 0.80 $/L (the renewable fraction less than in case of diesel price 0.60 $/L), because of the electricity losses in the system where the excess of electricity goes to waste. For example with solar radiation 6.37 kWh/m^2/d with diesel price 0.60 $/L the renewable fraction is 36% with 11.3% excess of electricity in the system, while at diesel price 0.80 $/L the renewable fraction is 35% with 11.8% excess of electricity (see, the example of these losses shown in Appendix 5 paragraph 17).

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

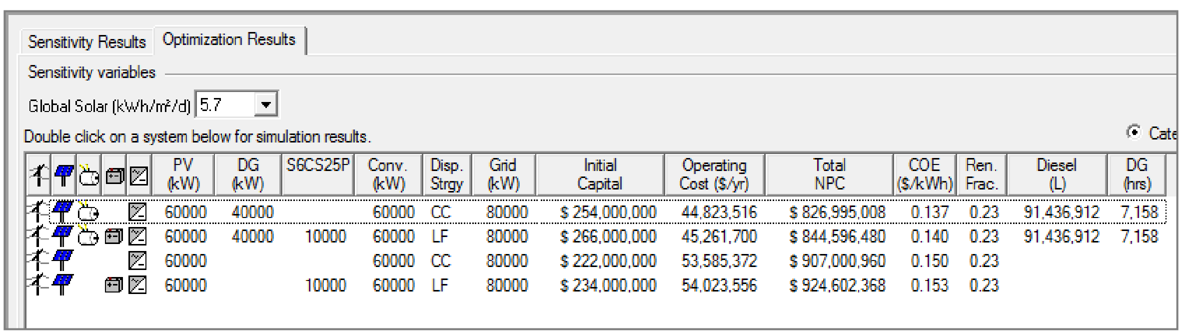
Solar (kWh/m²/d)	Diesel ($/L)	PV (kW)	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
4.920	0.200	80000	60000	30000	80000	CC	$ 380,000,000	47,893,840	$ 992,244,032	0.164	0.24	125,450,696	7,417
4.920	0.400	140000	60000	30000	80000	CC	$ 560,000,000	68,038,448	$ 1,429,759,744	0.236	0.35	106,570,552	6,175
4.920	0.600	140000	60000	30000	80000	CC	$ 560,000,000	90,868,000	$ 1,721,598,080	0.284	0.34	107,799,472	6,242
4.920	0.800	140000	60000	30000	80000	CC	$ 560,000,000	114,666,544	$ 2,025,823,360	0.335	0.33	109,768,288	6,434
5.700	0.200	60000	60000	30000	60000	CC	$ 306,000,000	48,642,976	$ 927,820,544	0.153	0.21	132,276,952	8,104
5.700	0.400	60000	60000	30000	80000	CC	$ 320,000,000	73,975,248	$ 1,265,651,968	0.209	0.21	130,510,272	7,696
5.700	0.600	80000	60000	30000	80000	CC	$ 380,000,000	94,418,872	$ 1,586,990,080	0.262	0.27	119,802,288	7,021
5.700	0.800	80000	60000	30000	80000	CC	$ 380,000,000	120,348,984	$ 1,918,464,000	0.317	0.26	121,432,688	7,163
6.370	0.200	60000	60000	30000	80000	CC	$ 320,000,000	46,552,300	$ 915,094,656	0.151	0.24	126,297,136	7,486
6.370	0.400	60000	60000	30000	80000	CC	$ 320,000,000	71,876,416	$ 1,238,821,760	0.205	0.23	126,345,440	7,448
6.370	0.600	120000	60000	30000	80000	CC	$ 500,000,000	86,576,848	$ 1,606,742,784	0.265	0.36	104,135,032	5,997
6.370	0.800	120000	60000	30000	80000	CC	$ 500,000,000	109,541,072	$ 1,900,302,592	0.314	0.35	106,052,472	6,184

Figure 6.4: Sensitivity result categories for solar stand-alone HES for Brak City

6.1.3. Result Analysis of Solar Grid-Connected System

6.1.3.1. Optimization Results

In design grid-connected system need to specify the maximum amount of electricity that can flow to and from the grid. Lambert clarified how to specify this value as “specify a value equal to or greater than the peak load” (2010, HOMER online support). In the design of Brak City HRES the grid value specified greater than the peak load of the system (see Figure 5.1a, where the peak load of the system is 76,204 kW), and specified to 80,000 kW as illustrated in Figure 6.5. As shown from this Figure, the optimization results of solar grid-connected HES for Brak City at the average solar radiation in the site of 5.7 kWh/m^2/d and diesel price at 0.20 $/L show that the minimum COE is 0.137 $/kWh. The renewable fraction is 23% and does not changing even the system configuration changed, because all systems produced same amount of the electricity from PV, which equal to 25%. The system comes in first rank from the four possible systems, where the OST configuration is grid/PV/DG/converter, and dispatch strategy is CC, while the system comes in second rank in the case of use small battery bank in system configuration with LF of dispatch strategy.


Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 5.7

Double click on a system below for simulation results.

PV (kW)	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
60000	40000		60000	CC	80000	$ 254,000,000	44,823,516	$ 826,995,008	0.137	0.23	91,436,912	7,158
60000	40000	10000	60000	LF	80000	$ 266,000,000	45,261,700	$ 844,596,480	0.140	0.23	91,436,912	7,158
60000			60000	CC	80000	$ 222,000,000	53,585,372	$ 907,000,960	0.150	0.23		
60000		10000	60000	LF	80000	$ 234,000,000	54,023,556	$ 924,602,368	0.153	0.23		

Figure 6.5: Optimization results for solar grid-connected HES for Brak City at sensitivity variables of solar radiation 5.7 kWh/m^2/d and diesel price 0.20 $/L

6.1.3.2. Simulation Results of Energy Production of the Optimal System

The simulation results for the design of solar grid-connected HES at solar radiation value of 5.7 kWh/m^2/d and diesel price 0.20 $/L is represented in Figure 6.6, where the share of RE in the system produced from PV module results in a 25% share. The value of excess electricity in system is 0.09%, and the system has no shortage capacity and thus meets the electric load in a year.

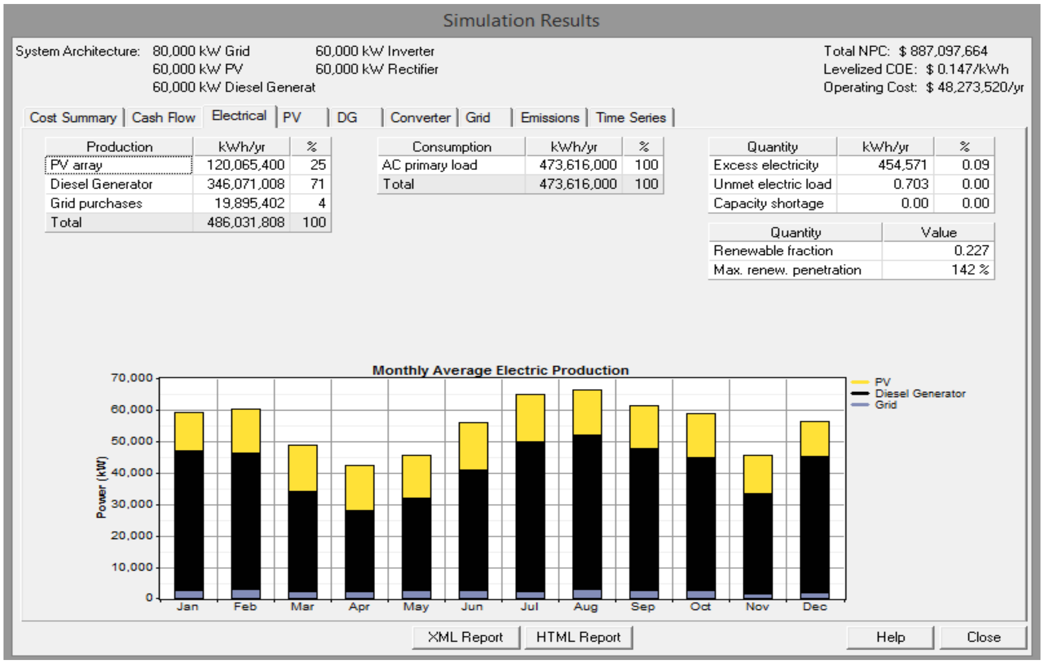


Figure 6.6: Simulation results for solar grid-connected HES for Brak City at solar radiation of 5.7 kWh/m^2/d and diesel price 0.20 $/L

6.1.3.3. Sensitivity Results

The COE for electricity produced in the grid is increasing whenever diesel price increased. Because of that, firstly must be calculated this dependency of the COE produced by DG only from diesel price (these COE had been calculated for the system configuration that presented in Appendix 5, paragraph 12). This is shown in Figure 6.7, and used also in the other scenarios.

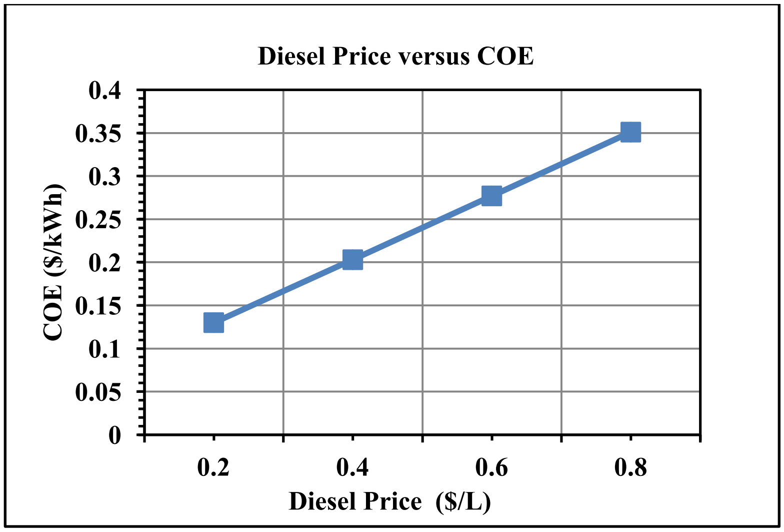


Figure 6.7: Sensitivity study on diesel price versus grid COE

As shown from Figure 6.8a, Figure 6.8b, Figure 6.8c and Figure 6.8d, the OST configurations for all system variable cases considered in the design is grid/PV/DG/converter. Also, here even if the diesel price and solar radiation changed the OST configuration is not changing, which may be refer to that this optimal configuration system through sensitivity variables that have been used in the design. As in stand-alone system, the CC is optimal dispatch strategy overall system components sizes as well here. Also, the all systems used the same size of DG, converter, while the PV size is changing, especially at low solar radiation of 4.92 kWh/m^2/d the system used big size of PV, because need to more size to satisfy the electricity needs. This may be indicating to that this the optimal size in system configuration that fit with electricity load requirements. The renewable fraction in some cases are similar, despite the PV size changes, which may be referred to that this the maximum energy can be produced from PV with these system components and variables, even at case of increase solar radiation and diesel price. A comparison of stand-alone system and grid-connected system is given in paragraph 6.1.5.

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Solar (kWh/m²/d)	PV (kW)	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
4.920	80000	40000		60000	CC	80000	$ 314,000,000	45,087,988	$ 890,375,808	0.147	0.25	87,653,312	6,846
5.700	60000	40000		60000	CC	80000	$ 254,000,000	44,823,516	$ 826,995,008	0.137	0.23	91,436,912	7,158
6.370	60000	40000		60000	CC	80000	$ 254,000,000	43,630,776	$ 811,747,776	0.134	0.25	87,958,936	6,884

Figure 6.8a: Sensitivity result categories for solar grid-connected HES for Brak City at diesel price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Solar (kWh/m²/d)	PV (kW)	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
4.920	80000	40000		60000	CC	80000	$ 314,000,000	69,192,672	$ 1,198,514,688	0.198	0.25	87,114,824	6,789
5.700	60000	40000		60000	CC	80000	$ 254,000,000	69,817,792	$ 1,146,505,728	0.189	0.23	90,803,520	7,091
6.370	60000	40000		60000	CC	80000	$ 254,000,000	67,843,984	$ 1,121,273,856	0.185	0.25	87,344,960	6,819

Figure 6.8b: Sensitivity result categories for solar grid-connected HES for Brak City at diesel price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Solar (kWh/m²/d)	PV (kW)	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
4.920	80000	40000		60000	CC	80000	$ 314,000,000	93,384,000	$ 1,507,760,896	0.249	0.25	86,980,784	6,775
5.700	80000	40000		60000	CC	80000	$ 314,000,000	89,308,704	$ 1,455,665,024	0.240	0.29	82,772,984	6,440
6.370	80000	40000		60000	CC	80000	$ 314,000,000	86,567,712	$ 1,420,625,920	0.235	0.31	79,869,568	6,205

Figure 6.8c: Sensitivity result categories for solar grid-connected HES for Brak City at diesel price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Solar (kWh/m²/d)	PV (kW)	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
4.920	100000	40000		60000	CC	80000	$ 374,000,000	112,307,144	$ 1,809,662,336	0.299	0.30	81,416,568	6,323
5.700	80000	40000		60000	CC	80000	$ 314,000,000	112,356,288	$ 1,750,290,432	0.289	0.29	82,705,600	6,433
6.370	80000	40000		60000	CC	80000	$ 314,000,000	108,847,024	$ 1,705,430,400	0.282	0.31	79,773,376	6,195

Figure 6.8d: Sensitivity result categories for solar grid-connected HES for Brak City at diesel price 0.80 $/L

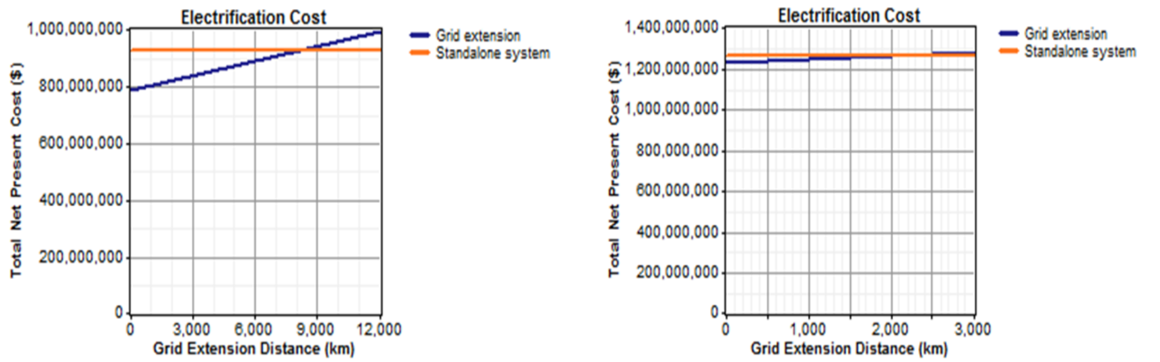
6.1.4. Breakeven Grid Extension Distance of Solar Hybrid Energy System

The comparison study was conducted on grid extension in order to compare the solar stand-alone HES cost with grid extension cost, indicated to the breakeven grid extension distance which varies by the price of diesel. Lambert simplified and describes the breakeven grid extension distance as "the distance from the grid which makes the net present cost of extending the grid equal to the net present cost of the stand-alone system. Farther away from the grid, the stand-alone system is optimal. Nearer to the grid, grid extension is optimal" (2010, HOMER online support).

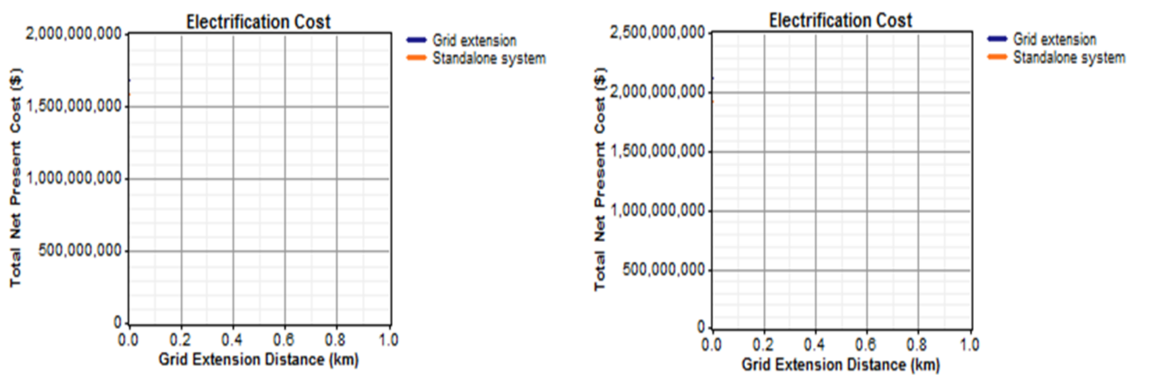
So, findings that the cost of grid extension distance is influenced by diesel price categories, and various from negative value to 8,257 km depending on NPC as illustrated in Figure 6.9. In case of grid extension distance comes in negative value, the stand-alone system will be optimal as clarified in the study that "the EDL[45] comes out be a negative value meaning that a decentralised RE hybrid system is a better option than the grid extension" (Battacharyya and Palit, 2014, p.227). Based on this, the following points can be simply stated:

- At diesel price 0.20 $/L the grid extension cost less than solar stand-alone system up to 8,257 km, thereafter the grid extension becomes more expensive. If the system is farther away from the grid the stand-alone system is optimal to use.
- At diesel price 0.40 $/L the grid extension cost less than solar stand-alone system up to 2,148 km, thereafter the grid extension becomes more expensive.
- The grid extension distance at diesel price 0.60 $/L and 0.80 $/L is in negative value, which indicates to the solar stand-alone system is optimal option than grid extension (because COE produced by the grid is higher than COE produced by the stand-alone system).

[45] The grid extension known also as economical distance line (EDL).



Breakeven Grid Extension Distance:	8,257 Km	Breakeven Grid Extension Distance:	2,148 Km
Diesel Price:	0.20 $/L	Diesel Price:	0.40 $/L



Breakeven Grid Extension Distance:	-5,285 Km	Breakeven Grid Extension Distance:	-12,122 Km
Diesel Price:	0.60 $/L	Diesel Price:	0.80 $/L

Figure 6.9: Breakeven grid extension distances for solar HES for Brak City at sensitivity variables of solar radiation 5.7 kWh/m^2/d and with different diesel price categories

6.1.5. Conclusion

The study conducted on design solar HES be it a stand-alone system or grid-connected system concluded that there is feasibility for the use of PV technology, where the potential is high. The solar energy shares in the system vary from 21% to 36% for all the feasible systems that have been tested and used in the design with COE being between 0.134 $/kWh to 0.335 $/kWh.

The solar grid-connected systems are most cost-effective (i.e. lower-cost) than solar stand-alone systems in terms of energy at all sensitivity variables as shown in the comparison represented in Figure 6.10. In addition, in comparison the COE for both systems in terms of average renewable sources and actual diesel cost in Libya is lower than the current COE in existing energy system in region (i.e. the COE in Libya without subsidies, which equal 0.20 $/kWh). The OST configurations are PV/DG/battery/converter and grid/PV/DG/converter in a stand-alone system and grid-connected system respectively. This configuration and system schematic is clearly shown in Figure 6.11, which represents the result of the simulation process of the design solar HES for Brak City.

In summary, the advantages of implementation of such technology results in COE that is less than that in the existing system, and furthermore is environmentally-friendly as well meets the electricity demand for Brak City region.

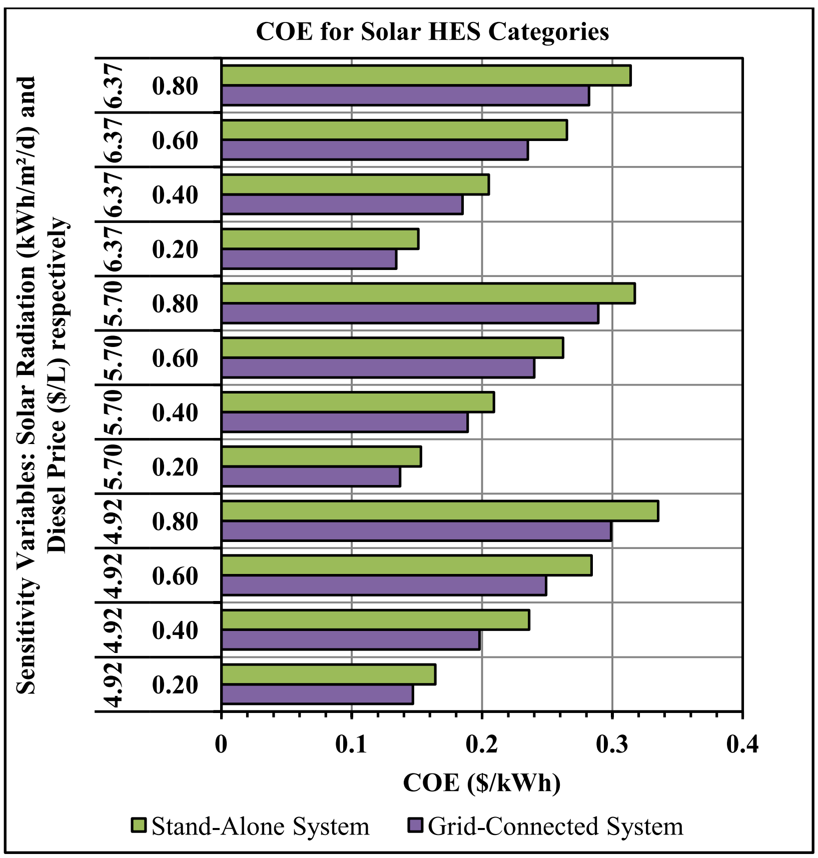
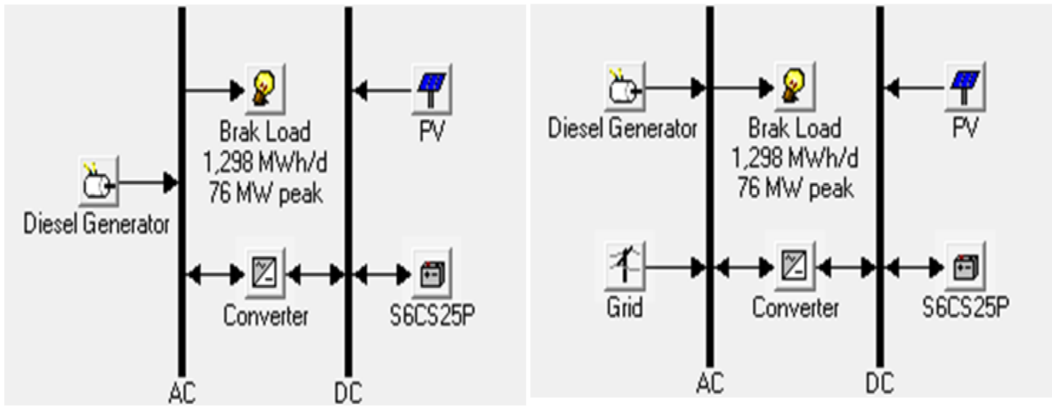


Figure 6.10: Comparison of COE for solar HES categories for Brak City



Solar Stand-Alone System — Solar Grid-Connected System

Figure 6.11: Schematic configurations of solar HES categories for Brak City

6.2. Scenario II: Design Wind Hybrid Energy System for Electricity Supply to Brak City

6.2.1. Scenario II: Concept Formulation

The concept of this scenario is like the previous scenario, but it differs in the type of RE technology, wherein wind energy technology has been used in the design. The scenario concentrated on the design of HRES for Brak City using wind and diesel as the main sources of energy, thus combining wind turbine and DG. The design was into considered in two categories, wherein the first design concentrated on designing a wind stand-alone system, and the second design concentrated on designing a wind grid-connected system in order to meet the electricity demand in Brak City. The scenario aims to determine and explore the following:

- Is it cost-effective and feasibility of use wind energy technology in the region?
- The gained COE from the scenario as well as wind energy shares in the system.
- Which most cost-effective system to use in the region, wind stand-alone system or wind grid-connected system?
- To compare the COE gained from the study with the COE of existing system.
- What OST configurations in wind stand-alone system and wind grid-connected system?

- If the design meets the electricity demand for Brak City.

Thus, the result of 2496 systems designs (see Appendix 5, paragraph 16) was tested and simulated in order to realize these tasks. In addition, 12 sensitivity variables have been used in the design, including four variables of diesel price and three variables of wind speed as specified previously (as mentioned in paragraphs 5.3.2 and 5.3.3). Thus, the sensitivity study in this scenario was conducted within two dimensions; first, the wind speed; second, diesel price.[46] The system categories and winning components for the design wind HES is illustrated in detail in Appendix 6, paragraph 2 (the objectives answer presented in paragraph 6.2.5).

6.2.2. Result Analysis of Wind Stand-Alone System

6.2.2.1. Optimization Results

The optimization results for wind stand-alone HES for Brak City with wind speed in the site of 4.3 m/s with diesel price of 0.20 $/L shows that the OST configuration is wind/DG/battery/converter as shown in Figure 6.12. The system preferred to use the wind turbine E-82 instead of the wind turbine E-101 in the system configuration. This indicates that the wind capture is more efficient at the hub height of wind turbine E-82, although the wind turbine E-101 has more powered. As a result, COE in this system is 0.139 $/kWh with a contribution of 36% of RE and with CC of dispatch strategy.

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[46] Again, because of huge amount of data gathered the result analysis represented the average renewable sources in the project site of Brak City HRES and current diesel price without subsidies for all scenarios in order to compare them in one case and situation. The same goes for the case design of the wind energy system.

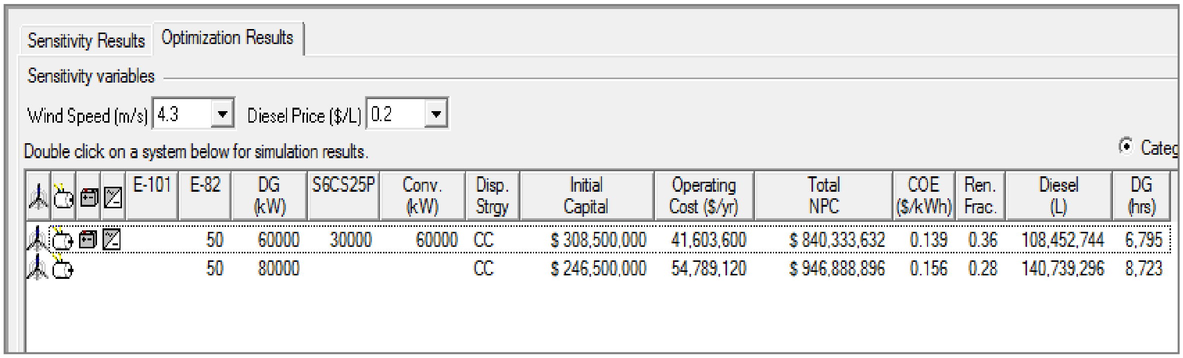


Figure 6.12: Optimization results for wind stand-alone HES for Brak City at sensitivity variables of wind speed 4.3 m/s and diesel price 0.20 $/L

6.2.2.2. Simulation Results of Energy Production of the Optimal System

The simulation result for wind stand-alone HES at average wind speed in the site is 4.3 m/s and diesel price of 0.20 $/L resulting in the contribution of 40% of energy produced by wind turbine E-82 as shown in Figure 6.13. The excess of electricity through system components is 4.21% and the system meets the electric load with very low capacity shortage in a year, which equal to 0.03%.

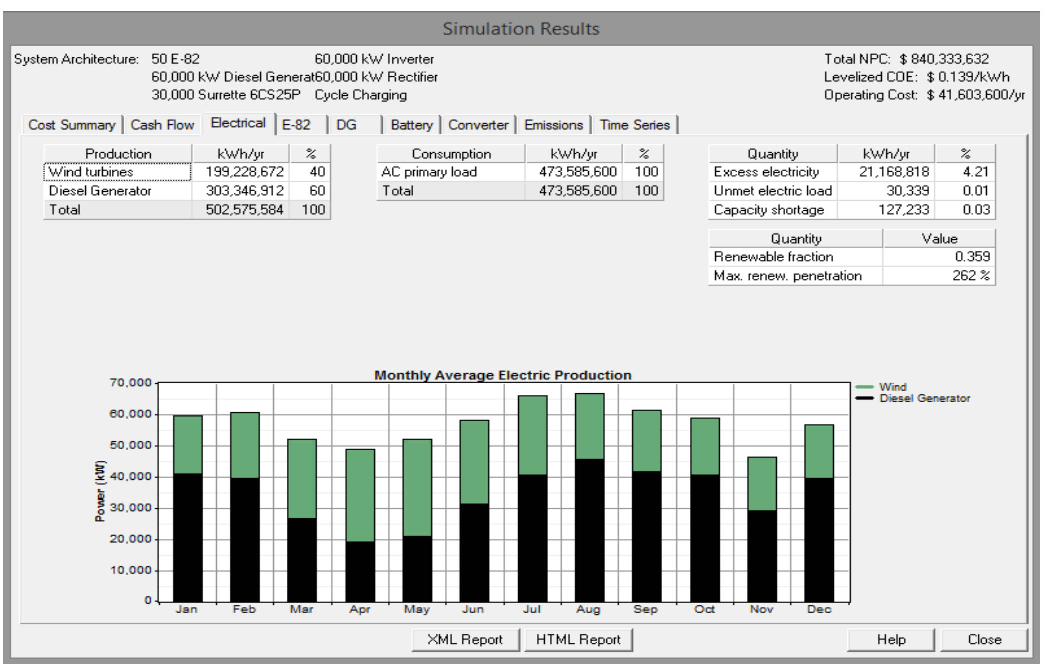


Figure 6.13: Simulation results for wind stand-alone HES for Brak City at wind speed 4.3 m/s and diesel price 0.20 $/L

6.2.2.3. Sensitivity Results

The sensitivity results for wind stand-alone HES indicates to that the system configuration has not changed and causes an effect through the increasing of the fuel price as well as wind speed in the site, where the OST for all variables cases is wind/DG/battery, as shown in Figure 6.14. The system configuration especially the number of turbines remains at the same structure for all wind speed values. Only the number of hours during which the diesel generators are running decreased dramatically with increasing diesel price. The amount of diesel needed in case of wind speed 3.9 m/s and diesel price of 0.20 $/L is more than half than in use of wind speed 5.2 m/s and diesel price 0.80 $/L. This is clearly shown in Figure 6.15, where CC is optimal dispatch strategy overall system components sizes as well as the sensitivity variables used in the design. The minimum COE is 0.122 $/kWh at wind speed of 5.2 m/s and diesel price at 0.20 $/L and with share of the RE set to 52%, which reflects the low diesel price and maximum wind speed. Therefore, the COE increasing whenever diesel price and wind speed increased.

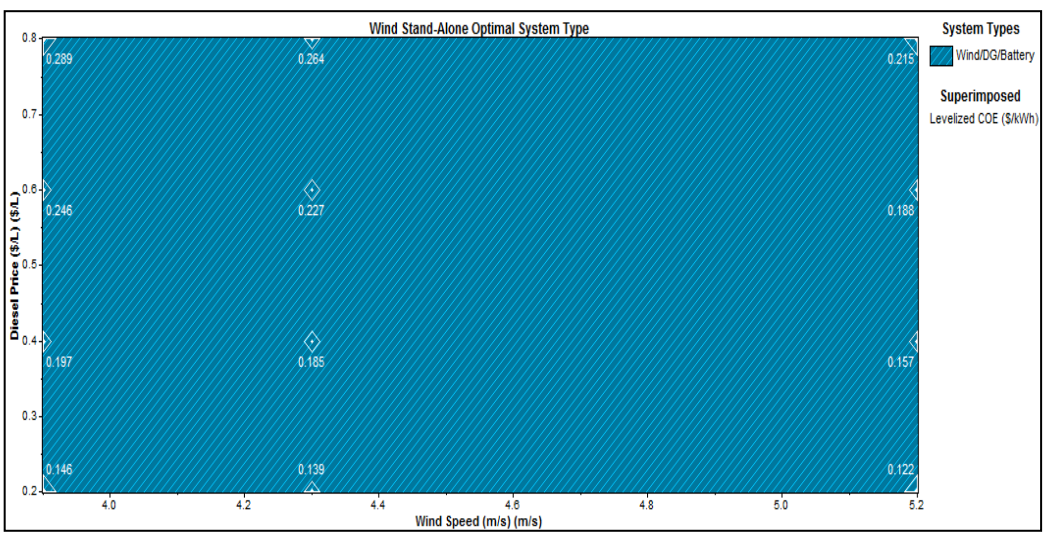


Figure 6.14: Sensitivity results and OST for the wind stand-alone HES for Brak city with superimposed LCOE,

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Wind (m/s)	Diesel ($/L)		E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
3.900	0.200			50	60000	30000	60000	CC	$ 308,500,000	45,207,560	$ 886,404,416	0.146	0.29	120,306,784	7,431
3.900	0.400			50	60000	30000	60000	CC	$ 308,500,000	69,204,416	$ 1,193,164,800	0.197	0.28	120,453,872	7,370
3.900	0.600			75	60000	30000	60000	CC	$ 399,750,016	85,255,688	$ 1,489,603,840	0.246	0.37	105,400,384	6,514
3.900	0.800			100	60000	30000	60000	CC	$ 491,000,000	98,540,904	$ 1,750,683,520	0.289	0.44	93,722,984	5,823
4.300	0.200			50	60000	30000	60000	CC	$ 308,500,000	41,603,600	$ 840,333,632	0.139	0.36	108,452,744	6,795
4.300	0.400			50	60000	30000	60000	CC	$ 308,500,000	63,333,648	$ 1,118,116,608	0.185	0.35	108,773,728	6,748
4.300	0.600			75	60000	30000	60000	CC	$ 399,750,016	76,135,232	$ 1,373,013,760	0.227	0.45	92,369,624	5,779
4.300	0.800			100	60000	30000	60000	CC	$ 491,000,000	86,552,344	$ 1,597,429,504	0.264	0.53	80,547,640	5,085
5.200	0.200			50	60000	30000	60000	CC	$ 308,500,000	33,483,050	$ 736,525,760	0.122	0.52	82,477,920	5,248
5.200	0.400			50	60000	30000	60000	CC	$ 308,500,000	50,116,192	$ 949,153,216	0.157	0.51	82,892,744	5,233
5.200	0.600			75	60000	30000	60000	CC	$ 399,750,016	57,899,992	$ 1,139,906,176	0.188	0.61	66,839,424	4,283
5.200	0.800			100	60000	30000	60000	CC	$ 491,000,000	63,529,400	$ 1,303,118,976	0.215	0.67	55,590,272	3,557

Figure 6.15: Sensitivity results categories for wind stand-alone HES for Brak City

6.2.3. Result Analysis of Wind Grid-Connected System

6.2.3.1. Optimization Results

The OST for wind grid-connected HES for Brak City is grid/wind/DG at wind speed of 4.3 m/s and diesel price of 0.20 $/L as shown in Figure 6.16, which represents the optimization results of the system. Likewise, in the case of the wind stand-alone, the system which preferred to use the wind turbine E-82 instead of wind turbine E-101 in the system configuration, where the COE is 0.113 $/kWh with the renewable fraction by 37% in the system, and CC of dispatch strategy.

Sensitivity Results | Optimization Results

Sensitivity variables

Wind Speed (m/s) 4.3

Double click on a system below for simulation results. ⦿ Categorized

	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	36,864,336	$ 685,749,952	0.113	0.37	77,585,576	6,146
		50				CC	80000	$ 182,500,000	44,153,592	$ 746,931,136	0.123	0.37		
		50	40000	10000	60000	LF	80000	$ 268,500,000	38,107,648	$ 755,643,648	0.125	0.37	77,576,200	6,145
		50		10000	60000	LF	80000	$ 236,500,000	45,396,400	$ 816,818,368	0.135	0.37		

Figure 6.16: Optimization results for wind grid-connected HES for Brak City at sensitivity variables of wind speed 4.3 m/s and diesel price 0.20 $/L

6.2.3.2. Simulation Results of Energy Production of the Optimal System

The simulation results for wind grid-connected HES presents that the system meets the load demand and has no capacity shortage, wherein 40% of energy produced by wind turbine (E-82) as shown in Figure 6.17. The excess of electricity through system components is a little high, which equates to 4.96% of total energy produced in a year.

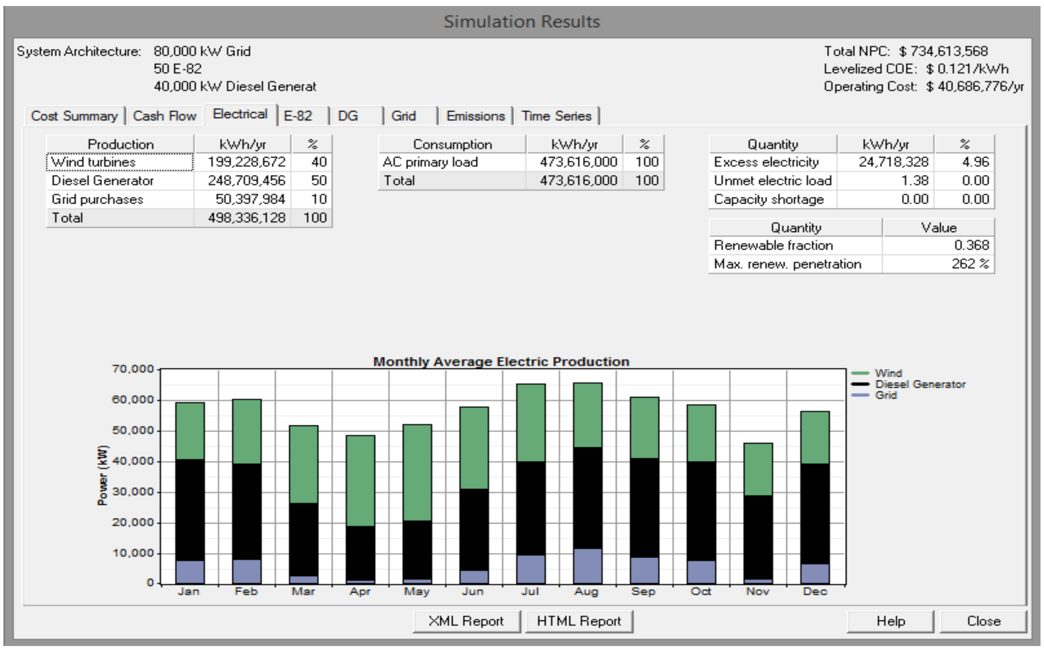


Figure 6.17: Simulation results for wind grid-connected HES for Brak City with wind speed 4.3 m/s and diesel price 0.20 $/L

6.2.3.3. Sensitivity Results

The sensitivity results for wind grid-connected HES concluded that the OST configurations for all sensitivity variables is grid/wind/DG as shown in Figure 6.18a, Figure 6.18b, Figure 6.18c Figure 6.18d. Therefore, the increasing of fuel price and wind speed value in the site has no effect on the system configuration. This may be referring to that this the optimal size in system configuration, which fit with electricity load requirements. Likewise in wind stand-alone system, the CC is optimal dispatch strategy overall system components sizes as well as the sensitivity variables used in the design.

At diesel price 0.60 $/L and 0.80 $/L, the system use more quantity of wind turbine to producing the electricity, and this may be refer to tis most economically than producing by diesel generators at that diesel cost. Consequently, the renewable fraction increased whenever number of wind turbines used in the system increased. Except, in sensitivity variables of 5.2 m/s and diesel price of 0.60 $/L and 0.80 $/L the system prefer to use 75 wind turbines and gives the same renewable fraction 62% (also except in Figure 6.18d, where the number of wind turbines decreased from 100 to 75 despite the wind speed increasing), which is may be indicates to that the system influenced by strength of wind speed and not influenced by increase of diesel price.

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Wind (m/s)		E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
3.900			50	40000			CC	80000	$ 214,500,000	40,494,472	$ 732,155,328	0.121	0.29	87,387,456	6,900
4.300			50	40000			CC	80000	$ 214,500,000	36,864,336	$ 685,749,952	0.113	0.37	77,585,576	6,146
5.200			50	40000			CC	80000	$ 214,500,000	29,289,328	$ 588,915,968	0.097	0.52	58,601,484	4,690

Figure 6.18a: Sensitivity result categories for wind grid-connected HES for Brak City at diesel price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Wind (m/s)		E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
3.900			50	40000			CC	80000	$ 214,500,000	63,301,120	$ 1,023,700,800	0.169	0.29	86,650,432	6,822
4.300			50	40000			CC	80000	$ 214,500,000	57,306,280	$ 947,066,624	0.156	0.37	77,027,720	6,087
5.200			50	40000			CC	80000	$ 214,500,000	44,843,384	$ 787,748,992	0.130	0.52	58,081,748	4,635

Figure 6.18b: Sensitivity result categories for wind grid-connected HES for Brak City at diesel price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Wind (m/s)		E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
3.900			75	40000			CC	80000	$ 305,750,016	77,964,928	$ 1,302,403,584	0.215	0.39	74,239,328	5,871
4.300			75	40000			CC	80000	$ 305,750,016	68,971,424	$ 1,187,436,416	0.196	0.47	64,305,608	5,106
5.200			75	40000			CC	80000	$ 305,750,016	52,076,468	$ 971,462,080	0.160	0.62	45,379,140	3,624

Figure 6.18c: Sensitivity result categories for wind grid-connected HES for Brak City at diesel price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Wind (m/s)						E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
3.900							100	40000			CC	80000	$ 397,000,000	90,055,112	$ 1,548,206,592	0.256	0.46	65,067,264	5,156
4.300							100	40000			CC	80000	$ 397,000,000	78,556,952	$ 1,401,221,504	0.231	0.54	55,349,504	4,408
5.200							75	40000			CC	80000	$ 305,750,016	64,576,324	$ 1,131,252,224	0.187	0.62	45,244,468	3,610

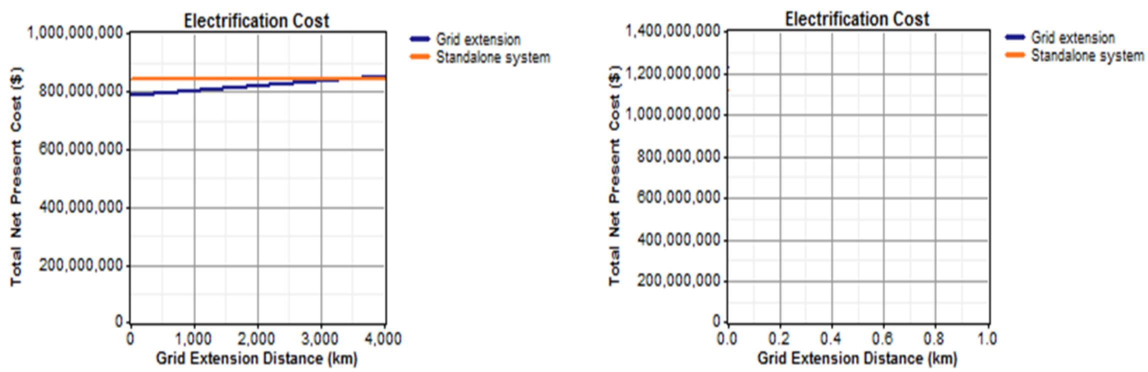
Figure 6.18d: Sensitivity result categories for wind grid-connected HES for Brak City at diesel price 0.80 $/L

6.2.4. Breakeven Grid Extension Distance of Wind Hybrid Energy System

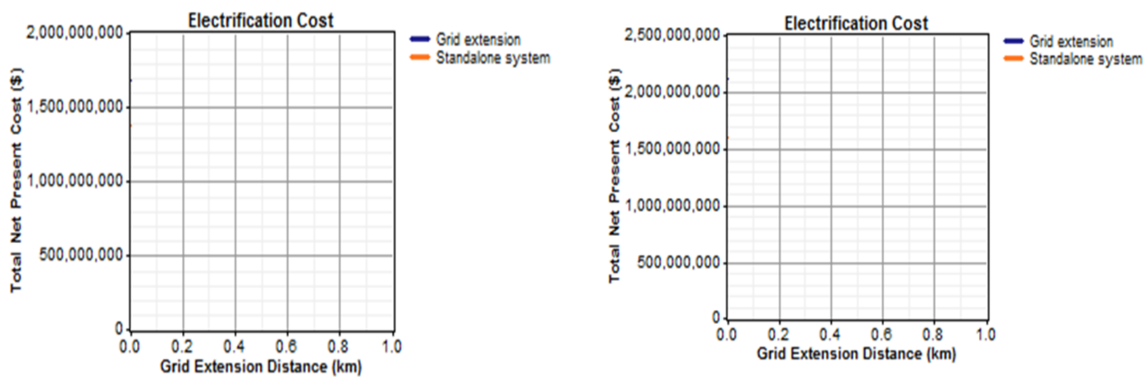
The results of the study were conducted on breakeven grid extension distance in order to compare the wind stand-alone system cost with grid extension cost and determine if it is similar as the results in solar HES categories. The grid extension distance is influenced by varying diesel prices as shown in Figure 6.19 and can summarized in the following way:

- The cost of the grid extension with diesel price of 0.20 $/L is cheaper than wind stand-alone system before breakeven distance 3,125 km, and after that the wind stand-alone system is less in cost.
- By comparing the systems at diesel price 0.40 $/L, 0.60 $/L and 0.80 $/L the grid extension distance is in negative values (-6,508, -17838 and -30,957 prospectively), which indicates to the grid extension is expensive than wind stand-alone system, which indicating to that wind stand-alone system optimal to implemented.

In conclusion, the economically sound system is wind stand-alone system than grid extension with all diesel cost used in the study, and is optimal to use.



Breakeven Grid Extension Distance:	3,125 Km	Breakeven Grid Extension Distance:	-6,508 Km
Diesel Price:	0.20 $/L	Diesel Price:	0.40 $/L



Breakeven Grid Extension Distance:	-17,838 Km	Breakeven Grid Extension Distance:	-30,957 Km
Diesel Price:	0.60 $/L	Diesel Price:	0.80 $/L

Figure 6.19: Breakeven grid extension distances for wind HES for Brak City at sensitivity variable of wind speed 4.3 m/s and with different diesel price categories

6.2.5. Conclusion

The study results of this scenario concluded that there is a high prospect and feasibility for establishing wind HES in region, whether wind stand-alone system or wind grid-connected system as well as its cost-effectiveness for using such technology. The COE that resulted from using wind energy technology was 0.097 $/kWh to 0.289 $/kWh for all feasible system categories that were tested in the design, and the renewable fraction varied from 28% to 67%. Moreover, the comparison of COE for all design categories indicates that the grid-connected systems are lower in cost than stand-alone systems at all sensitivity variables, as illustrated in Figure 6.20. In addition, the COE at average wind speed at the site and at current diesel cost in Libya is low-cost compared to the COE in the existing energy system of Libya, where the OST configuration is wind/DG/battery/converter and grid/wind/DG in stand-alone system and grid-connected system respectively.

The system configuration and its structure are represented in the schematic diagram in Figure 6.21, which reflects the results of the simulation process related to wind HES for Brak City. To conclude, the use of such technology is sound in terms of cost-effectiveness whether in stand-alone system or grid-connected system as well as being more environmentally conservative than the existing energy system in the region, with the share of RE being at least 28% in the system. Additionally to, the design is meets the electricity demand of Brak City region.

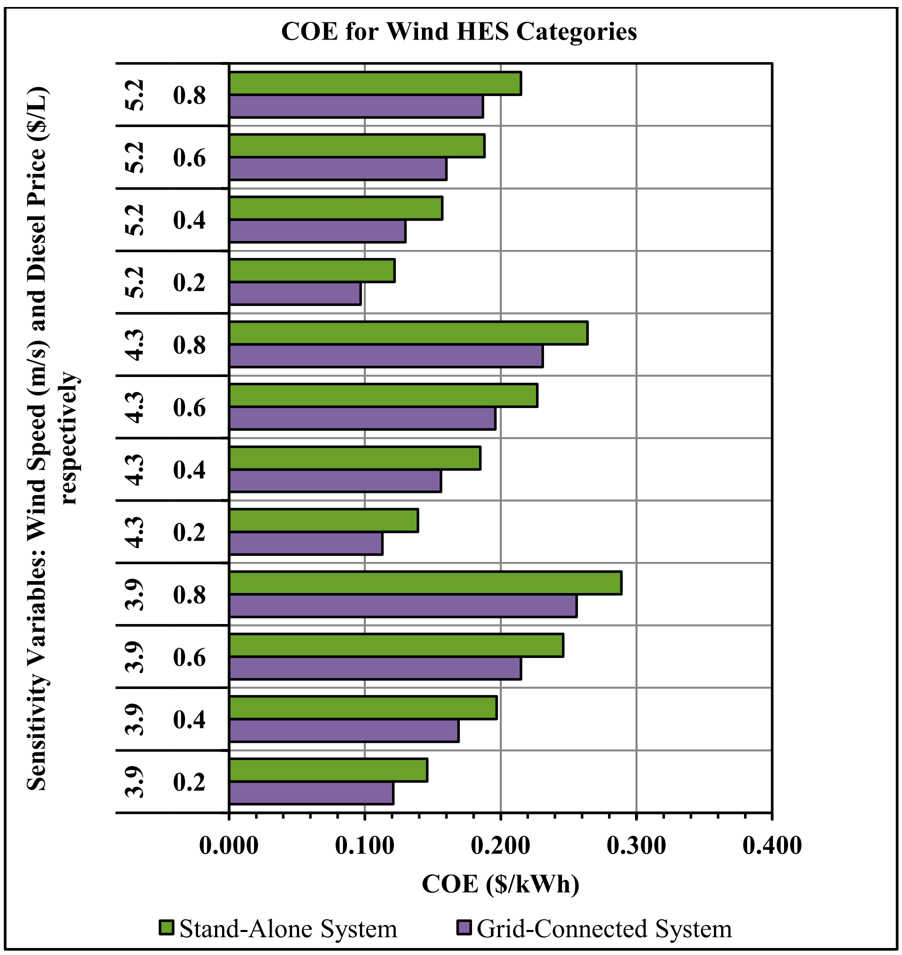
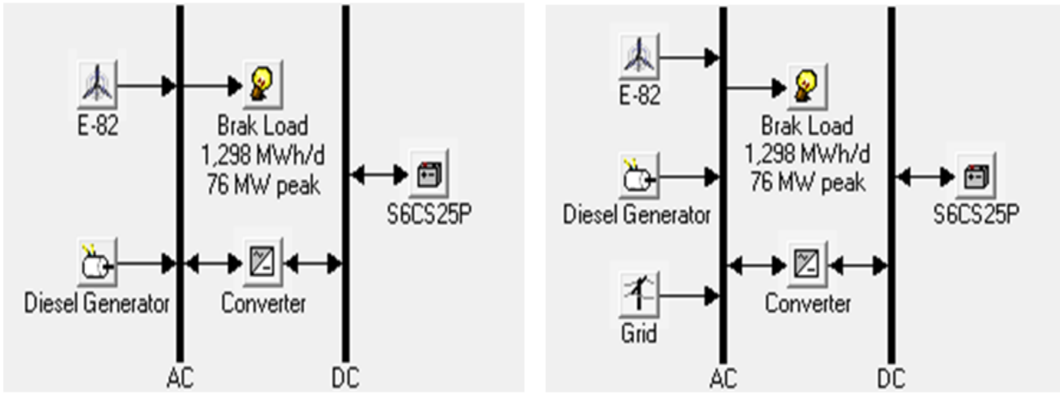


Figure 6.20: Comparison of COE for wind HES categories for Brak City



Wind Stand-Alone System   Wind Grid-Connected System

Figure 6.21: Schematic configurations for wind HES categories for Brak City

6.3. Scenario III: Design Solar and Wind Hybrid Energy System for Electricity Supply to Brak City

6.3.1. Scenario III: Concept Formulation

Solar energy and wind energy technologies have been used in this scenario in order to design the HRES for Brak City, which operates by solar, wind and diesel as the main sources of energy. The system is a combination of PV module, wind turbines and DG. Similarly to the other scenarios, the design was into configured two styles, the first design focused on a solar and wind stand-alone system, while the second design concentrated on a solar and wind grid-connected system in order to meet the electricity demand in Brak City. The scenario objectives were to find out and explore the following:

- Is it cost-effective to use both solar and wind energy technology in region?
- To identify the gained COE from the scenario.
- Which most cost-effective system to use in the region, solar and wind stand-alone system or solar and wind grid-connected system?
- What OST configurations in solar and wind stand-alone system, solar and wind grid-connected system?

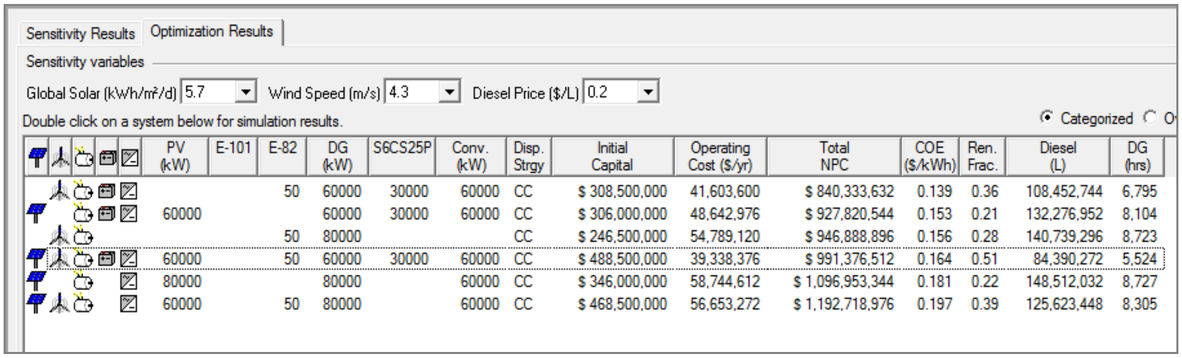
- If the design meets the electricity demand for Brak City.

Thus to realize these objectives a total of 22,464 systems designs (see Appendix 5, paragraph 16) were tested and simulated, in addition to 36 sensitivity variables that were used in the design. Also, in this scenario the sensitivity study was conducted through three dimensions, where in the first dimension four variables of diesel price were used, in the second dimension three variables for solar radiation, and three variables for wind speed in the third dimension. The components' quantity and the size winner relevant to the design of the solar and wind HES are represented in Appendix 6, paragraph 3 (the objectives answer presented in paragraph 6.3.5).

6.3.2. Result Analysis of Solar and Wind Stand-Alone System

6.3.2.1. Optimization Results

The OST for solar and wind stand-alone HES for Brak City at solar radiation 5.7 $kWh/m^2/d$, wind speed 4.3 m/s and diesel price of 0.20 \$/L is PV/wind/DG/battery/converter as shown in Figure 6.22, these attributes represent the optimization results of the system. The optimization results indicates that to be the most cost-effective the use of wind energy technology in the design outperforms of used both technologies in the design, wherein the solar and wind system comes in fourth rank after the wind-diesel system, solar-diesel system and wind-diesel system without battery respectively. On the other hand, the solar and wind system has a renewable fraction more than other systems which accounts for 51% at COE of 0.164 \$/kWh, because the system produces the energy from both technologies while confined in one technology in other systems. Likewise in other scenarios, the CC dispatch strategy is the optimal strategy in the system configuration.


Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 5.7 | Wind Speed (m/s) 4.3 | Diesel Price ($/L) 0.2

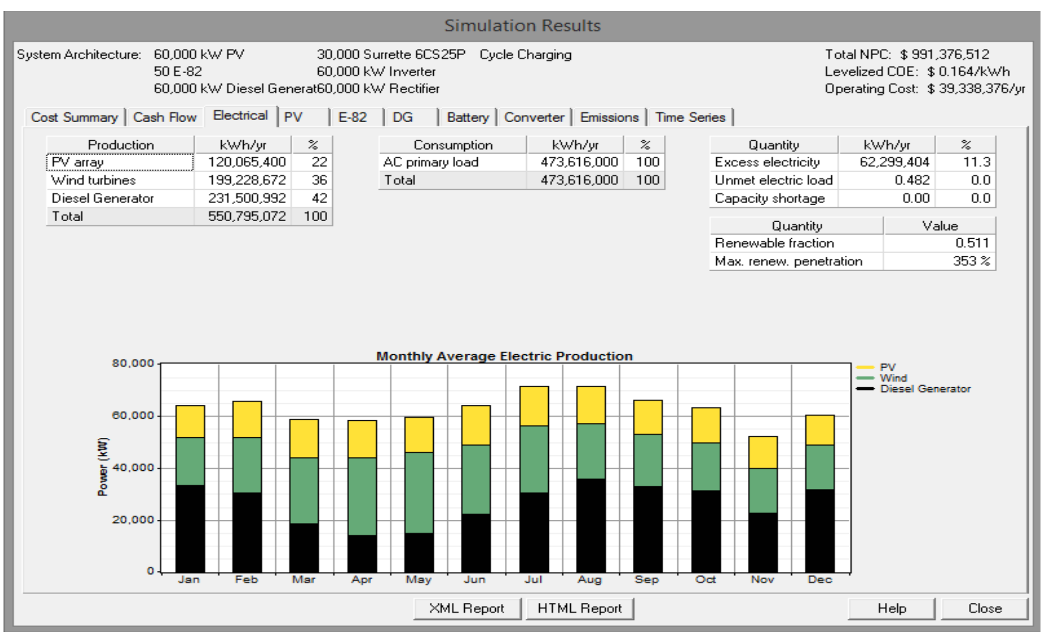
Double click on a system below for simulation results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	60000	30000	60000	CC	$ 308,500,000	41,603,600	$ 840,333,632	0.139	0.36	108,452,744	6,795
60000			60000	30000	60000	CC	$ 306,000,000	48,642,976	$ 927,820,544	0.153	0.21	132,276,952	8,104
		50	80000			CC	$ 246,500,000	54,789,120	$ 946,888,896	0.156	0.28	140,739,296	8,723
60000		50	60000	30000	60000	CC	$ 488,500,000	39,338,376	$ 991,376,512	0.164	0.51	84,390,272	5,524
80000			80000		60000	CC	$ 346,000,000	58,744,612	$ 1,096,953,344	0.181	0.22	148,512,032	8,727
60000		50	80000		60000	CC	$ 468,500,000	56,653,272	$ 1,192,718,976	0.197	0.39	125,623,448	8,305

Figure 6.22: Optimization results for solar and wind stand-alone HES for Brak City at sensitivity variables of solar radiation 5.7 kWh/m^2/d, wind speed 4.3 m/s and diesel price 0.20 $/L

6.3.2.2. Simulation Results of Energy Production of the Optimal System.

The simulation results for solar and wind stand-alone HES shows that the system meets the load demand and has no capacity shortage, but the excess of electricity through system components is very high, representing 11.3%, as clarified in Figure 6.23. The electricity produced by renewable technology represents 58% in the system (36% by wind turbine and 22% from PV module).


Simulation Results

System Architecture: 60,000 kW PV; 50 E-82; 60,000 kW Diesel Generator; 30,000 Surrette 6CS25P; 60,000 kW Inverter; 60,000 kW Rectifier; Cycle Charging

Total NPC: $ 991,376,512
Levelized COE: $ 0.164/kWh
Operating Cost: $ 39,338,376/yr

Production	kWh/yr	%
PV array	120,065,400	22
Wind turbines	199,228,672	36
Diesel Generator	231,500,992	42
Total	550,795,072	100

Consumption	kWh/yr	%
AC primary load	473,616,000	100
Total	473,616,000	100

Quantity	kWh/yr	%
Excess electricity	62,299,404	11.3
Unmet electric load	0.482	0.0
Capacity shortage	0.00	0.0

Quantity	Value
Renewable fraction	0.511
Max. renew. penetration	353 %

Figure 6.23: Simulation results for solar and wind stand-alone HES for Brak City at solar radiation 5.7 kWh/m^2/d, wind speed 4.3 m/s and diesel price 0.20 $/L

6.3.2.3. Sensitivity Results

The sensitivity results of the solar and wind stand-alone HES design concluded that the OST configuration for all sensitivity variables used in the design is wind/DG/battery/converter as shown in Figure 6.24. Also, system configuration does not influenced by increasing fuel price, solar radiation density and wind speed. Except at a sensitivity variable of solar radiation 6.37 kWh/m^2/d, wind speed 3.9 m/s and diesel price 0.80 $/L, where the OST is PV/wind/DG/battery/converter as illustrated in Figure 6.25a, and Figure 6.25b respectively. This indicates and concluded that wind energy most cost-effective to use than solar energy or both technologies in the design. The optimal dispatch strategy is CC overall system components sizes as well as the sensitivity variables used in the design. Also, here the system components size does not changing in DG, battery and converter, while is changing in number of wind turbines needed in the design, in case of diesel price at 0.60 $/L and 0.80 $/L. This is may be refer to, in case of rising the diesel price the system prefer to produce the electricity from wind turbine, because it is economically than producing from diesel generators.

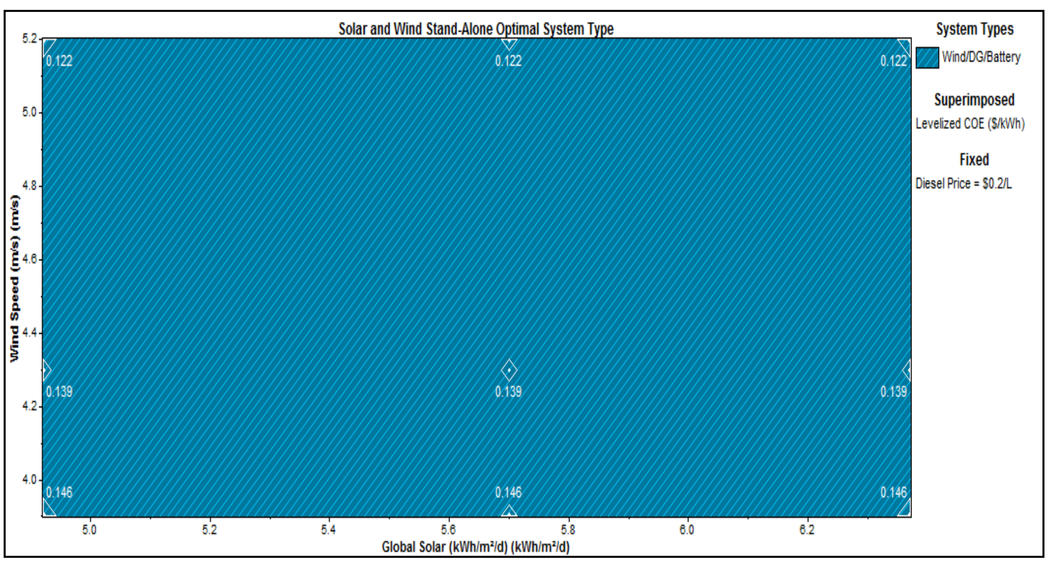


Figure 6.24: Sensitivity results and OST for solar and wind stand-alone HES for Brak City with superimposed LCOE and diesel price of 0.20 $/L

Sensitivity Results | Optimization Results

Tabular

Export...

Double click on a system below for optimization results.

Solar (kWh/m²/d)	Wind (m/s)	Diesel ($/L)	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
4.920	3.900	0.200			50	60000	30000	60000	CC	$ 308,500,000	45,207,560	$ 886,404,416	0.146	0.29	120,306,784	7,431
4.920	3.900	0.400			50	60000	30000	60000	CC	$ 308,500,000	69,204,416	$ 1,193,164,800	0.197	0.28	120,453,872	7,370
4.920	3.900	0.600			75	60000	30000	60000	CC	$ 399,750,016	85,255,688	$ 1,489,603,840	0.246	0.37	105,400,384	6,514
4.920	3.900	0.800			100	60000	30000	60000	CC	$ 491,000,000	98,540,904	$ 1,750,683,520	0.289	0.44	93,722,984	5,823
4.920	4.300	0.200			50	60000	30000	60000	CC	$ 308,500,000	41,603,600	$ 840,333,632	0.139	0.36	108,452,744	6,795
4.920	4.300	0.400			50	60000	30000	60000	CC	$ 308,500,000	63,333,648	$ 1,118,116,608	0.185	0.35	108,773,728	6,748
4.920	4.300	0.600			75	60000	30000	60000	CC	$ 399,750,016	76,135,232	$ 1,373,013,760	0.227	0.45	92,369,624	5,779
4.920	4.300	0.800			100	60000	30000	60000	CC	$ 491,000,000	86,552,344	$ 1,597,429,504	0.264	0.53	80,547,640	5,085
4.920	5.200	0.200			50	60000	30000	60000	CC	$ 308,500,000	33,483,050	$ 736,525,760	0.122	0.52	82,477,920	5,248
4.920	5.200	0.400			50	60000	30000	60000	CC	$ 308,500,000	50,116,192	$ 949,153,216	0.157	0.51	82,892,744	5,233

Figure 6.25a: Sensitivity result categories for solar and wind stand-alone HES for Brak City (10 of 36 sensitivity variables)

Sensitivity Results | Optimization Results

Tabular

Export...

Double click on a system below for optimization results.

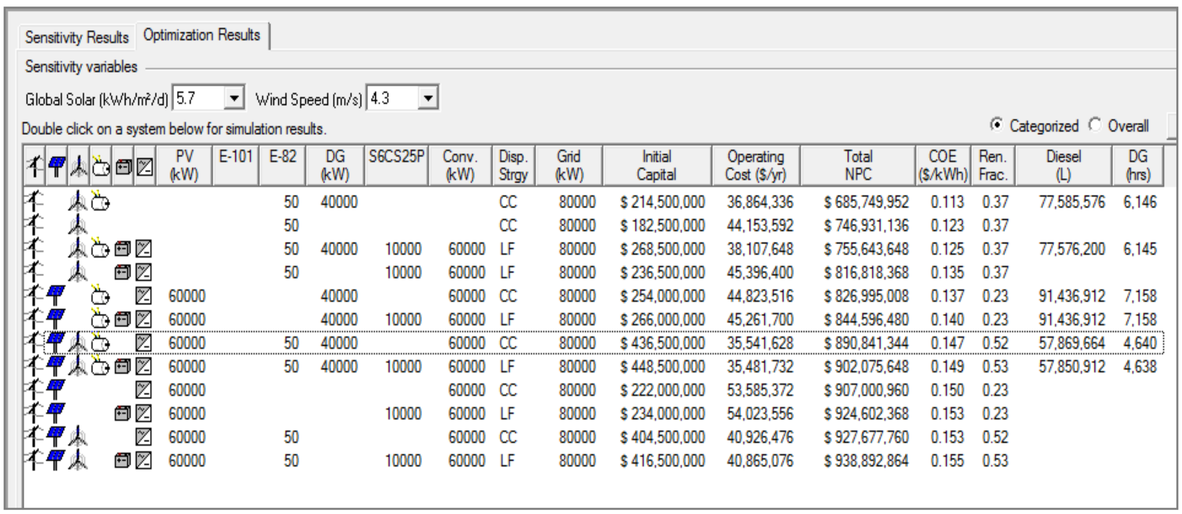
Solar (kWh/m²/d)	Wind (m/s)	Diesel ($/L)	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
4.920	5.200	0.600			75	60000	30000	60000	CC	$ 399,750,016	57,899,992	$ 1,139,906,176	0.188	0.61	66,839,424	4,283
4.920	5.200	0.800			100	60000	30000	60000	CC	$ 491,000,000	63,529,400	$ 1,303,118,976	0.215	0.67	55,590,272	3,557
5.700	3.900	0.200			50	60000	30000	60000	CC	$ 308,500,000	45,207,560	$ 886,404,416	0.146	0.29	120,306,784	7,431
5.700	3.900	0.400			50	60000	30000	60000	CC	$ 308,500,000	69,204,416	$ 1,193,164,800	0.197	0.28	120,453,872	7,370
5.700	3.900	0.600			75	60000	30000	60000	CC	$ 399,750,016	85,255,688	$ 1,489,603,840	0.246	0.37	105,400,384	6,514
5.700	3.900	0.800			100	60000	30000	60000	CC	$ 491,000,000	98,540,904	$ 1,750,683,520	0.289	0.44	93,722,984	5,823
5.700	4.300	0.200			50	60000	30000	60000	CC	$ 308,500,000	41,603,600	$ 840,333,632	0.139	0.36	108,452,744	6,795
5.700	4.300	0.400			50	60000	30000	60000	CC	$ 308,500,000	63,333,648	$ 1,118,116,608	0.185	0.35	108,773,728	6,748
5.700	4.300	0.600			75	60000	30000	60000	CC	$ 399,750,016	76,135,232	$ 1,373,013,760	0.227	0.45	92,369,624	5,779
5.700	4.300	0.800			100	60000	30000	60000	CC	$ 491,000,000	86,552,344	$ 1,597,429,504	0.264	0.53	80,547,640	5,085
5.700	5.200	0.200			50	60000	30000	60000	CC	$ 308,500,000	33,483,050	$ 736,525,760	0.122	0.52	82,477,920	5,248
5.700	5.200	0.400			50	60000	30000	60000	CC	$ 308,500,000	50,116,192	$ 949,153,216	0.157	0.51	82,892,744	5,233
5.700	5.200	0.600			75	60000	30000	60000	CC	$ 399,750,016	57,899,992	$ 1,139,906,176	0.188	0.61	66,839,424	4,283
5.700	5.200	0.800			100	60000	30000	60000	CC	$ 491,000,000	63,529,400	$ 1,303,118,976	0.215	0.67	55,590,272	3,557
6.370	3.900	0.200			50	60000	30000	60000	CC	$ 308,500,000	45,207,560	$ 886,404,416	0.146	0.29	120,306,784	7,431
6.370	3.900	0.400			50	60000	30000	60000	CC	$ 308,500,000	69,204,416	$ 1,193,164,800	0.197	0.28	120,453,872	7,370
6.370	3.900	0.600			75	60000	30000	60000	CC	$ 399,750,016	85,255,688	$ 1,489,603,840	0.246	0.37	105,400,384	6,514
6.370	3.900	0.800	60000		75	60000	30000	60000	CC	$ 579,750,016	90,209,920	$ 1,732,935,552	0.286	0.53	81,456,320	5,325
6.370	4.300	0.200			50	60000	30000	60000	CC	$ 308,500,000	41,603,600	$ 840,333,632	0.139	0.36	108,452,744	6,795
6.370	4.300	0.400			50	60000	30000	60000	CC	$ 308,500,000	63,333,648	$ 1,118,116,608	0.185	0.35	108,773,728	6,748
6.370	4.300	0.600			75	60000	30000	60000	CC	$ 399,750,016	76,135,232	$ 1,373,013,760	0.227	0.45	92,369,624	5,779
6.370	4.300	0.800			100	60000	30000	60000	CC	$ 491,000,000	86,552,344	$ 1,597,429,504	0.264	0.53	80,547,640	5,085
6.370	5.200	0.200			50	60000	30000	60000	CC	$ 308,500,000	33,483,050	$ 736,525,760	0.122	0.52	82,477,920	5,248
6.370	5.200	0.400			50	60000	30000	60000	CC	$ 308,500,000	50,116,192	$ 949,153,216	0.157	0.51	82,892,744	5,233
6.370	5.200	0.600			75	60000	30000	60000	CC	$ 399,750,016	57,899,992	$ 1,139,906,176	0.188	0.61	66,839,424	4,283
6.370	5.200	0.800			100	60000	30000	60000	CC	$ 491,000,000	63,529,400	$ 1,303,118,976	0.215	0.67	55,590,272	3,557

Figure 6.25b: Sensitivity result categories for solar and wind stand-alone HES for Brak City (26 of 36 sensitivity variables)

6.3.3. Result Analysis of Solar and Wind Grid-Connected System

6.3.3.1. Optimization Results

The optimization results for solar and wind grid-connected HES for Brak City result in average of renewable sources in the site indicating that the OST is Grid/PV/wind/DG/converter as shown in Figure 6.26. The system gives COE 0.147 $/kWh with renewable fraction 52%, and comes in seventh rank from a total of 12 feasible systems in cost, with CC of dispatch strategy.



PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	36,864,336	$ 685,749,952	0.113	0.37	77,585,576	6,146
		50				CC	80000	$ 182,500,000	44,153,592	$ 746,931,136	0.123	0.37		
		50	40000	10000	60000	LF	80000	$ 268,500,000	38,107,648	$ 755,643,648	0.125	0.37	77,576,200	6,145
		50		10000	60000	LF	80000	$ 236,500,000	45,396,400	$ 816,818,368	0.135	0.37		
60000			40000		60000	CC	80000	$ 254,000,000	44,823,516	$ 826,995,008	0.137	0.23	91,436,912	7,158
60000			40000	10000	60000	LF	80000	$ 266,000,000	45,261,700	$ 844,596,480	0.140	0.23	91,436,912	7,158
60000		50	40000		60000	CC	80000	$ 436,500,000	35,541,628	$ 890,841,344	0.147	0.52	57,869,664	4,640
60000		50	40000	10000	60000	LF	80000	$ 448,500,000	35,481,732	$ 902,075,648	0.149	0.53	57,850,912	4,638
60000					60000	CC	80000	$ 222,000,000	53,585,372	$ 907,000,960	0.150	0.23		
60000				10000	60000	LF	80000	$ 234,000,000	54,023,556	$ 924,602,368	0.153	0.23		
60000		50			60000	CC	80000	$ 404,500,000	40,926,476	$ 927,677,760	0.153	0.52		
60000		50		10000	60000	LF	80000	$ 416,500,000	40,865,076	$ 938,892,864	0.155	0.53		

Figure 6.26: Optimization results for solar and wind grid-connected HES for Brak City at sensitivity variables of solar radiation 5.7 $kWh/m^2/d$, wind speed 4.3 m/s and diesel price 0.20 $/L

6.3.3.2. Simulation Results of Energy Production of the Optimal System

The simulation results for solar and wind grid-connected HES indicates that the system meets the load demand and has no capacity shortage, as shown in Figure 6.27. The system produces 65% of total electricity from renewable technology, but the excess electricity through system components is very high, accounting 12%.

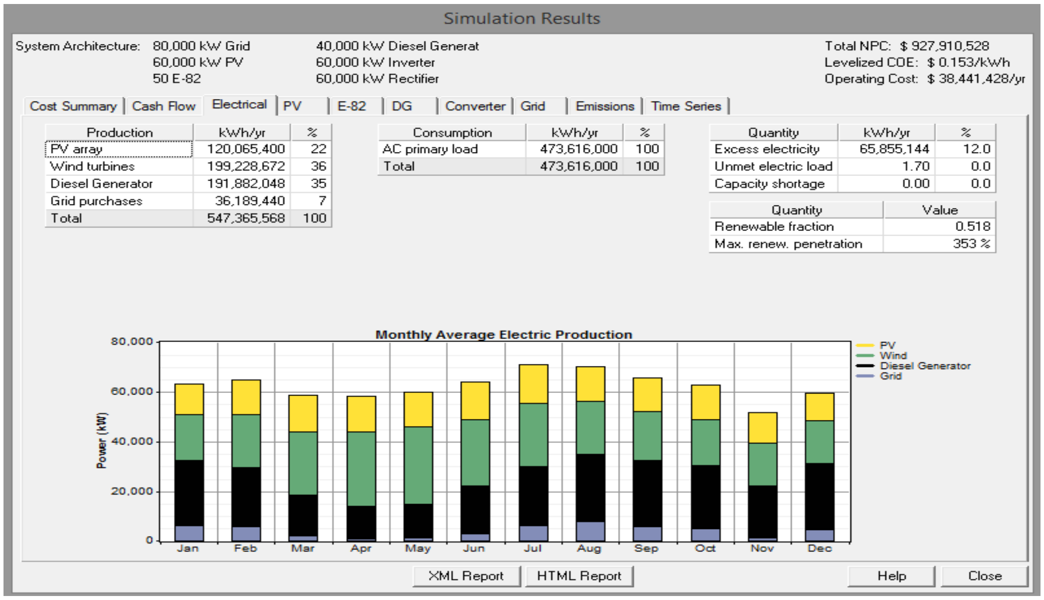
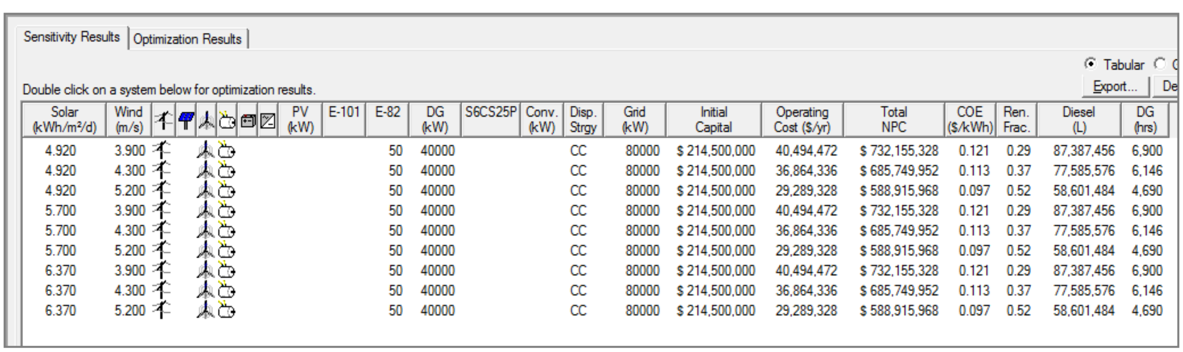


Figure 6.27: Simulation results for solar and wind grid-connected HES for Brak City at solar radiation 5.7 kWh/m^2/d, wind speed 4.3 m/s and diesel price 0.20 $/L

6.3.3.3. Sensitivity Results

The sensitivity results of design solar and wind grid-connected HES show that the OST is grid/wind/DG for all sensitivity variables as illustrated in Figure 6.28a, Figure 6.28b, Figure 6.28c and Figure 6.28d. Now even in case of high solar radiation it is always more economically not to use PV panels. In case of grid connection led this sensitivity study to the same results as gained in scenario II.


Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Solar (kWh/m²/d)	Wind (m/s)	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
4.920	3.900			50	40000			CC	80000	$ 214,500,000	40,494,472	$ 732,155,328	0.121	0.29	87,387,456	6,900
4.920	4.300			50	40000			CC	80000	$ 214,500,000	36,864,336	$ 685,749,952	0.113	0.37	77,585,576	6,146
4.920	5.200			50	40000			CC	80000	$ 214,500,000	29,289,328	$ 588,915,968	0.097	0.52	58,601,484	4,690
5.700	3.900			50	40000			CC	80000	$ 214,500,000	40,494,472	$ 732,155,328	0.121	0.29	87,387,456	6,900
5.700	4.300			50	40000			CC	80000	$ 214,500,000	36,864,336	$ 685,749,952	0.113	0.37	77,585,576	6,146
5.700	5.200			50	40000			CC	80000	$ 214,500,000	29,289,328	$ 588,915,968	0.097	0.52	58,601,484	4,690
6.370	3.900			50	40000			CC	80000	$ 214,500,000	40,494,472	$ 732,155,328	0.121	0.29	87,387,456	6,900
6.370	4.300			50	40000			CC	80000	$ 214,500,000	36,864,336	$ 685,749,952	0.113	0.37	77,585,576	6,146
6.370	5.200			50	40000			CC	80000	$ 214,500,000	29,289,328	$ 588,915,968	0.097	0.52	58,601,484	4,690

Figure 6.28a: Sensitivity result categories for solar and wind grid-connected HES for Brak City at diesel price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Solar (kWh/m^2/d)	Wind (m/s)	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
4.920	3.900			50	40000			CC	80000	$ 214,500,000	63,301,120	$ 1,023,700,800	0.169	0.29	86,650,432	6,822
4.920	4.300			50	40000			CC	80000	$ 214,500,000	57,306,280	$ 947,066,624	0.156	0.37	77,027,720	6,087
4.920	5.200			50	40000			CC	80000	$ 214,500,000	44,843,384	$ 787,748,992	0.130	0.52	58,081,748	4,635
5.700	3.900			50	40000			CC	80000	$ 214,500,000	63,301,120	$ 1,023,700,800	0.169	0.29	86,650,432	6,822
5.700	4.300			50	40000			CC	80000	$ 214,500,000	57,306,280	$ 947,066,624	0.156	0.37	77,027,720	6,087
5.700	5.200			50	40000			CC	80000	$ 214,500,000	44,843,384	$ 787,748,992	0.130	0.52	58,081,748	4,635
6.370	3.900			50	40000			CC	80000	$ 214,500,000	63,301,120	$ 1,023,700,800	0.169	0.29	86,650,432	6,822
6.370	4.300			50	40000			CC	80000	$ 214,500,000	57,306,280	$ 947,066,624	0.156	0.37	77,027,720	6,087
6.370	5.200			50	40000			CC	80000	$ 214,500,000	44,843,384	$ 787,748,992	0.130	0.52	58,081,748	4,635

Figure 6.28b: Sensitivity result categories for solar and wind grid-connected HES for Brak City at diesel price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Solar (kWh/m^2/d)	Wind (m/s)	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
4.920	3.900			75	40000			CC	80000	$ 305,750,016	77,964,928	$ 1,302,403,584	0.215	0.39	74,239,328	5,871
4.920	4.300			75	40000			CC	80000	$ 305,750,016	68,971,424	$ 1,187,436,416	0.196	0.47	64,305,608	5,106
4.920	5.200			75	40000			CC	80000	$ 305,750,016	52,076,468	$ 971,462,080	0.160	0.62	45,379,140	3,624
5.700	3.900			75	40000			CC	80000	$ 305,750,016	77,964,928	$ 1,302,403,584	0.215	0.39	74,239,328	5,871
5.700	4.300			75	40000			CC	80000	$ 305,750,016	68,971,424	$ 1,187,436,416	0.196	0.47	64,305,608	5,106
5.700	5.200			75	40000			CC	80000	$ 305,750,016	52,076,468	$ 971,462,080	0.160	0.62	45,379,140	3,624
6.370	3.900			75	40000			CC	80000	$ 305,750,016	77,964,928	$ 1,302,403,584	0.215	0.39	74,239,328	5,871
6.370	4.300			75	40000			CC	80000	$ 305,750,016	68,971,424	$ 1,187,436,416	0.196	0.47	64,305,608	5,106
6.370	5.200			75	40000			CC	80000	$ 305,750,016	52,076,468	$ 971,462,080	0.160	0.62	45,379,140	3,624

Figure 6.28c: Sensitivity result categories for solar and wind grid-connected HES for Brak City at diesel price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

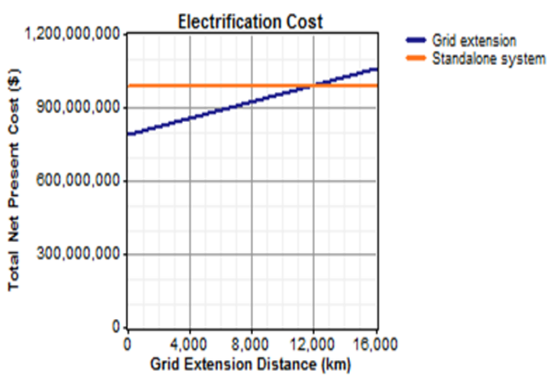
Solar (kWh/m^2/d)	Wind (m/s)	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
4.920	3.900			100	40000			CC	80000	$ 397,000,...	90,055,112	$ 1,548,206,592	0.256	0.46	65,067,264	5,156
4.920	4.300			100	40000			CC	80000	$ 397,000,...	78,556,952	$ 1,401,221,504	0.231	0.54	55,349,504	4,408
4.920	5.200			75	40000			CC	80000	$ 305,750,...	64,576,324	$ 1,131,252,224	0.187	0.62	45,244,468	3,610
5.700	3.900			100	40000			CC	80000	$ 397,000,...	90,055,112	$ 1,548,206,592	0.256	0.46	65,067,264	5,156
5.700	4.300			100	40000			CC	80000	$ 397,000,...	78,556,952	$ 1,401,221,504	0.231	0.54	55,349,504	4,408
5.700	5.200			75	40000			CC	80000	$ 305,750,...	64,576,324	$ 1,131,252,224	0.187	0.62	45,244,468	3,610
6.370	3.900			100	40000			CC	80000	$ 397,000,...	90,055,112	$ 1,548,206,592	0.256	0.46	65,067,264	5,156
6.370	4.300			100	40000			CC	80000	$ 397,000,...	78,556,952	$ 1,401,221,504	0.231	0.54	55,349,504	4,408
6.370	5.200			75	40000			CC	80000	$ 305,750,...	64,576,324	$ 1,131,252,224	0.187	0.62	45,244,468	3,610

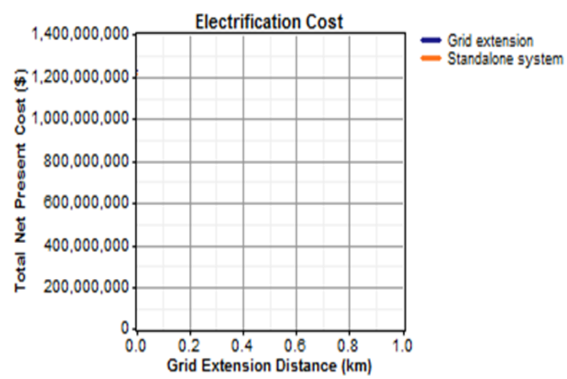
Figure 6.28d: Sensitivity result categories for solar and wind grid-connected HES for Brak City at diesel price 0.80 $/L

6.3.4. Breakeven Grid Extension distance of Solar and Wind Hybrid Energy System

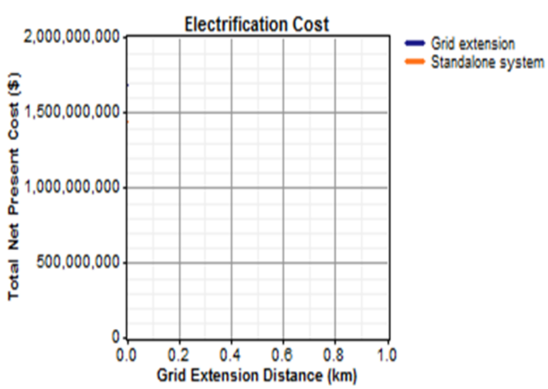
Similar to other scenarios, the study was conducted on a breakeven grid extension distance, indicated by comparing the solar and wind stand-alone system costs with grid extension cost, where influenced with varying diesel price. The results for grid extension distance in each of the diesel price variables are represented in Figure 6.29 and can be concluded in the following:

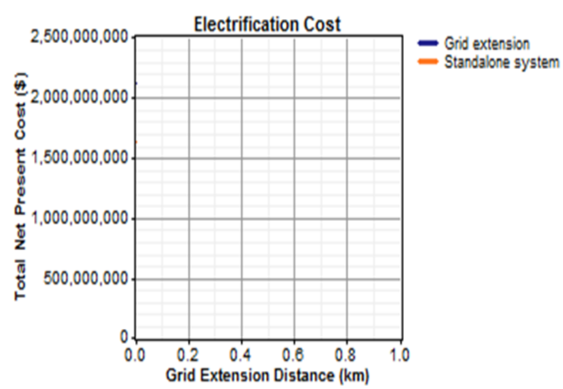
- The cost of the grid extension in diesel price 0.20 $/L (and system configuration 4 of Figure 6.22) up to a distance of 11,986 km is the less expensive, after which the solar and wind stand-alone system is costs less.
- Comparing the systems in terms of diesel price 0.40 $/L, 0.60 $/L and 0.80 $/L, the grid extension distance also resulted here in a negative value, which indicates that the grid extension is expensive than a solar and wind stand-alone system.





Breakeven Grid Extension Distance:	11,986 Km	Breakeven Grid Extension Distance:	-1,165 Km
Diesel Price:	0.20 $/L	Diesel Price:	0.40 $/L





Breakeven Grid Extension Distance:	-13,856 Km	Breakeven Grid Extension Distance:	-29,101 Km
Diesel Price:	0.60 $/L	Diesel Price:	0.80 $/L

Figure 6.29: Breakeven grid extension distance for solar and wind HES for Brak City at solar radiation 5.7 kWh/m^2/d, wind speed 4.3 m/s and with different diesel price categories

6.3.5. Conclusion

The study concludes from this scenario that the design for solar and wind HES is non-feasible, and that use of both technologies in one system is not cost-effective in this region. Consequently, the sensitivity analysis results from this scenario leads to the same outcome as scenario II, where wind energy is the most cost-effective technology to use in the region, instead of combining these technologies in one system whether stand-alone or grid-connected (as shown in Figure 6.26, Figure 6.28a, Figure 6.28b, Figure 6.28c and Figure 6.28d).

To the questions posted in section 6.3.1; the COE gained from using both technologies in one system: the cost rates are between 0.134 $/kWh to 0.295 $/kWh in stand-alone system and from 0.134 $/kWh to 0.295 $/kWh in grid-connected system (see, results in Appendix 5 paragraph 18). Also, here comparable to other scenarios, the COE in grid-connected systems are lower in cost than stand-alone systems in all design categories at all sensitivity variables, as shown. Furthermore, the OST resulting from the simulation process is PV/wind/DG/battery/converter for the stand-alone system and grid/PV/wind/DG in the grid-connected system.

In summary, the study concluded that using both technologies in the design is not cost-effective, and should accordingly be avoided.

6.4. Comparison the Cost of Energy of Scenarios

The comparison of the COE for all scenario categories, at average solar radiation and wind speed, with sensitivity variables for diesel price is illustrated in Table 6.1 (see, solar and wind HES values in Figure 6.22, Figure 6.26 and Appendix 5, paragraph 18). A resulting in the conclusion that the use of wind HES is most economical versus solar HES or solar and wind HES overall diesel price levels, whether in case of stand-alone systems or in grid-connected systems as shown in Figure 6.32 and Figure 6.33 respectively.

Table 6.1: Rank of COE for all system categories of the scenarios at average renewable sources at the site of Brak City HRES with different diesel prices

System type	Sensitivity variables			COE ($/kWh)		Rank	
	Solar (kWh/m²/d)	Wind (m/s)	Diesel ($/L)	Stand-alone system	Grid-connected system	Stand-alone system	Grid-connected system
Solar HES	5.7	-	0.2	0.153	0.137	11	11
	5.7	-	0.4	0.209	0.189	7	7
	5.7	-	0.6	0.262	0.240	3	3
	5.7	-	0.8	0.317	0.289	1	1
Wind HES	-	4.3	0.2	0.139	0.113	12	12
	-	4.3	0.4	0.185	0.156	9	9
	-	4.3	0.6	0.227	0.196	6	6
	-	4.3	0.8	0.264	0.231	2	4
Solar and wind HES	5.7	4.3	0.2	0.164	0.147	10	10
	5.7	4.3	0.4	0.200	0.180	8	8
	5.7	4.3	0.6	0.238	0.213	4	5
	5.7	4.3	0.8	0.269	0.245	4	2

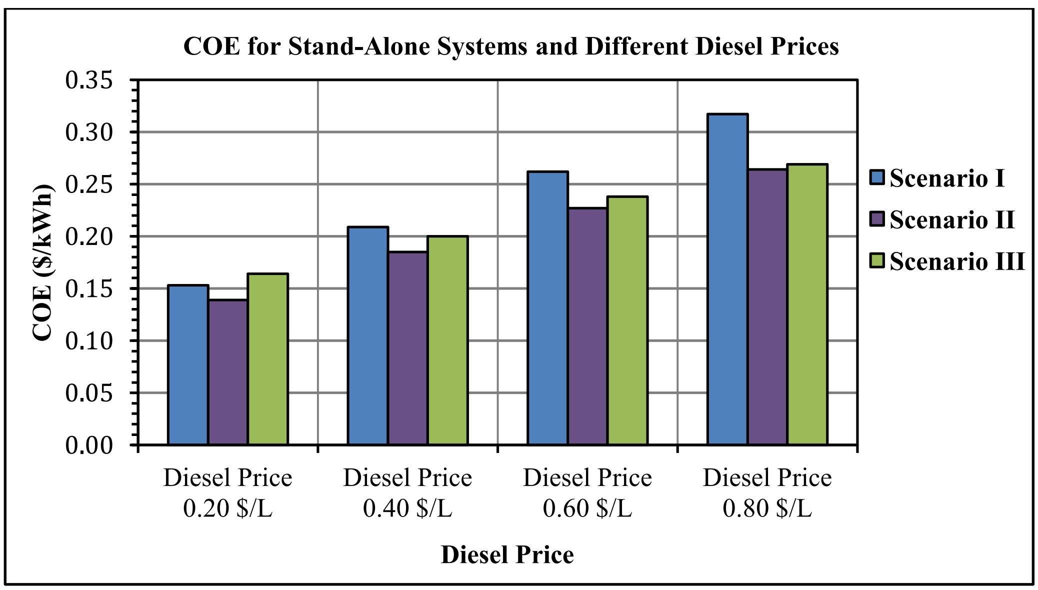


Figure 6.30: Comparison of COE for stand-alone systems of scenarios at different diesel prices

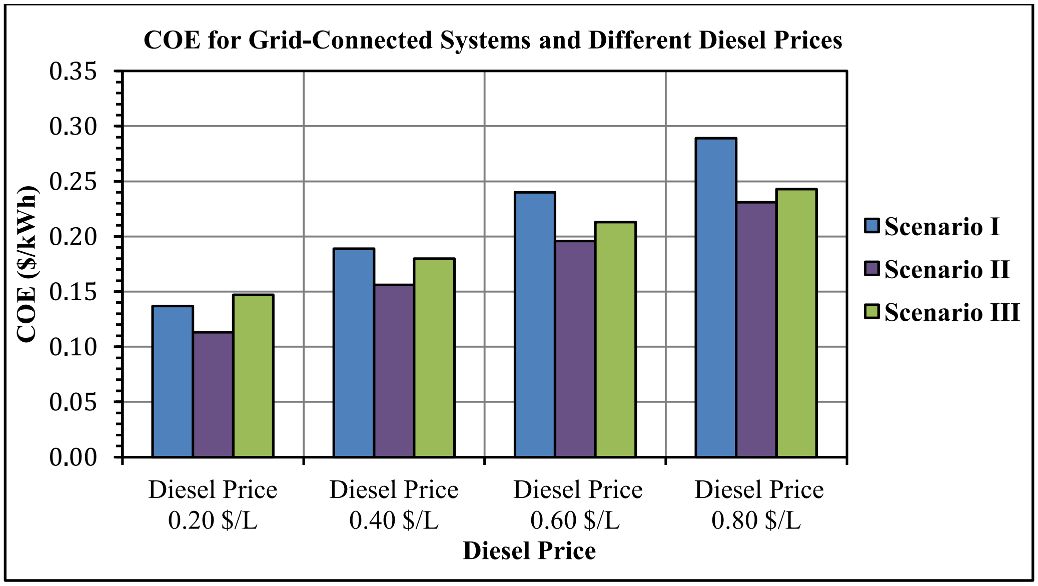


Figure 6.31: Comparison of COE for grid-connected systems of scenarios at different diesel prices

6.5. Summary of Findings

In the IRENA - study (2015a, p.94 and p.73) the typical COE-range had been calculated between 0.08 $/kWh to 0.50 $/kWh in solar PV system and between 0.045 $/kWh to 0.14 $/kWh in wind-onshore system in 2014. It was found to be within this global level ranges. The key findings of this study can summarized as following:

- The most cost-effective viable technology to use in the area is wind energy, whether in stand-alone systems or grid-connected systems overall diesel price that has been used in study scenarios.
- The OST in the case of solar energy technology usage in the region is PV/DG/battery/converter for the stand-alone system, and grid/solar/DG/ converter for the grid-connected system.
- In the case of wind energy technology usage in the region, the OST configuration is wind/DG/battery/converter for the stand-alone system, and grid/wind/DG for the grid-connected system.

- By using both solar and wind energy technologies in the design, the OST is PV/wind/DG/battery/converter for the stand-alone system, and grid/PV/wind/DG/ converter for the grid-connected system. But that lead to higher COE than using wind turbines only.
- The grid-connected systems are more sustainable economically and environmentally, and meet the electricity demand for Brak City society.
- The optimal dispatch strategy is CC for all scenario categories at an average of sensitivity variables, as well as a majority of the feasible systems, whether stand-alone systems or grid-connected systems, which indicates that CC is better than LF strategy.

In summary, implementing such as these technologies can be contributing partly to solving the problem of electricity outage facing the present energy system in Brak City as well as in Libya in sustainable energy manner instead of the current fossil energy sources.

7. Vision for Implementing Renewable Energy Technologies in Libya

7.1. Outlook of Implementing Solar and Wind Energy in Other Regions of Libya

Regarding the outlook for implementing solar and wind energy technologies in other regions of the country: Based on the case study that has been conducted in order to design HRES in the Brak City region, as well as on the scenario results (clarifying the potential for RE technologies in this region as well as other regions of Libya), the scope of further studies can be expanded to additional regions of Libya. The outlook of the optimal RET that can be used in each region of Libya has been determined based on approximate design criteria - not adjusted to real district energy requirements because the populations as well as energy load differ from region to region[47] (See the districts details and results in Appendix 7). Because of that, not surprising that some districts have similar COE.

The results of the simulation process concluded in Figure 7.1 indicate the optimal RET to use in each region, is wind energy at a range of diesel price levels, in stand-alone HRES operation by solar and wind energy technologies. Also, in the case of grid-connected HRES, the optimal RET is wind energy at all diesel price levels; indicating that increasing fuel price has no substantial effect on the type of optimal technology as shown in Figure 7.2. Even in the south of Libya, where the solar radiation value is high, wind energy technology is still optimal.

In summary, the optimal RET to implement does not vary by geography or diesel cost. There is no effect in the case of using for stand-alone energy systems or grid-connected energy systems as shown in Figure 7.3, where wind energy technology is the optimal in all categories. The COE overall regions of Libya varies from 0.121 to 0.286 $/kWh in stand-alone systems, and ranges from 0.096 to 0.254 $/kWh in grid-connected systems in all categories. Accordingly, the grid-connected system is cheaper. Although Libyan districts

[47] The criteria designed based on the average of RE sources of districts of Libya, and application the scenarios parameters in the same procedure used in the case study with consideration of the diesel price levels in order to specify the optimal RET to use in each region. Also, in the consideration to satisfy the same energy load value used in Brak City energy system, and simulate HOMER based on this energy load.

exhibit variations in the fine details of RE sources, implementation of these technologies is feasible and viable in all regions of the country.

Libya Districts with their COE ($/kWh)	Diesel Price $/L 0.20	0.40	0.60	0.80
22	0.135	0.178	0.218	0.253
21	0.146	0.184	0.223	0.259
20	0.144	0.181	0.218	0.254
19	0.139	0.185	0.227	0.264
18	0.150	0.191	0.232	0.271
17	0.152	0.193	0.235	0.275
16	0.152	0.193	0.235	0.275
15	0.152	0.193	0.235	0.276
14	0.151	0.192	0.234	0.274
13	0.149	0.189	0.230	0.268
12	0.149	0.197	0.233	0.268
11	0.149	0.197	0.233	0.268
10	0.140	0.186	0.229	0.267
9	0.149	0.189	0.230	0.268
8	0.145	0.182	0.220	0.255
7	0.132	0.174	0.212	0.246
6	0.153	0.195	0.237	0.279
5	0.121	0.155	0.187	0.215
4	0.121	0.155	0.187	0.215
3	0.153	0.195	0.237	0.279
2	0.149	0.188	0.229	0.267
1	0.155	0.199	0.243	0.286

Technology Type

Wind Energy

Figure 7.1: Outlook of the optimal RET to use for each district of Libya at various diesel price levels with COE related to establishing stand-alone HRES

Libya Districts with their COE ($/kWh)	0.20	0.40	0.60	0.80
22	0.110	0.150	0.188	0.222
21	0.112	0.154	0.193	0.227
20	0.110	0.151	0.189	0.223
19	0.113	0.156	0.196	0.231
18	0.115	0.159	0.201	0.238
17	0.116	0.161	0.204	0.242
16	0.116	0.162	0.204	0.242
15	0.116	0.162	0.204	0.242
14	0.116	0.161	0.203	0.241
13	0.114	0.158	0.199	0.236
12	0.114	0.158	0.199	0.236
11	0.114	0.158	0.199	0.236
10	0.114	0.158	0.199	0.235
9	0.114	0.158	0.199	0.236
8	0.110	0.151	0.190	0.224
7	0.107	0.146	0.182	0.214
6	0.117	0.163	0.207	0.245
5	0.096	0.129	0.159	0.185
4	0.096	0.129	0.159	0.185
3	0.117	0.163	0.207	0.245
2	0.114	0.158	0.200	0.236
1	0.120	0.168	0.214	0.254

Diesel Price $/L

Technology Type

Wind Energy

Figure 7.2: Outlook of the optimal RET to use for each district of Libya at various diesel price levels with COE related to establishing grid-connected HRES

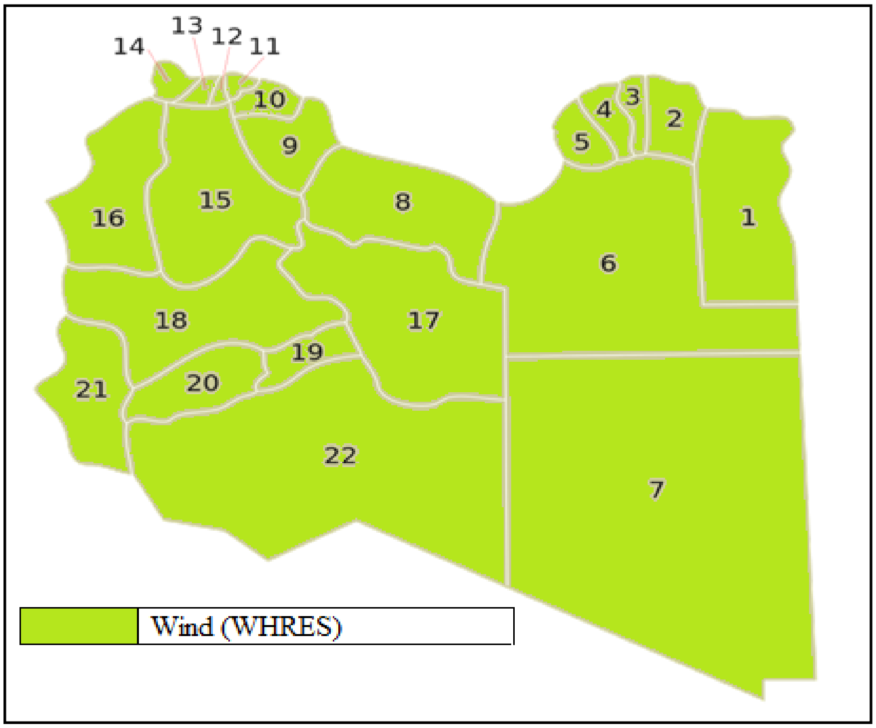


Figure 7.3: Libya outlook map for optimal RET to use in each district of Libya at diesel price 0.20 $/L, 0.40 $/L, 0.60 $/L and 0.80 $/L, related to establishing stand-alone HRES as well as grid-connected HRES

7.2. Role of Using Renewable Energy Technologies in Energy System of Libya

From the case study key findings related to use the solar and wind energy in Brak City region and the outlook of implementation such as those technologies in other regions of the country. Also, for the problems that discussed previously (in paragraph 1.1) which are facing current energy system of Libya could conclude the role of using the RE technologies in Libya.

The implementation of RE technologies in a variety of applications may lead to an active role and improve the performance of the energy sector as well as overcoming the current problems facing Libyan energy system in both local and global level. Implementation of wind energy in application of stand-alone system and grid-connected system can enable Libya's partly to overcome the outage of electricity. Other role for implementing RE technologies related to economic progress, that electricity import can be reduced and implementing strategic development option long-term in order to exporting the electricity, which will contribute effectively in economic progress. Regarding the environment prospective, the CO_2 emission from the current conventional generating technologies can be gradually reduced. The implementations will enable Libya to participate with world communities for the first time at the global climate protection level.

In summary, the using of RE technologies in variety of application in Libya can be lead an active role toward the development of energy sector and fill partly or as first step the insufficiency in electricity production facing Libya in present time.

8. Conclusion

8.1. Conclusion

The objective of this thesis is implementation of RE technologies in the Libyan energy system in order to overcome the problems and insufficiency in energy capacity facing the current energy system by using alternative energy instead of present fossil energy resources. To achieve this objective, a case study to design HRES in the Brak City region has been conducted in several scenarios and system configurations.

From the assessment the existing energy system and by determining the causes hindering development of this sector, it can be concluded that the present energy system of Libya is non-sustainable. It does not meet Libyan energy demands whether economic, environmental, or societal. Beyond the national level, expectations to act with energy policy against climate changes are unfulfilled. Therefore the existing capacity does not meet peak load requirements, and causing outages in electricity supply for several hours, up to days in some regions of the country. Additionally, the environmental impact of CO2 emissions from conventional generating technologies used, dependent on oil and gas as primary energy sources, is an issue.

The task posted in the thesis is identifying the challenges and opportunities for development of the Libyan energy sector. This concluded in the most pressing challenges: increasing energy demand versus inability of the current installed power capacity to meet this demand now and in the foreseeable future. Of importance here are inefficient generating technologies with high electrical losses due to transmission and distribution processes. The policy of the government is nowadays one of the most major challenges, where centralization in decision-making, and investment law making in particular, is hindering RET-based development. In the context of the described opportunities, upgrading the energy infrastructure and optimising the energy transmission and distribution systems would substantially contribute to development. However, the greatest opportunity lies in implementing sustainable RE technologies.

Libya has considerable RE resources; especially solar and wind energy. Other RE technologies such as biomass energy and geothermal energy have lower potential in Libya, because lack of the resources. Priority is given here to solar energy and wind energy and by case study is analysed, where the availability of resources making the implementation of such technologies possible.

Accordingly, by use of solar and wind energy is designed a HRES for Brak City region. This is then enlarged to other regions of Libya in order to develop the energy system more sustainable. The scenario analysis shows that RET have an active role and advantages in the present and in the future (i.e. long-term use), where the COE is cost-effective and competitive to the current COE. But this is only true for a RE share between 21% and 67%. With increased diesel price, RET would be increasingly viable, especially in use of wind energy where COE is lower as for PV technology. Also, RET in a grid-connected system is more effective than stand-alone system application. In case of use solar energy in the design of Brak City HRES, the COE is 0.151 \$/kWh to 0.335 \$/kWh in a solar stand -alone system and from 0.134 \$/kWh to 0.299 \$/kWh in a solar grid-connected system. In case of use wind energy technology in the design, the COE is 0.122 \$/kWh to o.289 \$/kWh in a stand-alone system and between 0.097 \$/kWh to 0.256 \$/kWh in a grid-connected system. On the other hand, the share of RE is 0.21% to 0.36% in solar stand-alone system, and from 0.23% to 0.31% in solar grid-connected system, while it is 0.28% to 0.67% in wind stand-alone system and from 0.29% to 0.62 in wind grid-connected system.

Regarding the co-use of solar and wind energy technology in the design of Brak City HRES, this is not cost-effective as well as not optimal to be implemented in one system as concluded from the study of scenario III. Therefore, the combination of solar and wind energy technologies is not beneficial and should be avoided.

In summary, RET is the most sustainable way to develop the Libyan energy sector. It can feasibly and viably contribute to solving the currently problems facing this sector. Implementation of these technologies would deliver advantages for the Libyan environment, economy, and society. Further, this would contribute to climate-political requirements at the global level. As closing words for this work, Libya's energy future lies in renewable.

Appendixes

Appendix 1: Administrative Districts of Libya (*shabiyaat*)

Table districts of Libya with solar and wind energy resources

Nr.	Name of district	Population	Coordinates		Average Renewable source	
			Latitude	Longitude	Solar irradiation ($kWh/m^2/d$)	Wind speed (m/s)
			N	E		
1	Butnan	159,536	30	24	5.58	3.9
2	Derna	163,351	32.5	22.666	5.27	4.2
3	Jabal al Akhdar	203,156	30.766	21.733	5.62	4.0
4	Marj	185,848	32.5	20.833	5.44	5.2
5	Benghazi	670,797	32.116	20.066	5.44	5.2
6	Al Wahat	177,047	30	22	5.6	4.0
7	Kufra	50,104	24	23	6.37	4.6
8	Sirte	141,378	31.204	16.587	5.65	4.4
9	Misrata	550,938	32.366	12.083	5.32	4.2
10	Murqub	432,202	32.65	14.266	4.92	4.2
11	Tripoli	1,065,405	32.65	13.316	5.11	4.2
12	Jafara	453,198	32.15	13	5.11	4.2
13	Zawiya	290,993	32.75	12.716	5.32	4.2
14	Nuqat al Khams	287,662	32.594	11.894	5.42	4.1
15	Jabal al Gharbi	304,159	31.75	12.5	5.36	4.1
16	Nalut	93,224	31.866	11	5.42	4.1
17	Jufra	52,342	28	17	5.57	4.1
18	Wadi al Shatii	78,532	28	13	5.68	4.2
19	Sabha	134,162	27.033	14.433	5.7	4.3
20	Wadi al Hayaa	76,858	26.25	12.5	5.9	4.5
21	Ghat	23,518	25.333	11	5.89	4.4
22	Murzuq	78,621	25.9	13.9	6.27	4.5

Appendix 2: Determine Energy Demand for Brak City

1- Libya's Population Growth Rate

Table of population growth rate in Libya for 10 years (2003-2012)

Item	Year	Growth rate %
1	2003	1.5
2	2004	1.5
3	2005	1.6
4	2006	1.6
5	2007	1.7
6	2008	1.6
7	2009	1.5
8	2010	1.3
9	2011	1.0
10	2012	0.8
Average		**1.4**

Calculation formula[48]:

$$PR = \frac{(V_{Present} - V_{Past})}{V_{Past}} x100$$

Where:
PR = Percent Rate.
$V_{Present}$ = Present.
V_{Past} = Past.

2- Growth Rate of Electricity Consumption Per Capita in Libya

Table of growth rate for electricity consumption per capita in Libya for 8 years (2003-2010), (see also Figure 2.7 in paragraph 2.2.3).

Number	Year	Electricity consumption per capita (kWh)	Growth rate %
0	2002	2,871	-
1	2003	3,055	6.4
2	2004	3,221	5.4
3	2005	3,553	10.3
4	2006	3,969	11.7
5	2007	4,158	4.8

[48]The calculation formula from http://pages.uoregon.edu/rgp/PPPM613/class8a.htm , online accessed date [30th March 2014].

6	2008	4,360	4.9
7	2009	4,602	5.6
8	2010	4,651	1.1
Average			**6.3**

3- Electricity Load for Brak City HRES

The table illustrates the calculation details for expected required electricity loads to design Brak City HRES that designed to operate in 2017, which have been determined by considering only the average increase of population and electricity consumption per capita (see above).

Number	Year	Population growth rate (=1.4% ann.)	Electricity consumption growth rate (kWh per capita). (= 2% ann.)	Energy demand (kWh/yr)
1	2012	82505	4,850	400,149,250
2	2013	83660	4,947	413,866,020
3	2014	84831	5,046	428,057,226
4	2015	86019	5,147	442,739,793
5	2016	87223	5,250	457,920,750
6	2017	88444	5,355	473,617,620

4- Monthly Load of Libya's Electricity Network in 2012

The table represents the monthly load values of Libya's electricity network in 2012, which has been used in order to determine the primary monthly load of HRES for Brak City, where the average monthly load values have been used in the design.

Month	Max. Load (kW)	Min. Load (kW)	Ave. Load (kW)	Monthly load percentage %
Jan	5,560,000	3,200,000	4,380,000	9.13
Feb	5,627,000	2,388,000	4,007,500	8.35
Mar	4,925,000	2,205,000	3,565,000	7.43
Apr	3,850,000	2,080,000	2,965,000	6.18
May	4,355,000	2,307,000	3,331,000	6.94
Jun	5,300,000	2,638,000	3,969,000	8.27
Jul	5,740,000	3,851,000	4,795,500	9.99
Aug	5,981,000	3,807,000	4,894,000	10.2
Sep	5,595,000	3,135,000	4,365,000	9.1
Oct	5,250,000	3,408,000	4,329,000	9.02
Nov	4,220,000	2,201,000	3,210,500	6.69
Dec	5,810,000	2,547,000	4,178,500	8.7
Sum			**47,990,000**	**100**

5- Daily Load of Libya's Electricity Network in 2008

The table represents the daily load values of Libya's electricity network in 2008, which has been used in order to determine hourly average percentages values based on the average daily load value.

Hour	Max. Load (kW)	Min. Load (kW)	Ave. Load (kW)	Hourly energy percentage %
1	4,050,000	2,400,000	3,225,000	3.92
2	3,750,000	2,290,000	3,020,000	3.67
3	3,580,000	2,070,000	2,825,000	3.43
4	3,600,000	2,085,000	2,842,500	3.45
5	3,530,000	1,920,000	2,725,000	3.31
6	3,600,000	2,200,000	2,900,000	3.52
7	3,730,000	2,440,000	3,085,000	3.75
8	3,830,000	2,740,000	3,285,000	3.99
9	3,970,000	2,860,000	3,415,000	4.15
10	4,030,000	2,960,000	3,495,000	4.25
11	4,050,000	3,050,000	3,550,000	4.31
12	4,040,000	3,030,000	3,535,000	4.29
13	4,240,000	2,980,000	3,610,000	4.38
14	4,260,000	2,900,000	3,580,000	4.35
15	4,250,000	2,800,000	3,525,000	4.28
16	4,190,000	2,790,000	3,490,000	4.24
17	4,330,000	2,940,000	3,635,000	4.42
18	4,350,000	3,030,000	3,690,000	4.48
19	4,370,000	3,200,000	3,785,000	4.6
20	4,410,000	3,510,000	3,960,000	4.81
21	4,750,000	3,300,000	4,025,000	4.89
22	4,650,000	3,250,000	3,950,000	4.8
23	4,400,000	2,960,000	3,680,000	4.47
24	4,240,000	2,750,000	3,495,000	4.24
Sum				**100**

6- Distributions Load of System

This table illustrates the details of distribution energy load for the both monthly and daily load, where calculated based on the load percentage that has been determined in the preceding steps.

A- Monthly Load of System

Month	Monthly distribution load %	Yearly load of system (kWh/yr)	Monthly load of system (KWh/mon.)	Month days	Daily load of system (kWh/d)
Jan	9.13	473,617,620	43,241,289	31	1,394,880

Feb	8.35	473,617,620	39,547,071	28	1,412,395
Mar	7.43	473,617,620	35,189,789	31	1,135,154
Apr	6.18	473,617,620	29,269,569	30	975,652
May	6.94	473,617,620	32,869,063	31	1,060,292
Jun	8.27	473,617,620	39,168,177	30	1,305,606
Jul	9.99	473,617,620	47,314,400	31	1,526,271
Aug	10.2	473,617,620	48,308,997	31	1,558,355
Sep	9.1	473,617,620	43,099,203	30	1,436,640
Oct	9.02	473,617,620	42,720,309	31	1,378,074
Nov	6.69	473,617,620	31,685,019	30	1,056,167
Dec	8.7	473,617,620	41,204,733	31	1,329,185
Sum	**100**		**473,617,620**	**365**	**15,568,673**
Average			**39,468,135**		**1,297,389**

B- Daily Load of System

Hour	**Daily/ hourly distribution load %**	**Hourly load in each month (kW)**					
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**
1	3.92	54,679	55,366	44,498	38,246	41,563	51,180
2	3.67	51,192	51,835	41,660	35,806	38,913	47,916
3	3.43	47,844	48,445	38,936	33,465	36,368	44,782
4	3.45	48,123	48,728	39,163	33,660	36,580	45,043
5	3.31	46,171	46,750	37,574	32,294	35,096	43,216
6	3.52	49,100	49,716	39,957	34,343	37,322	45,957
7	3.75	52,308	52,965	42,568	36,587	39,761	48,960
8	3.99	55,656	56,355	45,293	38,929	42,306	52,094
9	4.15	57,888	58,614	47,109	40,490	44,002	54,183
10	4.25	59,282	60,027	48,244	41,465	45,062	55,488
11	4.31	60,119	60,874	48,925	42,051	45,699	56,272
12	4.29	59,840	60,592	48,698	41,855	45,487	56,010
13	4.38	61,096	61,863	49,720	42,734	46,441	57,186
14	4.35	60,677	61,439	49,379	42,441	46,123	56,794
15	4.28	59,701	60,451	48,585	41,758	45,381	55,880
16	4.24	59,143	59,886	48,131	41,368	44,956	55,358
17	4.42	61,654	62,428	50,174	43,124	46,865	57,708
18	4.48	62,491	63,275	50,855	43,709	47,501	58,491
19	4.6	64,164	64,970	52,217	44,880	48,773	60,058
20	4.81	67,094	67,936	54,601	46,929	51,000	62,800
21	4.89	68,210	69,066	55,509	47,709	51,848	63,844
22	4.8	66,954	67,795	54,487	46,831	50,894	62,669
23	4.47	62,351	63,134	50,741	43,612	47,395	58,361
24	4.24	59,143	59,886	48,131	41,368	44,956	55,358
Average hourly load		**58,120**	**58,850**	**47,298**	**40,652**	**44,179**	**54,400**

Hour	Daily/ hourly distribution load %	Hourly load in each month (kW)					
		Jul	Aug	Sep	Oct	Nov	Dec
1	3.92	59,830	61,088	56,316	54,021	41,402	52,104
2	3.67	56,014	57,192	52,725	50,575	38,761	48,781
3	3.43	52,351	53,452	49,277	47,268	36,227	45,591
4	3.45	52,656	53,763	49,564	47,544	36,438	45,857
5	3.31	50,520	51,582	47,553	45,614	34,959	43,996
6	3.52	53,725	54,854	50,570	48,508	37,177	46,787
7	3.75	57,235	58,438	53,874	51,678	39,606	49,844
8	3.99	60,898	62,178	57,322	54,985	42,141	53,034
9	4.15	63,340	64,672	59,621	57,190	43,831	55,161
10	4.25	64,867	66,230	61,057	58,568	44,887	56,490
11	4.31	65,782	67,165	61,919	59,395	45,521	57,288
12	4.29	65,477	66,853	61,632	59,119	45,310	57,022
13	4.38	66,851	68,256	62,925	60,360	46,260	58,218
14	4.35	66,393	67,788	62,494	59,946	45,943	57,820
15	4.28	65,324	66,698	61,488	58,982	45,204	56,889
16	4.24	64,714	66,074	60,914	58,430	44,781	56,357
17	4.42	67,461	68,879	63,499	60,911	46,683	58,750
18	4.48	68,377	69,814	64,361	61,738	47,316	59,547
19	4.6	70,208	71,684	66,085	63,391	48,584	61,143
20	4.81	73,414	74,957	69,102	66,285	50,802	63,934
21	4.89	74,635	76,204	70,252	67,388	51,647	64,997
22	4.8	73,261	74,801	68,959	66,148	50,696	63,801
23	4.47	68,224	69,658	64,218	61,600	47,211	59,415
24	4.24	64,714	66,074	60,914	58,430	44,781	56,357
Average hourly load		**63,595**	**64,931**	**59,860**	**57,420**	**44,007**	**55,383**

Appendix 3: Project Locations Characteristics and Data

- **Selected Location**

Number	Location name	Location coordinates	
		Latitude	Longitude
1	Ashkida	27.567	14.498
2	Brak	27.682	14.264
3	Tamazawa	27.631	14.087
4	Getta	27.496	14.123
5	Bergin	27.633	13.630
6	Adri	27.545	13.456
7	Wenzreek	27.478	13.170

Location 1: Ashkida

Item	Unit	Climate data location
Latitude	°N	27.567
Longitude	°E	14.264
Elevation	m	491
Heating design temperature	°C	4.52
Cooling design temperature	°C	37.83
Earth temperature amplitude	°C	25.35
Frost days at site	day	0

Month	**Air temperature** °C	**Relative humidity** %	**Daily solar radiation - horizontal** $kWh/m^2/d$	**Atmospheric pressure** kPa	**Wind speed** m/s	**Earth temperature** °C	**Heating degree-days** °C-d	**Cooling degree-days** °C-d
Jan	10.8	44.8%	3.56	96.4	4.0	12.1	216	49
Feb	12.8	36.8%	4.68	96.3	4.2	14.7	146	89
Mar	17.5	29.3%	5.86	96.0	4.5	20.2	47	246
Apr	23.0	22.8%	6.66	95.6	4.8	26.2	5	401
May	27.7	21.4%	6.79	95.6	4.9	31.2	0	552
Jun	31.0	20.0%	7.62	95.7	4.6	35.0	0	628
Jul	31.1	20.9%	7.78	95.7	4.5	35.7	0	648
Aug	31.0	22.5%	7.12	95.7	4.2	35.4	0	648
Sep	29.4	24.7%	6.12	95.8	4.1	32.8	0	588
Oct	23.9	30.3%	5.20	96.0	4.0	26.5	1	442
Nov	17.6	35.4%	3.81	96.2	3.9	19.3	38	237
Dec	12.3	42.5%	3.17	96.4	3.9	13.4	171	87
Annual	22.3	29.3%	5.70	96.0	4.3	25.2	624	4615
Measured at (m)					10.0	0.0		

Location 2: Brak

Item	Unit	Climate data location
Latitude	°N	27.682

Longitude	°E	14.264
Elevation	m	491
Heating design temperature	°C	4.52
Cooling design temperature	°C	37.83
Earth temperature amplitude	°C	25.35
Frost days at site	day	0

Month	**Air temperature** °C	**Relative humidity** %	**Daily solar radiation - horizontal** kWh/m²/d	**Atmospheric pressure** kPa	**Wind speed** m/s	**Earth temperature** °C	**Heating degree-days** °C-d	**Cooling degree-days** °C-d
Jan	10.8	44.8%	3.56	96.4	4.0	12.1	216	49
Feb	12.8	36.8%	4.68	96.3	4.2	14.7	146	89
Mar	17.5	29.3%	5.86	96.0	4.5	20.2	47	246
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May	27.7	21.4%	6.79	95.6	4.9	31.2	0	552
Jun	31.0	20.0%	7.62	95.7	4.6	35.0	0	628
Jul	31.1	20.9%	7.78	95.7	4.5	35.7	0	648
Aug	31.0	22.5%	7.12	95.7	4.2	35.4	0	648
Sep	29.4	24.7%	6.12	95.8	4.1	32.8	0	588
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Nov	17.6	35.4%	3.81	96.2	3.9	19.3	38	237
Dec	12.3	42.5%	3.17	96.4	3.9	13.4	171	87
Annual	22.3	29.3%	5.70	96.0	4.3	25.2	624	4615
Measured at (m)					10.0	0.0		

Location 3: Tamazawa

Item	Unit	Climate data location
Latitude	°N	27.631
Longitude	°E	14.087
Elevation	m	491
Heating design temperature	°C	4.52
Cooling design temperature	°C	37.83
Earth temperature amplitude	°C	25.35
Frost days at site	day	0

Month	**Air temperature** °C	**Relative humidity** %	**Daily solar radiation - horizontal** kWh/m²/d	**Atmospheric pressure** kPa	**Wind speed** m/s	**Earth temperature** °C	**Heating degree-days** °C-d	**Cooling degree-days** °C-d
Jan	10.8	44.8%	3.56	96.4	4.0	12.1	216	49
Feb	12.8	36.8%	4.68	96.3	4.2	14.7	146	89
Mar	17.5	29.3%	5.86	96.0	4.5	20.2	47	246
Apr	23.0	22.8%	6.66	95.6	4.8	26.2	5	401
May	27.7	21.4%	6.79	95.6	4.9	31.2	0	552

Jun	31.0	20.0%	7.62	95.7	4.6	35.0	0	628
Jul	31.1	20.9%	7.78	95.7	4.5	35.7	0	648
Aug	31.0	22.5%	7.12	95.7	4.2	35.4	0	648
Sep	29.4	24.7%	6.12	95.8	4.1	32.8	0	588
Oct	23.9	30.3%	5.20	96.0	4.0	26.5	1	442
Nov	17.6	35.4%	3.81	96.2	3.9	19.3	38	237
Dec	12.3	42.5%	3.17	96.4	3.9	13.4	171	87
Annual	22.3	29.3%	5.70	96.0	4.3	25.2	624	4615
Measured at (m)					10.0	0.0		

Location 4: Getta

Item	Unit	Climate data location
Latitude	°N	27.496
Longitude	°E	14.123
Elevation	m	491
Heating design temperature	°C	4.52
Cooling design temperature	°C	37.83
Earth temperature amplitude	°C	25.35
Frost days at site	day	0

Month	**Air temperature** °C	**Relative humidity** %	**Daily solar radiation - horizontal** kWh/m²/d	**Atmospheric pressure** kPa	**Wind speed** m/s	**Earth temperature** °C	**Heating degree-days** °C-d	**Cooling degree-days** °C-d
Jan	10.8	44.8%	3.56	96.4	4.0	12.1	216	49
Feb	12.8	36.8%	4.68	96.3	4.2	14.7	146	89
Mar	17.5	29.3%	5.86	96.0	4.5	20.2	47	246
Apr	23.0	22.8%	6.66	95.6	4.8	26.2	5	401
May	27.7	21.4%	6.79	95.6	4.9	31.2	0	552
Jun	31.0	20.0%	7.62	95.7	4.6	35.0	0	628
Jul	31.1	20.9%	7.78	95.7	4.5	35.7	0	648
Aug	31.0	22.5%	7.12	95.7	4.2	35.4	0	648
Sep	29.4	24.7%	6.12	95.8	4.1	32.8	0	588
Oct	23.9	30.3%	5.20	96.0	4.0	26.5	1	442
Nov	17.6	35.4%	3.81	96.2	3.9	19.3	38	237
Dec	12.3	42.5%	3.17	96.4	3.9	13.4	171	87
Annual	22.3	29.3%	5.70	96.0	4.3	25.2	624	4615
Measured at (m)					10.0	0.0		

Location 5: Bergin

Item	Unit	Climate data location
Latitude	°N	27.633
Longitude	°E	13.63
Elevation	m	503
Heating design temperature	°C	4.13
Cooling design temperature	°C	38.22
Earth temperature amplitude	°C	25.84

Frost days at site	day	1

Month	Air temperature °C	Relative humidity %	Daily solar radiation - horizontal kWh/m²/d	Atmospheric pressure kPa	Wind speed m/s	Earth temperature °C	Heating degree-days °C-d	Cooling degree-days °C-d
Jan	10.3	45.1%	3.64	96.3	4.0	11.7	227	43
Feb	12.5	36.2%	4.83	96.1	4.2	14.5	152	84
Mar	17.4	28.5%	6.03	95.8	4.5	20.0	50	242
Apr	22.9	22.1%	6.81	95.5	4.8	26.1	6	398
May	27.7	21.1%	7.08	95.5	5.0	31.1	0	553
Jun	31.2	19.4%	7.85	95.5	4.6	35.0	0	633
Jul	31.3	19.4%	8.04	95.5	4.5	35.8	0	655
Aug	31.1	21.1%	7.30	95.6	4.2	35.4	0	653
Sep	29.4	23.7%	6.20	95.7	4.1	32.7	0	590
Oct	23.9	29.5%	5.30	95.9	4.1	26.3	1	438
Nov	17.4	35.0%	3.96	96.0	4.0	19.1	42	231
Dec	11.8	42.6%	3.23	96.2	3.9	13.1	182	79
Annual	22.2	28.6%	5.86	95.8	4.3	25.1	660	4599
Measured at (m)					10.0	0.0		

Location 6: Adri

Item	Unit	Climate data location
Latitude	°N	27.545
Longitude	°E	13.456
Elevation	m	503
Heating design temperature	°C	4.13
Cooling design temperature	°C	38.22
Earth temperature amplitude	°C	25.84
Frost days at site	day	1

Month	Air temperature °C	Relative humidity %	Daily solar radiation - horizontal kWh/m²/d	Atmospheric pressure kPa	Wind speed m/s	Earth temperature °C	Heating degree-days °C-d	Cooling degree-days °C-d
Jan	10.3	45.1%	3.64	96.3	4.0	11.7	227	43
Feb	12.5	36.2%	4.83	96.1	4.2	14.5	152	84
Mar	17.4	28.5%	6.03	95.8	4.5	20.0	50	242
Apr	22.9	22.1%	6.81	95.5	4.8	26.1	6	398
May	27.7	21.1%	7.08	95.5	5.0	31.1	0	553
Jun	31.2	19.4%	7.85	95.5	4.6	35.0	0	633
Jul	31.3	19.4%	8.04	95.5	4.5	35.8	0	655
Aug	31.1	21.1%	7.30	95.6	4.2	35.4	0	653
Sep	29.4	23.7%	6.20	95.7	4.1	32.7	0	590
Oct	23.9	29.5%	5.30	95.9	4.1	26.3	1	438
Nov	17.4	35.0%	3.96	96.0	4.0	19.1	42	231
Dec	11.8	42.6%	3.23	96.2	3.9	13.1	182	79

Annual	22.2	28.6%	5.86	95.8	4.3	25.1	660	4599
Measured at (m)					10.0	0.0		

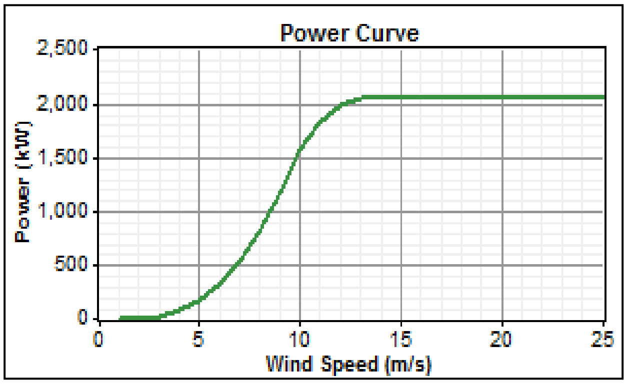
Location 7: Wenzreek

Item	Unit	Climate data location
Latitude	°N	27.478
Longitude	°E	13.17
Elevation	m	503
Heating design temperature	°C	4.13
Cooling design temperature	°C	38.22
Earth temperature amplitude	°C	25.84
Frost days at site	day	1

Month	**Air temperature** °C	**Relative humidity** %	**Daily solar radiation - horizontal** kWh/m²/d	**Atmospheric pressure** kPa	**Wind speed** m/s	**Earth temperature** °C	**Heating degree-days** °C-d	**Cooling degree-days** °C-d
Jan	10.3	45.1%	3.64	96.3	4.0	11.7	227	43
Feb	12.5	36.2%	4.83	96.1	4.2	14.5	152	84
Mar	17.4	28.5%	6.03	95.8	4.5	20.0	50	242
Apr	22.9	22.1%	6.81	95.5	4.8	26.1	6	398
May	27.7	21.1%	7.08	95.5	5.0	31.1	0	553
Jun	31.2	19.4%	7.85	95.5	4.6	35.0	0	633
Jul	31.3	19.4%	8.04	95.5	4.5	35.8	0	655
Aug	31.1	21.1%	7.30	95.6	4.2	35.4	0	653
Sep	29.4	23.7%	6.20	95.7	4.1	32.7	0	590
Oct	23.9	29.5%	5.30	95.9	4.1	26.3	1	438
Nov	17.4	35.0%	3.96	96.0	4.0	19.1	42	231
Dec	11.8	42.6%	3.23	96.2	3.9	13.1	182	79
Annual	22.2	28.6%	5.86	95.8	4.3	25.1	660	4599
Measured at (m)					10.0	0.0		

Appendix 4: Wind Turbines Technical Specifications

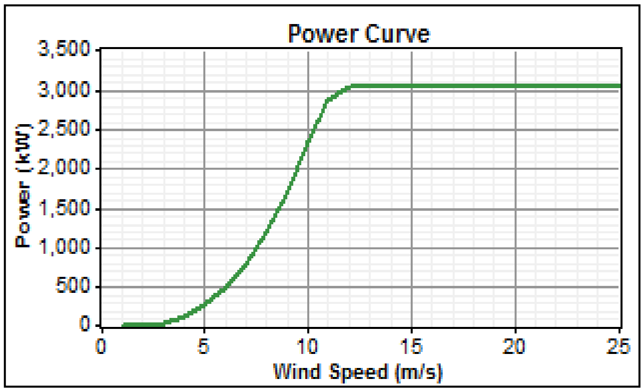
1- Wind Turbine E-82 E2



Wind (m/s)	Power (kW)	Power-coefficient Cp(-)
1	0	0
2	3	0.12
3	25	0.29
4	82	0.40
5	174	0.43
6	321	0.46
7	532	0.48
8	815	0.49
9	1180	0.50
10	1580	0.49
11	1810	042
12	1980	0.35
13	2050	0.29
14	2050	0.23
15	2050	0.19
16	2050	0.15
17	2050	0.13
18	2050	0.11
19	2050	0.09
20	2050	0.08
21	2050	0.07
22	2050	0.06
23	2050	0.05
24	2050	0.05
25	2050	0.04

Technical specification E-82 E2	
Rated power	2,000 KW
Rotor dimension	82 m
Hub height in meter	78/85/98/108/138
Wind zone (DIBt)	WZ III
Wind class (IED)	IEC/EN IIA
WEC concept	Gearless, variable speed Single blade adjustment
Rotor	
Type	Upwind rotor with active pitch control
Rotational direction	Clockwise
No. of blades	3
Swept area	5,281 m^2
Blade material	GRP (epoxy resin); Built-in lightning protection
Rotational speed	Variable, 6 - 18 rpm
Pitch control	ENERCON single blade pitch system per rotor blade with allocated emergency supply
Drive train with generator	
Hub	Rigid
Main bearing	Double row tapered/cylindrical roller bearings
Generator	ENERCON direct-drive annular generator
Grid feed	ENERCON inverter
Brake systems	– 3 independent pitch control systems with emergency power supply – Rotor brake – Rotor lock
Yaw system	Active via yaw gear, load-dependent damping
Cut-out wind speed	28 - 34 m/s (with ENERCON storm control)
Remote monitoring	ENERCON SCADA

2- Wind Turbine E-101



Wind (m/s)	Power (KW)	Power-coefficient Cp(-)
1	0	0
2	3	0.07
3	37	0.279
4	118	0.376
5	258	0.421
6	479	0.452
7	790	0.469
8	1200	0.478
9	1710	0.478
10	2340	0.477
11	2867	0.439
12	3034	0.358
13	3050	0.283
14	3050	0.227
15	3050	0.184
16	3050	0.152
17	3050	0.127
18	3050	0.107
19	3050	0.091
20	3050	0.078
21	3050	0.067
22	3050	0.058
23	3050	0.051
24	3050	0.045
25	3050	0.040

Technical specification E-101	
Rated power	3,050 KW
Rotor dimension	101 m
Hub height in meter	99/135/149
Wind zone (DIBt)	WZ III
Wind class (IED)	IEC/EN IIA
WEC concept	Gearless, variable speed Single blade adjustment
Rotor	
Type	Upwind rotor with active pitch control
Rotational direction	Clockwise
No. of blades	3
Swept area	8012 m^2
Blade material	GRP (epoxy resin); Built-in lightning protection
Rotational speed	Variable, 4 - 14.5 rpm
Pitch control	ENERCON single blade pitch system per rotor blade with allocated emergency supply
Drive train with generator	
Hub	Rigid
Main bearing	Double row tapered/cylindrical roller bearings
Generator	ENERCON direct-drive annular generator
Grid feed	ENERCON inverter
Brake systems	– 3 independent pitch control systems with emergency power supply – Rotor brake – Rotor lock, latching (10°)
Yaw system	Active via yaw gear, load-dependent damping
Cut-out wind speed	28 - 34 m/s (with ENERCON storm control)
Remote monitoring	ENERCON SCADA

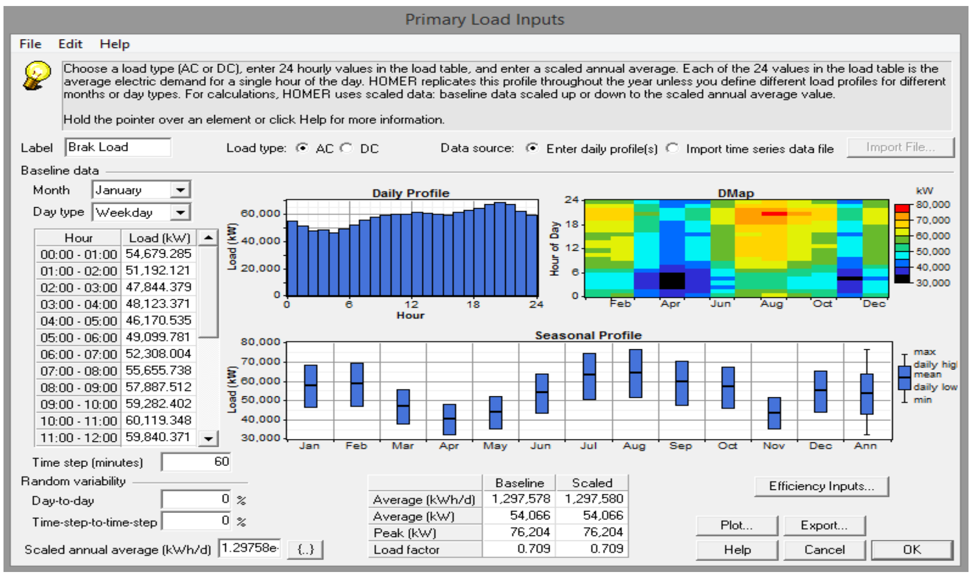
Appendix 5: HOMER Input Summary

- **HOMER 2 Licenses**

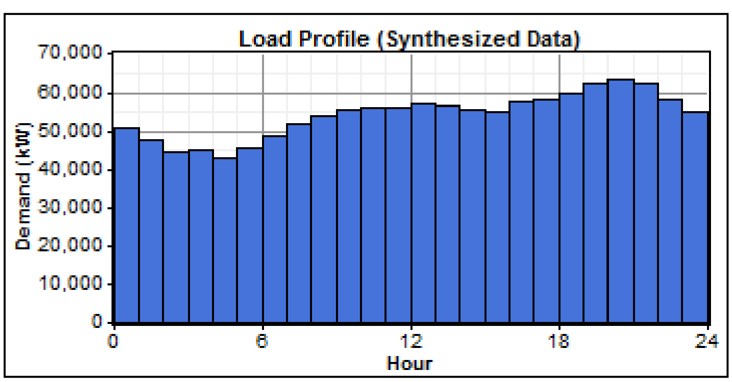
Activated

Order	License id	Serial Numbers	Renewal Code	Renewal Date	Expiration Date
7172	8846	273801h2	6f060q	2015-03-26	2015-09-22
9145	26261	20f80176	am04as	2015-11-26	2016-05-24
9145	26262	295801s9	7w02wx	2016-09-08	2017-03-07

1- Load: Brak Load (AC Load)



Data source:	Synthetic
Daily noise:	0%
Hourly noise:	0%
Scaled annual average:	1,297,578 kWh/d
Scaled peak load:	76,204 kW
Load factor:	0.709



2- PV

- Costs

Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
1.000	3,000	2,100	60

- Inputs

Sizes to consider:	0, 60,000, 80,000, 100,000, 120,000, 140,000, 180,000, 220,000, 260,000 kW
Lifetime:	20 yr
Derating factor:	90%
Tracking system:	Horizontal Axis, daily adjustment
Ground reflectance:	40%

3- Solar Resource

- Location Coordinates

Latitude:	27 degrees 40 minutes North
Longitude:	14 degrees 15 minutes East
Time zone:	GMT +2:00

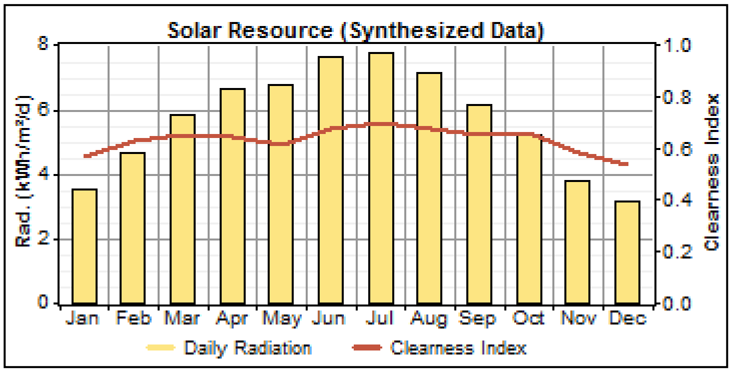
- Date Source: Average Daily Radiation

Month	Clearness Index	Average Radiation (kWh/m^2/day)
Jan	0.565	3.560
Feb	0.626	4.680
Mar	0.652	5.860
Apr	0.645	6.660
May	0.612	6.790
Jun	0.672	7.620
Jul	0.696	7.780
Aug	0.674	7.120
Sep	0.650	6.120
Oct	0.658	5.200
Nov	0.582	3.810
Dec	0.536	3.170

- Variable: Solar Date Scaled Average

Scaled annual average	4.92, 5.7 & 6.37 (kWh/m^2/d)

- Solar Resource Profeile



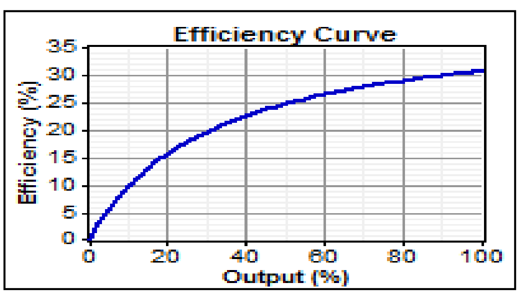
4- AC Generator: Diesel Generator

- Costs

Size (kW)	Capital ($)	Replacement ($)	O&M ($/hr)
1.000	800	600	0.030

- Inputs

Sizes to consider:	0, 20,000, 40,000, 60,000, 80,000, 100,000 kW
Lifetime:	180,000 hrs
Min. load ratio:	30%
Heat recovery ratio:	0%
Fuel used:	Diesel
Fuel curve intercept:	0.08 L/hr/kW
Fuel curve slope:	0.25 L/hr/kW



5- Fuel: Diesel

Price:	0.2, 0.4, 0.6, 0.8 $/L
Lower heating value:	43.2 MJ/kg
Density:	820 kg/m^3
Carbon content:	88.0%
Sulfur content:	0.330%

6- Battery: Surrette 6CS25P

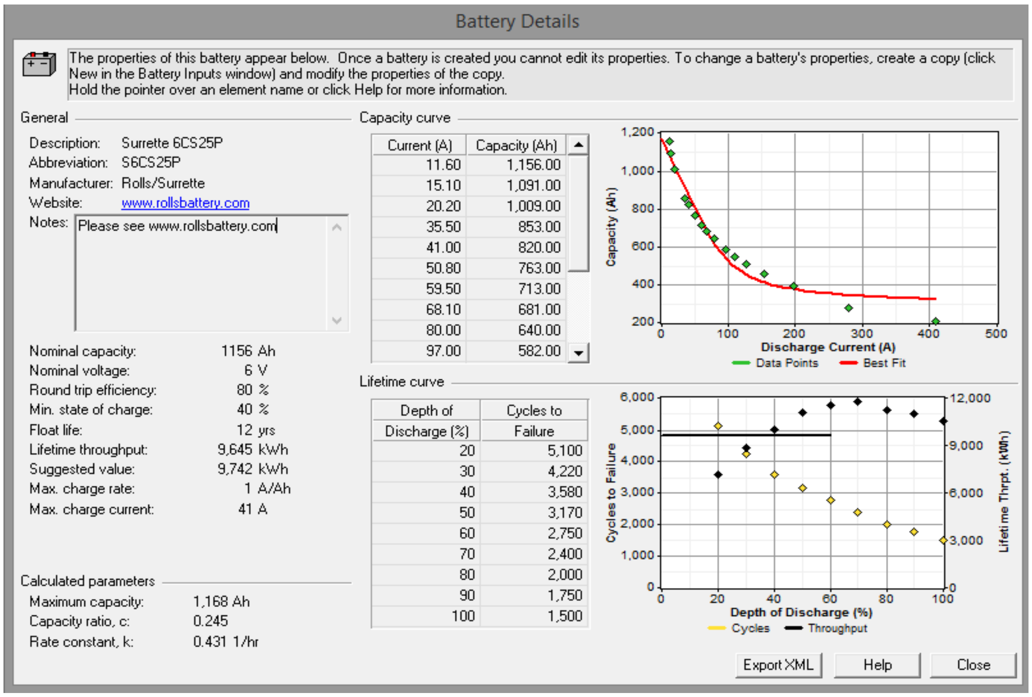
- Costs

Quantity	Capital ($)	Replacement ($)	O&M ($/yr)
1	1,200	1,000	5.00

- Inputs

Quantities to consider:	0, 10,000, 20,000, 30,000
Voltage:	6 V
Nominal capacity:	1,156 Ah
Lifetime throughput:	9,645 kWh

- **Details Profile**



7- Converter

- Costs

Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
1.000	700	550	3

- Inputs

Sizes to consider:	0, 60,000, 80,000, 100,000 kW
Lifetime:	15 yr
Inverter efficiency:	90%
Inverter can parallel with AC generator:	Yes
Rectifier relative capacity:	100%
Rectifier efficiency:	85%

8- Economics

Annual real interest rate:	6%
Project lifetime:	25 yr
Capacity shortage penalty:	$ 0/kWh

System fixed capital cost:	$ 0
System fixed O&M cost:	$ 0/yr

9- System Control

- Dispatch strategy

Check load following:	Yes
Check cycle charging:	Yes
Setpoint state of charge:	80%

- Generator Control

Allow systems with multiple generators:	Yes
Allow multiple generators to operate simultaneously:	Yes
Allow systems with generator capacity less than peak load:	Yes

10- Emissions

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

11- Constraints

- Load Capacity Constrain

Maximum annual capacity shortage:	0%
Minimum renewable fraction:	20%

- Operating Reserve

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

12- Grid

- Grid Connected Costs

This Figure represents the sensitivity study conducted on electricity price from the grid versus COE, that presented in Figure 6.7 paragraph 6.1.3.3.

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)				DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200				80000			CC	$ 64,000,000	56,366,176	$ 784,548,928	0.130	0.00	174,467,488	8,760
0.400				80000			CC	$ 64,000,000	91,259,672	$ 1,230,604,928	0.203	0.00	174,467,488	8,760
0.600				80000			CC	$ 64,000,000	126,153,168	$ 1,676,660,992	0.277	0.00	174,467,488	8,760
0.800				80000			CC	$ 64,000,000	161,046,672	$ 2,122,717,056	0.351	0.00	174,467,488	8,760

- Inputs

CO2 emissions factor:	632 g/kWh
CO emissions factor:	0 g/kWh
UHC emissions factor:	0 g/kWh
PM emissions factor:	0 g/kWh
SO2 emissions factor:	2.74 g/kWh
NOx emissions factor:	1.34 g/kWh
Interconnection cost:	$ 0
Standby charge:	$ 2,000/yr
Purchase capacity:	80,000 kW
Sale capacity:	kW

- Grid Extension costs

Capital cost:	$ 15,000/km
O&M cost	$ 160/yr/km
Power price:	$ 0.130/kWh $ 0.203/kWh $ 0.227/kWh $ 0.351/kWh

13- AC Wind Turbine: E-101

- Costs

Quantity	Capital ($)	Replacement ($)	O&M ($/yr)
1	5,566,250	5,120,950	105,759

- Inputs

Quantities to consider:	0, 50, 75, 100, 125, 150, 175
Lifetime:	20 yr
Hub height:	99 m

14- AC Wind Turbine: E-82

- Costs

Quantity	Capital ($)	Replacement ($)	O&M ($/yr)
1	3,650,000	3,358,000	69,350

- Inputs

Quantities to consider:	0, 50, 75, 100, 125, 150, 175
Lifetime:	20 yr
Hub height:	138 m

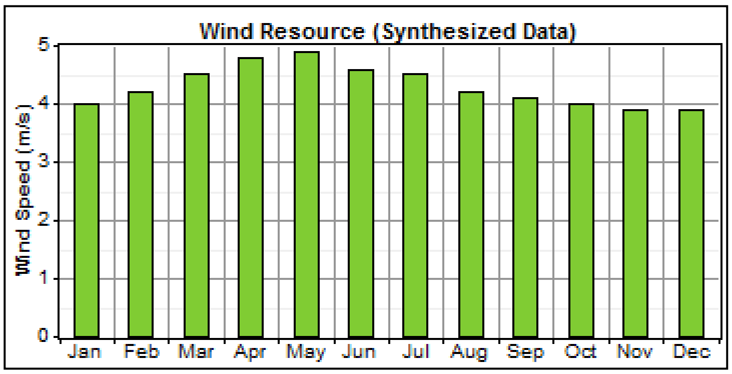
15- Wind Resource

- Data source: Average Wind Speed

Month	Wind Speed (m/s)
Jan	4.0

Feb	4.2
Mar	4.5
Apr	4.8
May	4.9
Jun	4.6
Jul	4.5
Aug	4.2
Sep	4.1
Oct	4.0
Nov	3.9
Dec	3.9

- Wind Resource Profeile

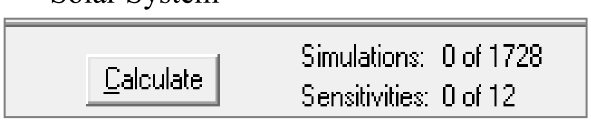


- Inputs

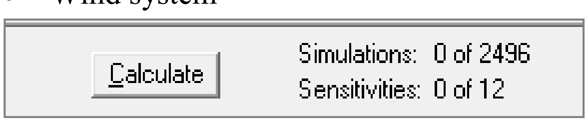
Weibull k:	2.5
Autocorrelation factor:	0.85
Diurnal pattern strength:	0.200
Hour of peak wind speed:	15
Scaled annual average:	3.9, 4.3, 5.2 m/s
Anemometer height:	10 m
Altitude:	491 m
Wind shear profile:	Logarithmic
Surface roughness length:	0.01 m

16- Simulation Systems

- Solar System



- Wind system



- Solar and wind system

Calculate   Simulations: 0 of 22464
Sensitivities: 0 of 36

17- Example of Electricity Losses of System

System Architecture: 120,000 kW PV; 80,000 kW Inverter; 60,000 kW Diesel Generat; 80,000 kW Rectifier; 30,000 Surrette 6CS25P; Cycle Charging

Total NPC: $ 1,900,302,592
Levelized COE: $ 0.314/kWh
Operating Cost: $ 109,541,072/yr

Cost Summary | Cash Flow | Electrical | PV | DG | Battery | Converter | Emissions | Time Series

Production	kWh/yr	%
PV array	267,365,936	47
Diesel Generator	305,479,136	53
Total	572,845,056	100

Consumption	kWh/yr	%
AC primary load	473,591,040	100
Total	473,591,040	100

Quantity	kWh/yr	%
Excess electricity	67,853,768	11.8
Unmet electric load	24,871	0.0
Capacity shortage	319,451	0.1

Quantity	Value
Renewable fraction	0.355
Max. renew. penetration	290 %

System Architecture: 120,000 kW PV; 80,000 kW Inverter; 60,000 kW Diesel Generat; 80,000 kW Rectifier; 30,000 Surrette 6CS25P; Cycle Charging

Total NPC: $ 1,606,742,784
Levelized COE: $ 0.265/kWh
Operating Cost: $ 86,576,848/yr

Cost Summary | Cash Flow | Electrical | PV | DG | Battery | Converter | Emissions | Time Series

Production	kWh/yr	%
PV array	267,365,936	47
Diesel Generator	301,399,904	53
Total	568,765,824	100

Consumption	kWh/yr	%
AC primary load	473,591,040	100
Total	473,591,040	100

Quantity	kWh/yr	%
Excess electricity	64,411,380	11.3
Unmet electric load	24,871	0.0
Capacity shortage	319,451	0.1

Quantity	Value
Renewable fraction	0.364
Max. renew. penetration	290 %

18- Solar and Wind System Results

A- Solar and Wind HES, COE

Minimum COE in stand-alone system

Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 6.37   Wind Speed (m/s) 5.2   Diesel Price ($/L) 0.2

Double click on a system below for simulation results.   Categorized

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	60000	30000	60000	CC	$ 308,500,000	33,483,050	$ 736,525,760	0.122	0.52	82,477,920	5,248
60000		50	60000	30000	60000	CC	$ 488,500,000	32,637,768	$ 905,720,256	0.150	0.63	63,406,552	4,200
		50	80000			CC	$ 246,500,000	52,243,184	$ 914,343,296	0.151	0.37	129,710,112	8,596
60000			60000	30000	80000	CC	$ 320,000,000	46,552,300	$ 915,094,656	0.151	0.24	126,297,136	7,486
60000			80000		60000	CC	$ 286,000,000	57,572,304	$ 1,021,967,296	0.169	0.20	150,460,304	8,760
60000		50	80000		60000	CC	$ 468,500,000	52,081,872	$ 1,134,281,088	0.187	0.47	111,366,728	7,665

Maximum COE in stand-alone system

Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 4.92 Wind Speed (m/s) 3.9 Diesel Price ($/L) 0.8

Double click on a system below for simulation results. Categorized

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		100	60000	30000	60000	CC	$ 491,000,000	98,540,904	$ 1,750,683,520	0.289	0.44	93,722,984	5,823
60000		75	60000	30000	60000	CC	$ 579,750,016	94,397,648	$ 1,786,468,736	0.295	0.50	85,932,480	5,587
140000			60000	30000	80000	CC	$ 560,000,000	114,666,544	$ 2,025,823,360	0.335	0.33	109,768,288	6,434
		50	80000			CC	$ 246,500,000	143,681,056	$ 2,083,226,112	0.344	0.24	146,219,424	8,747
60000		50	80000		60000	CC	$ 468,500,000	138,179,408	$ 2,234,896,640	0.369	0.34	132,545,992	8,534
80000			80000		60000	CC	$ 346,000,000	149,537,200	$ 2,257,587,456	0.373	0.20	150,521,696	8,756

Minimum COE in grid-connected system

Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 6.37 Wind Speed (m/s) 5.2

Double click on a system below for simulation results. Categorized Overall Expo

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	29,289,328	$ 588,915,968	0.097	0.52	58,601,484	4,690
		50				CC	80000	$ 182,500,000	34,762,128	$ 626,876,672	0.104	0.52		
		50	40000	10000	60000	LF	80000	$ 268,500,000	30,239,968	$ 655,068,288	0.108	0.53	58,592,108	4,689
		50		10000	60000	LF	80000	$ 236,500,000	35,705,784	$ 692,939,712	0.114	0.53		
60000			40000		60000	CC	80000	$ 254,000,000	43,630,776	$ 811,747,776	0.134	0.25	87,958,936	6,884
60000		50	20000		60000	CC	80000	$ 420,500,000	30,721,944	$ 813,229,568	0.134	0.64	28,739,664	4,433
60000		50	20000	10000	60000	LF	80000	$ 432,500,000	30,392,840	$ 821,022,528	0.136	0.65	28,702,036	4,425
60000			40000	10000	60000	LF	80000	$ 266,000,000	44,035,092	$ 828,916,288	0.137	0.25	87,958,936	6,884
60000		50			60000	CC	80000	$ 404,500,000	33,654,636	$ 834,719,232	0.138	0.64		
60000		50		10000	60000	LF	80000	$ 416,500,000	33,310,052	$ 842,314,304	0.139	0.65		
60000					60000	CC	80000	$ 222,000,000	52,081,044	$ 887,770,560	0.147	0.25		
60000				10000	60000	LF	80000	$ 234,000,000	52,485,364	$ 904,939,136	0.149	0.25		

Maximum COE in grid-connected system

Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 4.92 Wind Speed (m/s) 3.9

Double click on a system below for simulation results. Categorized Overall Export...

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		100	40000			CC	80000	$ 397,000,000	90,055,112	$ 1,548,206,592	0.256	0.46	65,067,264	5,156
		100	40000	10000	60000	LF	80000	$ 451,000,000	90,405,040	$ 1,606,679,808	0.265	0.47	64,277,324	5,092
60000		75	40000		60000	CC	80000	$ 527,750,016	85,499,960	$ 1,620,726,528	0.268	0.52	57,294,264	4,579
60000		75	40000	10000	60000	LF	80000	$ 539,750,016	84,662,664	$ 1,622,023,040	0.268	0.53	56,616,344	4,524
		100				CC	80000	$ 365,000,000	100,127,744	$ 1,644,968,704	0.272	0.46		
60000		75			60000	CC	80000	$ 495,750,016	94,197,632	$ 1,699,911,936	0.281	0.52		
60000		75		10000	60000	LF	80000	$ 507,750,016	93,267,312	$ 1,700,019,328	0.281	0.53		
		100		10000	60000	LF	80000	$ 419,000,000	100,368,800	$ 1,702,050,176	0.281	0.47		
100000			40000		60000	CC	80000	$ 374,000,000	112,307,144	$ 1,809,662,336	0.299	0.30	81,416,568	6,323
100000			40000	10000	60000	LF	80000	$ 386,000,000	112,123,000	$ 1,819,308,288	0.300	0.30	81,194,144	6,303
100000					60000	CC	80000	$ 342,000,000	125,540,352	$ 1,946,827,136	0.322	0.30		
100000				10000	60000	LF	80000	$ 354,000,000	125,336,928	$ 1,956,226,688	0.323	0.30		

B- At Average Renewable Resource at Site of Bark City HRES

These Figures represented values of solar and wind HES at average renewable sources and with different diesel price levels that presented in Table 6.1, paragraph 6.4.

Solar and Wind Stand-Alone Systems

Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 5.7 | Wind Speed (m/s) 4.3 | Diesel Price ($/L) 0.4

Double click on a system below for simulation results. (•) Categorized

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	60000	30000	60000	CC	$ 308,500,000	63,333,648	$ 1,118,116,608	0.185	0.35	108,773,728	6,748
60000		50	60000	30000	60000	LF	$ 488,500,000	56,376,776	$ 1,209,184,512	0.200	0.53	83,462,624	5,805
60000			60000	30000	80000	CC	$ 320,000,000	73,975,248	$ 1,265,651,968	0.209	0.21	130,510,272	7,696
		50	80000			CC	$ 246,500,000	82,936,976	$ 1,306,712,960	0.216	0.28	140,739,296	8,723
80000			80000		60000	CC	$ 346,000,000	88,447,024	$ 1,476,649,856	0.244	0.22	148,512,032	8,727
60000		50	80000		60000	CC	$ 468,500,000	81,777,968	$ 1,513,896,960	0.250	0.39	125,623,448	8,305

Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 5.7 | Wind Speed (m/s) 4.3 | Diesel Price ($/L) 0.6

Double click on a system below for simulation results. (•) Categorized

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		75	60000	30000	60000	CC	$ 399,750,016	76,135,232	$ 1,373,013,760	0.227	0.45	92,369,624	5,779
60000		50	60000	30000	60000	CC	$ 488,500,000	74,501,880	$ 1,440,884,096	0.238	0.50	85,930,528	5,597
80000			60000	30000	80000	CC	$ 380,000,000	94,418,872	$ 1,586,990,080	0.262	0.27	119,802,288	7,021
		50	80000			CC	$ 246,500,000	111,084,840	$ 1,666,537,216	0.275	0.28	140,739,296	8,723
60000		50	80000		60000	CC	$ 468,500,000	106,902,656	$ 1,835,074,816	0.303	0.39	125,623,448	8,305
80000			80000		60000	CC	$ 346,000,000	118,149,424	$ 1,856,346,240	0.307	0.22	148,512,032	8,727

Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 5.7 | Wind Speed (m/s) 4.3 | Diesel Price ($/L) 0.8

Double click on a system below for simulation results. (•) Categorized

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		100	60000	30000	60000	CC	$ 491,000,000	86,552,344	$ 1,597,429,504	0.264	0.53	80,547,640	5,085
60000		75	60000	30000	60000	CC	$ 579,750,016	82,083,360	$ 1,629,050,880	0.269	0.58	72,693,624	4,775
80000			60000	30000	80000	CC	$ 380,000,000	120,348,984	$ 1,918,464,000	0.317	0.26	121,432,688	7,163
		75	80000			CC	$ 337,750,016	131,478,240	$ 2,018,483,200	0.333	0.36	129,184,448	8,296
60000		75	80000		60000	CC	$ 559,750,016	124,370,544	$ 2,149,623,040	0.355	0.45	114,664,624	7,738
80000			80000		60000	CC	$ 346,000,000	147,851,824	$ 2,236,042,752	0.369	0.22	148,512,032	8,727

Solar and Wind Grid-Connected Systems

Sensitivity Results | Optimization Results

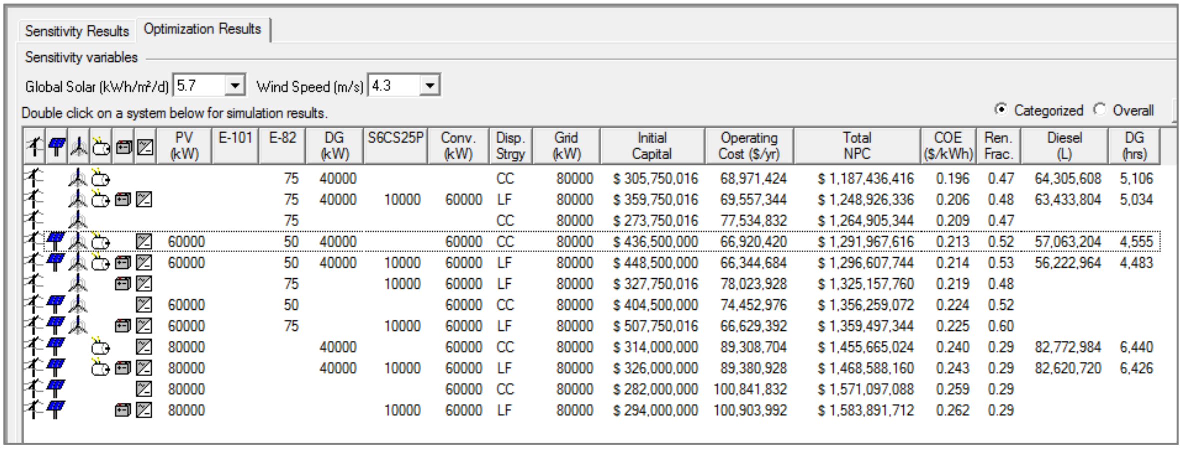
Sensitivity variables

Global Solar (kWh/m²/d) 5.7 | Wind Speed (m/s) 4.3

Double click on a system below for simulation results. (•) Categorized ( ) Overall

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	57,306,280	$ 947,066,624	0.156	0.37	77,027,720	6,087
		50	40000	10000	60000	LF	80000	$ 268,500,000	58,404,552	$ 1,015,106,176	0.168	0.37	76,661,440	6,051
		50				CC	80000	$ 182,500,000	65,988,432	$ 1,026,053,696	0.169	0.37		
		75		10000	60000	LF	80000	$ 327,750,016	59,697,856	$ 1,090,888,960	0.180	0.48		
60000		50	40000		60000	CC	80000	$ 436,500,000	51,205,100	$ 1,091,073,152	0.180	0.52	57,245,048	4,574
60000		50	40000	10000	60000	LF	80000	$ 448,500,000	50,873,092	$ 1,098,828,928	0.181	0.53	56,539,996	4,505
60000		50			60000	CC	80000	$ 404,500,000	57,575,692	$ 1,140,510,592	0.188	0.52		
60000			40000		60000	CC	80000	$ 254,000,000	69,817,792	$ 1,146,505,728	0.189	0.23	90,803,520	7,091
60000		50		10000	60000	LF	80000	$ 416,500,000	57,218,756	$ 1,147,947,776	0.190	0.53		
60000			40000	10000	60000	LF	80000	$ 266,000,000	70,240,992	$ 1,163,915,648	0.192	0.23	90,803,520	7,091
60000					60000	CC	80000	$ 222,000,000	80,301,024	$ 1,248,516,608	0.206	0.23		
60000				10000	60000	LF	80000	$ 234,000,000	80,724,208	$ 1,265,926,400	0.209	0.23		

At Diesel Price 0.40 $/L



Sensitivity Results | Optimization Results

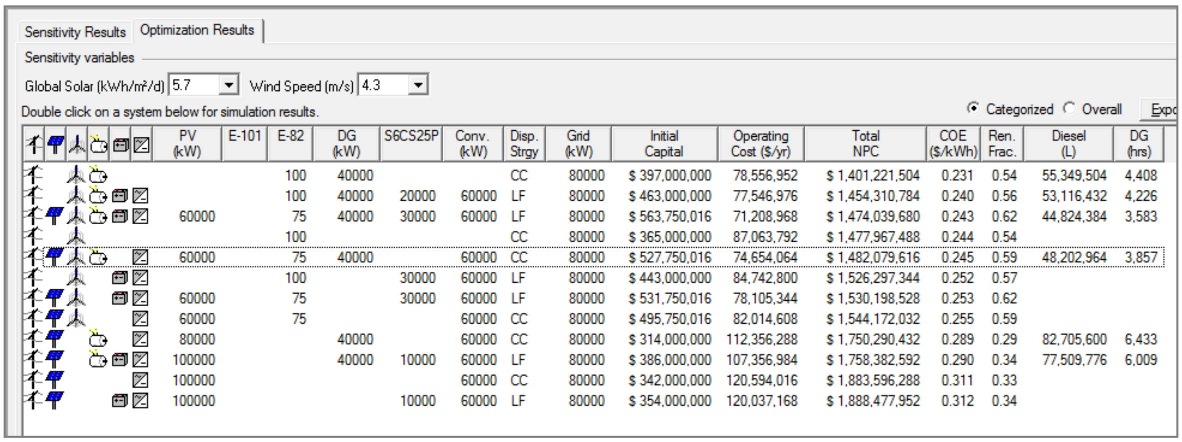
Sensitivity variables

Global Solar (kWh/m²/d) 5.7 Wind Speed (m/s) 4.3

Double click on a system below for simulation results. Categorized Overall

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		75	40000			CC	80000	$ 305,750,016	68,971,424	$ 1,187,436,416	0.196	0.47	64,305,608	5,106
		75	40000	10000	60000	LF	80000	$ 359,750,016	69,557,344	$ 1,248,926,336	0.206	0.48	63,433,804	5,034
		75				CC	80000	$ 273,750,016	77,534,832	$ 1,264,905,344	0.209	0.47		
60000		50	40000		60000	CC	80000	$ 436,500,000	66,920,420	$ 1,291,967,616	0.213	0.52	57,063,204	4,555
60000		50	40000	10000	60000	LF	80000	$ 448,500,000	66,344,684	$ 1,296,607,744	0.214	0.53	56,222,964	4,483
		75		10000	60000	LF	80000	$ 327,750,016	78,023,928	$ 1,325,157,760	0.219	0.48		
60000		50			60000	CC	80000	$ 404,500,000	74,452,976	$ 1,356,259,072	0.224	0.52		
60000		75		10000	60000	LF	80000	$ 507,750,016	66,629,392	$ 1,359,497,344	0.225	0.60		
80000			40000		60000	CC	80000	$ 314,000,000	89,308,704	$ 1,455,665,024	0.240	0.29	82,772,984	6,440
80000			40000	10000	60000	LF	80000	$ 326,000,000	89,380,928	$ 1,468,588,160	0.243	0.29	82,620,720	6,426
80000					60000	CC	80000	$ 282,000,000	100,841,832	$ 1,571,097,088	0.259	0.29		
80000				10000	60000	LF	80000	$ 294,000,000	100,903,992	$ 1,583,891,712	0.262	0.29		

At Diesel Price 0.60 $/L



Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 5.7 Wind Speed (m/s) 4.3

Double click on a system below for simulation results. Categorized Overall Expo

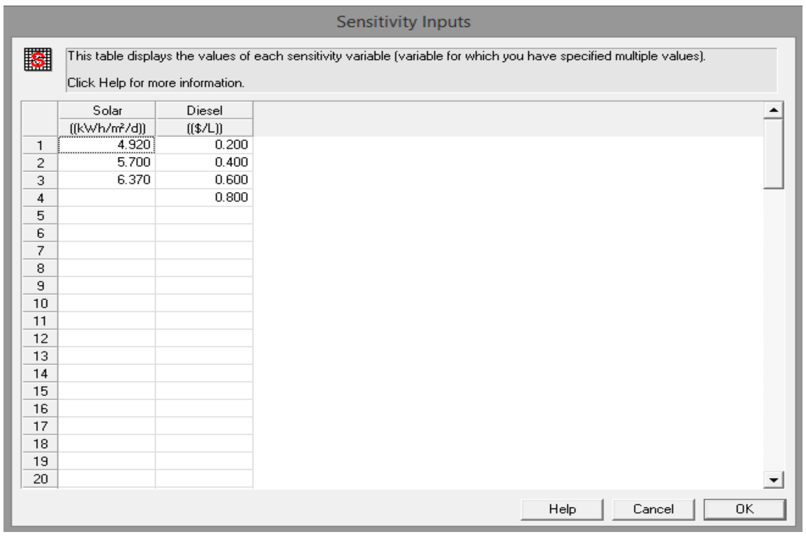
PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		100	40000			CC	80000	$ 397,000,000	78,556,952	$ 1,401,221,504	0.231	0.54	55,349,504	4,408
		100	40000	20000	60000	LF	80000	$ 463,000,000	77,546,976	$ 1,454,310,784	0.240	0.56	53,116,432	4,226
60000		75	40000	30000	60000	LF	80000	$ 563,750,016	71,208,968	$ 1,474,039,680	0.243	0.62	44,824,384	3,583
		100				CC	80000	$ 365,000,000	87,063,792	$ 1,477,967,488	0.244	0.54		
60000		75	40000		60000	CC	80000	$ 527,750,016	74,654,064	$ 1,482,079,616	0.245	0.59	48,202,964	3,857
		100		30000	60000	LF	80000	$ 443,000,000	84,742,800	$ 1,526,297,344	0.252	0.57		
60000		75		30000	60000	LF	80000	$ 531,750,016	78,105,344	$ 1,530,198,528	0.253	0.62		
60000		75			60000	CC	80000	$ 495,750,016	82,014,608	$ 1,544,172,032	0.255	0.59		
80000			40000		60000	CC	80000	$ 314,000,000	112,356,288	$ 1,750,290,432	0.289	0.29	82,705,600	6,433
100000			40000	10000	60000	LF	80000	$ 386,000,000	107,356,984	$ 1,758,382,592	0.290	0.34	77,509,776	6,009
100000					60000	CC	80000	$ 342,000,000	120,594,016	$ 1,883,596,288	0.311	0.33		
100000				10000	60000	LF	80000	$ 354,000,000	120,037,168	$ 1,888,477,952	0.312	0.34		

At Diesel Price 0.80 $/L

Appendix 6: Scenarios Component Sizes and Sensitivity Variables

1- Scenario 1: Solar Hybrid Renewable Energy System

- Sensitivity Inputs of Solar System



Sensitivity Inputs

This table displays the values of each sensitivity variable (variable for which you have specified multiple values).

Click Help for more information.

	Solar ((kWh/m²/d))	Diesel (($/L))
1	4.920	0.200
2	5.700	0.400
3	6.370	0.600
4		0.800
5		
6		
7		
8		
9		
10		
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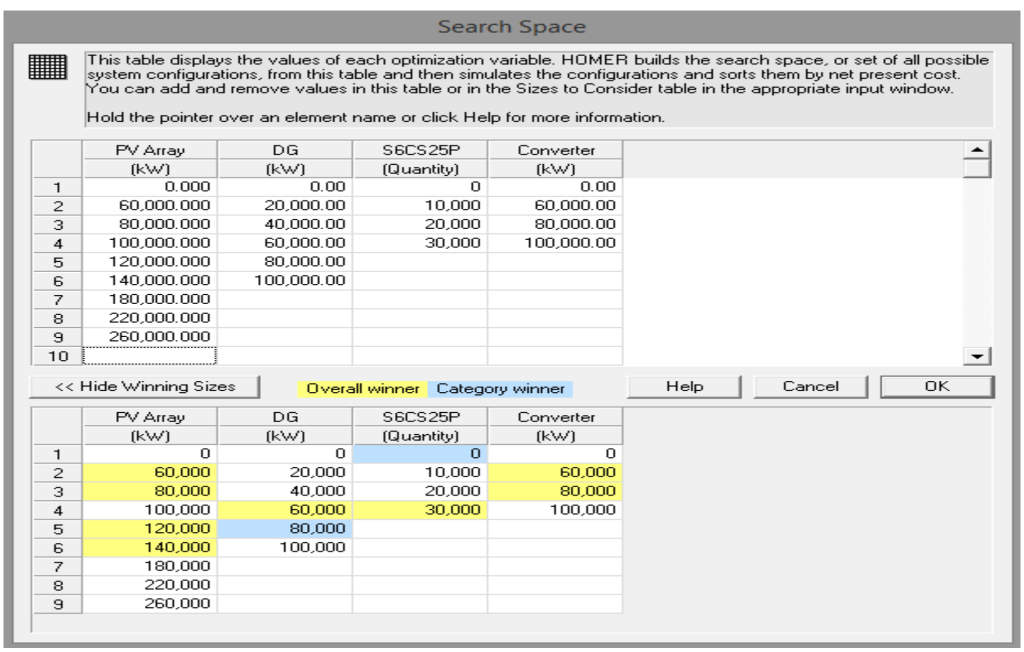
- Solar Stand-Alone System Search Space



Search Space

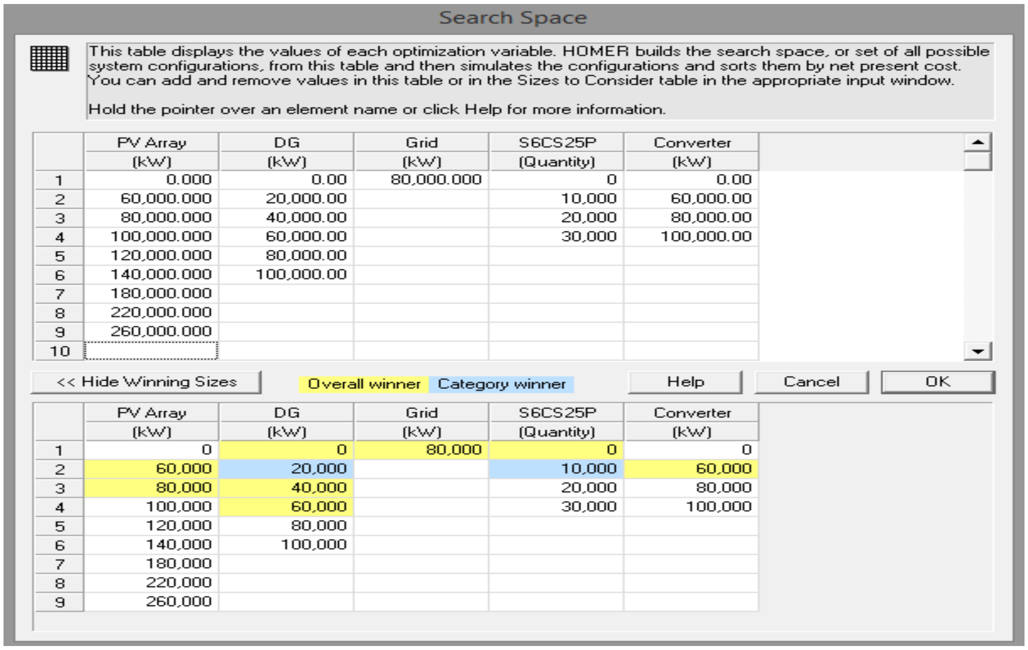
This table displays the values of each optimization variable. HOMER builds the search space, or set of all possible system configurations, from this table and then simulates the configurations and sorts them by net present cost. You can add and remove values in this table or in the Sizes to Consider table in the appropriate input window.

Hold the pointer over an element name or click Help for more information.

	PV Array (kW)	DG (kW)	S6CS25P (Quantity)	Converter (kW)
1	0.000	0.00	0	0.00
2	60,000.000	20,000.00	10,000	60,000.00
3	80,000.000	40,000.00	20,000	80,000.00
4	100,000.000	60,000.00	30,000	100,000.00
5	120,000.000	80,000.00		
6	140,000.000	100,000.00		
7	180,000.000			
8	220,000.000			
9	260,000.000			
10				

	PV Array (kW)	DG (kW)	S6CS25P (Quantity)	Converter (kW)
1	0	0	0	0
2	60,000	20,000	10,000	60,000
3	80,000	40,000	20,000	80,000
4	100,000	60,000	30,000	100,000
5	120,000	80,000		
6	140,000	100,000		
7	180,000			
8	220,000			
9	260,000			

- Solar Grid-Connected System Search Space



Search Space

This table displays the values of each optimization variable. HOMER builds the search space, or set of all possible system configurations, from this table and then simulates the configurations and sorts them by net present cost. You can add and remove values in this table or in the Sizes to Consider table in the appropriate input window.

Hold the pointer over an element name or click Help for more information.

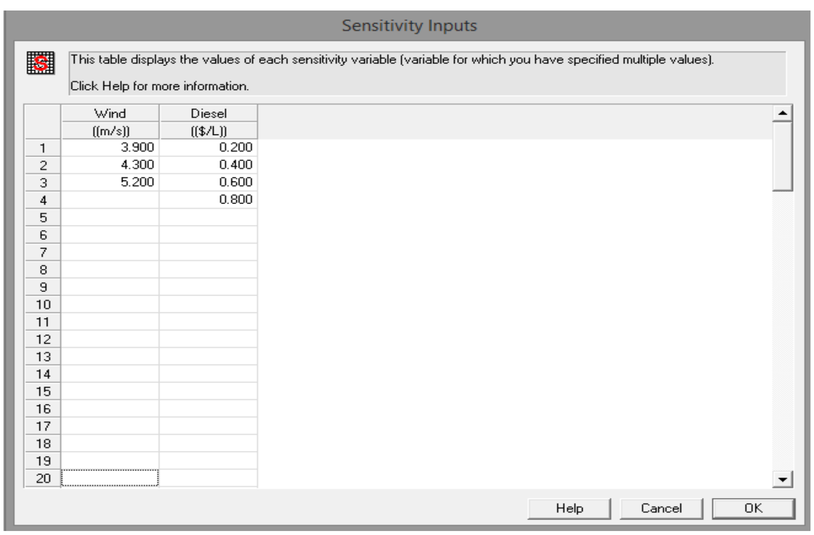
	PV Array (kW)	DG (kW)	Grid (kW)	S6CS25P (Quantity)	Converter (kW)
1	0.000	0.00	80,000.000	0	0.00
2	60,000.000	20,000.00		10,000	60,000.00
3	80,000.000	40,000.00		20,000	80,000.00
4	100,000.000	60,000.00		30,000	100,000.00
5	120,000.000	80,000.00			
6	140,000.000	100,000.00			
7	180,000.000				
8	220,000.000				
9	260,000.000				
10					

<< Hide Winning Sizes | Overall winner | Category winner | Help | Cancel | OK

	PV Array (kW)	DG (kW)	Grid (kW)	S6CS25P (Quantity)	Converter (kW)
1	0	0	80,000	0	0
2	60,000	20,000		10,000	60,000
3	80,000	40,000		20,000	80,000
4	100,000	60,000		30,000	100,000
5	120,000	80,000			
6	140,000	100,000			
7	180,000				
8	220,000				
9	260,000				

2- Scenario 2: Wind Hybrid Renewable Energy System

- Sensitivity Inputs of Wind System



Sensitivity Inputs

This table displays the values of each sensitivity variable (variable for which you have specified multiple values).

Click Help for more information.

	Wind ((m/s))	Diesel (($/L))
1	3.900	0.200
2	4.300	0.400
3	5.200	0.600
4		0.800
5		
6		
7		
8		
9		
10		
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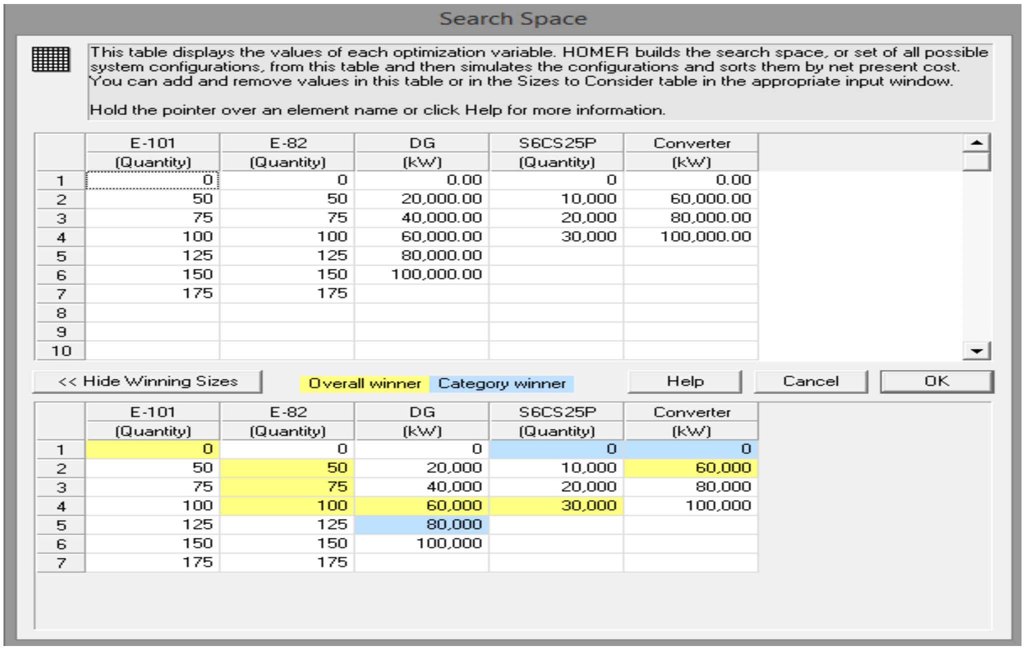
20		

Help | Cancel | OK

- Wind Stand-Alone System Search Space



Search Space

This table displays the values of each optimization variable. HOMER builds the search space, or set of all possible system configurations, from this table and then simulates the configurations and sorts them by net present cost. You can add and remove values in this table or in the Sizes to Consider table in the appropriate input window.

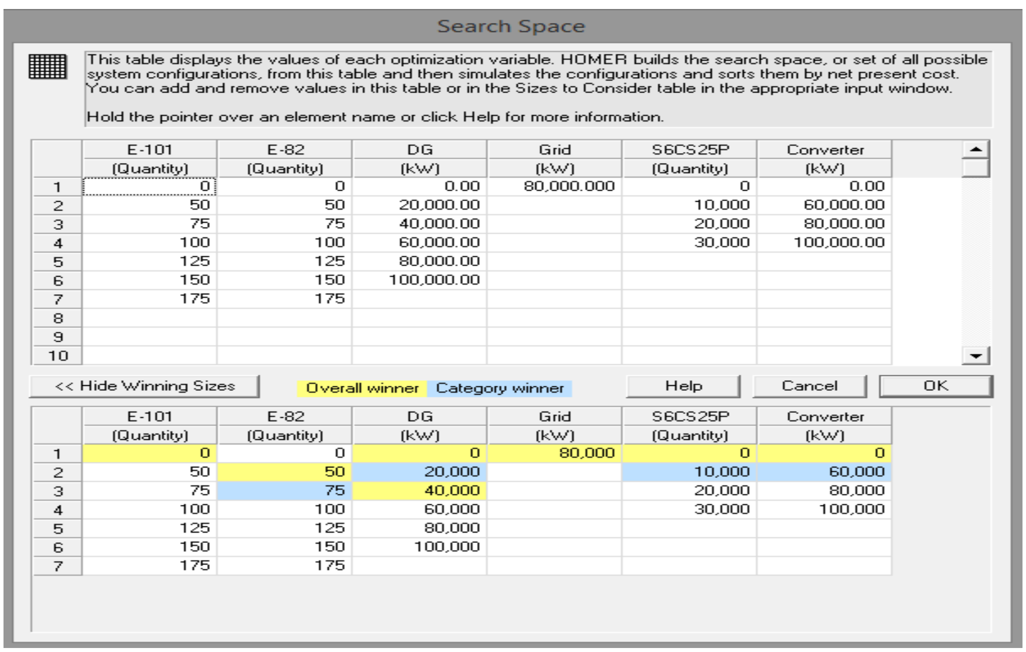
Hold the pointer over an element name or click Help for more information.

	E-101 (Quantity)	E-82 (Quantity)	DG (kW)	S6CS25P (Quantity)	Converter (kW)
1	0	0	0.00	0	0.00
2	50	50	20,000.00	10,000	60,000.00
3	75	75	40,000.00	20,000	80,000.00
4	100	100	60,000.00	30,000	100,000.00
5	125	125	80,000.00		
6	150	150	100,000.00		
7	175	175			
8					
9					
10					

<< Hide Winning Sizes   Overall winner   Category winner   Help   Cancel   OK

	E-101 (Quantity)	E-82 (Quantity)	DG (kW)	S6CS25P (Quantity)	Converter (kW)
1	0	0	0	0	0
2	50	50	20,000	10,000	60,000
3	75	75	40,000	20,000	80,000
4	100	100	60,000	30,000	100,000
5	125	125	80,000		
6	150	150	100,000		
7	175	175			

- Wind Grid-Connected System Search Space



Search Space

This table displays the values of each optimization variable. HOMER builds the search space, or set of all possible system configurations, from this table and then simulates the configurations and sorts them by net present cost. You can add and remove values in this table or in the Sizes to Consider table in the appropriate input window.

Hold the pointer over an element name or click Help for more information.

	E-101 (Quantity)	E-82 (Quantity)	DG (kW)	Grid (kW)	S6CS25P (Quantity)	Converter (kW)
1	0	0	0.00	80,000.000	0	0.00
2	50	50	20,000.00		10,000	60,000.00
3	75	75	40,000.00		20,000	80,000.00
4	100	100	60,000.00		30,000	100,000.00
5	125	125	80,000.00			
6	150	150	100,000.00			
7	175	175				
8						
9						
10						

<< Hide Winning Sizes   Overall winner   Category winner   Help   Cancel   OK

	E-101 (Quantity)	E-82 (Quantity)	DG (kW)	Grid (kW)	S6CS25P (Quantity)	Converter (kW)
1	0	0	0	80,000	0	0
2	50	50	20,000		10,000	60,000
3	75	75	40,000		20,000	80,000
4	100	100	60,000		30,000	100,000
5	125	125	80,000			
6	150	150	100,000			
7	175	175				

3- Scenario 3: Solar and Wind Hybrid Renewable Energy System

- Sensitivity Inputs of Solar and Wind System

Sensitivity Inputs

This table displays the values of each sensitivity variable (variable for which you have specified multiple values).

Click Help for more information.

	Solar ((kWh/m²/d))	Wind ((m/s))	Diesel (($/L))
1	4.920	3.900	0.200
2	5.700	4.300	0.400
3	6.370	5.200	0.600
4			0.800
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			

Help Cancel OK

- Solar and Wind Stand-Alone System Search Space

Search Space

This table displays the values of each optimization variable. HOMER builds the search space, or set of all possible system configurations, from this table and then simulates the configurations and sorts them by net present cost. You can add and remove values in this table or in the Sizes to Consider table in the appropriate input window.

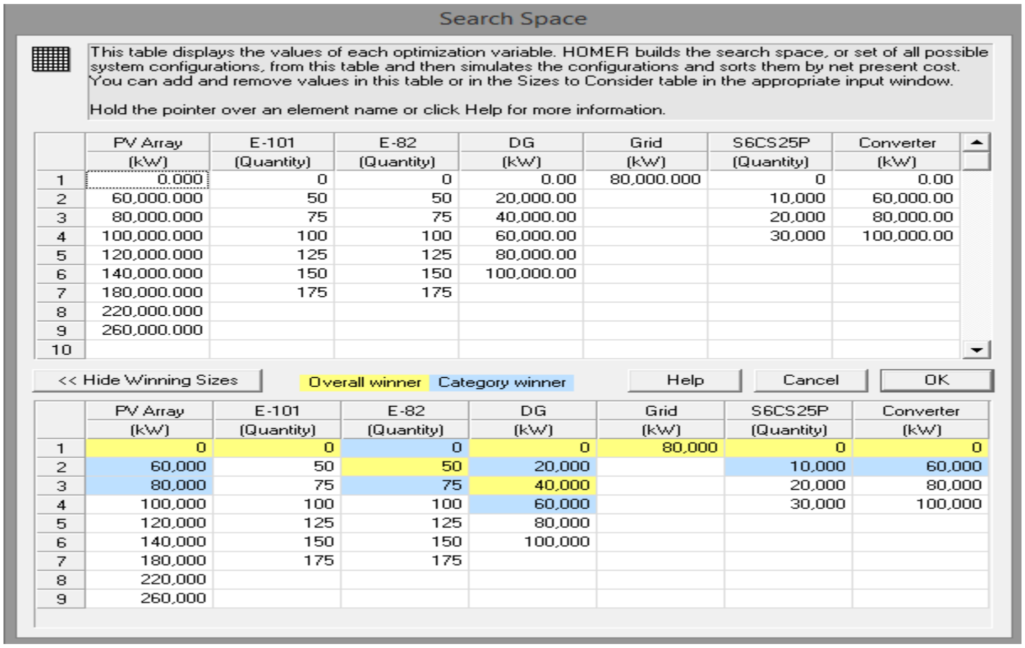
Hold the pointer over an element name or click Help for more information.

	PV Array (kW)	E-101 (Quantity)	E-82 (Quantity)	DG (kW)	S6CS25P (Quantity)	Converter (kW)
1	0.000	0	0	0.00	0	0.00
2	60,000.000	50	50	20,000.00	10,000	60,000.00
3	80,000.000	75	75	40,000.00	20,000	80,000.00
4	100,000.000	100	100	60,000.00	30,000	100,000.00
5	120,000.000	125	125	80,000.00		
6	140,000.000	150	150	100,000.00		
7	180,000.000	175	175			
8	220,000.000					
9	260,000.000					
10						

<< Hide Winning Sizes Overall winner Category winner Help Cancel OK

	PV Array (kW)	E-101 (Quantity)	E-82 (Quantity)	DG (kW)	S6CS25P (Quantity)	Converter (kW)
1	0	0	0	0	0	0
2	60,000	50	50	20,000	10,000	60,000
3	80,000	75	75	40,000	20,000	80,000
4	100,000	100	100	60,000	30,000	100,000
5	120,000	125	125	80,000		
6	140,000	150	150	100,000		
7	180,000	175	175			
8	220,000					
9	260,000					

- Solar and Wind Grid-Connected System Search Space



Search Space

This table displays the values of each optimization variable. HOMER builds the search space, or set of all possible system configurations, from this table and then simulates the configurations and sorts them by net present cost. You can add and remove values in this table or in the Sizes to Consider table in the appropriate input window.

Hold the pointer over an element name or click Help for more information.

	PV Array (kW)	E-101 (Quantity)	E-82 (Quantity)	DG (kW)	Grid (kW)	S6CS25P (Quantity)	Converter (kW)
1	0.000	0	0	0.00	80,000.000	0	0.00
2	60,000.000	50	50	20,000.00		10,000	60,000.00
3	80,000.000	75	75	40,000.00		20,000	80,000.00
4	100,000.000	100	100	60,000.00		30,000	100,000.00
5	120,000.000	125	125	80,000.00			
6	140,000.000	150	150	100,000.00			
7	180,000.000	175	175				
8	220,000.000						
9	260,000.000						
10							

<< Hide Winning Sizes | Overall winner | Category winner | Help | Cancel | OK

	PV Array (kW)	E-101 (Quantity)	E-82 (Quantity)	DG (kW)	Grid (kW)	S6CS25P (Quantity)	Converter (kW)
1	0	0	0	0	80,000	0	0
2	60,000	50	50	20,000		10,000	60,000
3	80,000	75	75	40,000		20,000	80,000
4	100,000	100	100	60,000		30,000	100,000
5	120,000	125	125	80,000			
6	140,000	150	150	100,000			
7	180,000	175	175				
8	220,000						
9	260,000						

Appendix 7: Districts Outlook Results

1. Butnan

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)		PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200				75	60000	30000	60000	CC	$ 399,750,016	42,278,536	$ 940,211,584	0.155	0.40	102,242,080	6,416
0.400				75	60000	30000	60000	CC	$ 399,750,016	62,770,720	$ 1,202,170,496	0.199	0.39	102,559,512	6,372
0.600				75	60000	30000	60000	CC	$ 399,750,016	83,700,248	$ 1,469,720,064	0.243	0.39	103,173,600	6,398
0.800				100	60000	30000	60000	CC	$ 491,000,000	97,026,248	$ 1,731,321,216	0.286	0.46	91,913,024	5,741

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	40,098,016	$ 727,087,232	0.120	0.30	86,944,008	6,858

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	62,672,896	$ 1,015,670,016	0.168	0.30	86,310,016	6,791

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			75	40000			CC	80000	$ 305,750,016	77,248,752	$ 1,293,248,384	0.214	0.40	74,209,296	5,879

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			100	40000			CC	80000	$ 397,000,000	89,430,776	$ 1,540,225,536	0.254	0.47	64,629,476	5,127

At Diesel Price 0.80 $/L

2. Derna

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200			75	60000	30000	60000	CC	$ 399,750,016	39,146,696	$ 900,176,128	0.149	0.46	92,294,080	5,812
0.400			75	60000	30000	60000	CC	$ 399,750,016	57,689,784	$ 1,137,219,072	0.188	0.45	92,637,144	5,784
0.600			75	60000	30000	60000	CC	$ 399,750,016	76,968,736	$ 1,383,668,736	0.229	0.45	93,484,144	5,841
0.800			100	60000	30000	60000	CC	$ 491,000,000	87,980,456	$ 1,615,685,632	0.267	0.52	81,961,848	5,172

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	37,440,336	$ 693,113,216	0.114	0.36	79,823,632	6,331

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	58,270,992	$ 959,398,912	0.158	0.36	79,265,784	6,272

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		75	40000			CC	80000	$ 305,750,016	70,695,696	$ 1,209,478,400	0.200	0.45	66,002,376	5,240

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		100	40000			CC	80000	$ 397,000,000	80,843,864	$ 1,430,455,936	0.236	0.52	56,848,196	4,513

At Diesel Price 0.80 $/L

3. Jabal al Akhdar

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)		PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200				75	60000	30000	60000	CC	$ 399,750,016	41,147,800	$ 925,756,992	0.153	0.42	98,640,272	6,199
0.400				75	60000	30000	60000	CC	$ 399,750,016	60,884,888	$ 1,178,063,232	0.195	0.41	98,875,584	6,154
0.600				75	60000	30000	60000	CC	$ 399,750,016	81,088,136	$ 1,436,328,576	0.237	0.41	99,522,960	6,175
0.800				100	60000	30000	60000	CC	$ 491,000,000	93,788,104	$ 1,689,926,784	0.279	0.48	88,371,816	5,534

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	38,775,712	$ 710,183,744	0.117	0.33	83,339,632	6,585

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	60,485,168	$ 987,703,488	0.163	0.33	82,668,384	6,514

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			75	40000			CC	80000	$ 305,750,016	73,966,080	$ 1,251,284,864	0.207	0.43	70,221,296	5,569

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			100	40000			CC	80000	$ 397,000,000	85,207,832	$ 1,486,242,176	0.245	0.49	60,838,388	4,829

At Diesel Price 0.80 $/L

4. Marj

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)		PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200				50	60000	30000	60000	CC	$ 308,500,000	32,961,218	$ 729,855,040	0.121	0.52	80,918,344	5,137
0.400				50	60000	30000	60000	CC	$ 308,500,000	49,375,784	$ 939,688,256	0.155	0.52	81,495,600	5,137
0.600				75	60000	30000	60000	CC	$ 399,750,016	57,360,120	$ 1,133,004,800	0.187	0.61	66,102,016	4,223
0.800				100	60000	30000	60000	CC	$ 491,000,000	63,436,376	$ 1,301,929,856	0.215	0.68	55,481,084	3,554

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	28,876,032	$ 583,632,640	0.096	0.53	56,985,108	4,551

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	44,154,984	$ 778,948,928	0.129	0.53	56,380,320	4,487

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			75	40000			CC	80000	$ 305,750,016	51,541,772	$ 964,626,880	0.159	0.62	45,070,172	3,599

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			75	40000			CC	80000	$ 305,750,016	63,895,156	$ 1,122,544,640	0.185	0.62	44,916,096	3,583

At Diesel Price 0.80 $/L

5. Benghazi

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200			50	60000	30000	60000	CC	$ 308,500,000	32,961,218	$ 729,855,040	0.121	0.52	80,918,344	5,137
0.400			50	60000	30000	60000	CC	$ 308,500,000	49,375,784	$ 939,688,256	0.155	0.52	81,495,600	5,137
0.600			75	60000	30000	60000	CC	$ 399,750,016	57,360,120	$ 1,133,004,800	0.187	0.61	66,102,016	4,223
0.800			100	60000	30000	60000	CC	$ 491,000,000	63,436,376	$ 1,301,929,856	0.215	0.68	55,481,084	3,554

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	28,876,032	$ 583,632,640	0.096	0.53	56,985,108	4,551

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	44,154,984	$ 778,948,928	0.129	0.53	56,380,320	4,487

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		75	40000			CC	80000	$ 305,750,016	51,541,772	$ 964,626,880	0.159	0.62	45,070,172	3,599

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		75	40000			CC	80000	$ 305,750,016	63,895,156	$ 1,122,544,640	0.185	0.62	44,916,096	3,583

At Diesel Price 0.80 $/L

6. Al Wahat

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)		PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200				75	60000	30000	60000	CC	$ 399,750,016	41,190,440	$ 926,302,080	0.153	0.42	98,711,616	6,214
0.400				75	60000	30000	60000	CC	$ 399,750,016	60,920,584	$ 1,178,519,552	0.195	0.41	98,931,728	6,161
0.600				75	60000	30000	60000	CC	$ 399,750,016	81,097,192	$ 1,436,444,288	0.237	0.41	99,534,880	6,176
0.800				100	60000	30000	60000	CC	$ 491,000,000	93,784,488	$ 1,689,880,576	0.279	0.48	88,374,816	5,533

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	38,769,344	$ 710,102,400	0.117	0.33	83,302,360	6,580

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	60,474,800	$ 987,570,944	0.163	0.33	82,763,944	6,523

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			75	40000			CC	80000	$ 305,750,016	73,954,112	$ 1,251,131,904	0.207	0.43	70,194,048	5,564

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			100	40000			CC	80000	$ 397,000,000	85,210,768	$ 1,486,279,680	0.245	0.49	60,948,104	4,839

At Diesel Price 0.80 $/L

7. Kufra

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200			50	60000	30000	60000	CC	$ 308,500,000	38,438,232	$ 799,869,632	0.132	0.42	98,223,656	6,203
0.400			50	60000	30000	60000	CC	$ 308,500,000	58,226,960	$ 1,052,836,032	0.174	0.42	98,687,672	6,181
0.600			75	60000	30000	60000	CC	$ 399,750,016	69,159,272	$ 1,283,837,568	0.212	0.51	82,463,576	5,210
0.800			100	60000	30000	60000	CC	$ 491,000,000	77,910,424	$ 1,486,956,800	0.246	0.58	71,093,584	4,525

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	33,837,980	$ 647,062,976	0.107	0.43	70,737,464	5,640

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	52,338,504	$ 883,561,792	0.146	0.43	70,019,664	5,564

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		75	40000			CC	80000	$ 305,750,016	62,263,516	$ 1,101,686,784	0.182	0.53	56,781,180	4,518

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		100	40000			CC	80000	$ 397,000,000	70,497,224	$ 1,298,191,232	0.214	0.59	48,461,412	3,863

At Diesel Price 0.80 $/L

8. Sirte

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)		PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200				75	60000	30000	60000	CC	$ 399,750,016	37,254,584	$ 875,988,608	0.145	0.49	86,341,576	5,441
0.400				75	60000	30000	60000	CC	$ 399,750,016	54,750,744	$ 1,099,648,256	0.182	0.49	86,920,632	5,439
0.600				75	60000	30000	60000	CC	$ 399,750,016	72,753,616	$ 1,329,785,344	0.220	0.48	87,525,928	5,466
0.800				100	60000	30000	60000	CC	$ 491,000,000	82,431,176	$ 1,544,747,136	0.255	0.55	76,028,272	4,797

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	35,411,160	$ 667,173,504	0.110	0.40	74,002,824	5,883

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	54,909,024	$ 916,421,632	0.151	0.40	73,407,712	5,820

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			75	40000			CC	80000	$ 305,750,016	65,874,308	$ 1,147,844,736	0.190	0.50	60,219,660	4,780

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			100	40000			CC	80000	$ 397,000,000	74,977,696	$ 1,355,466,624	0.224	0.56	51,827,332	4,119

At Diesel Price 0.80 $/L

9. Misrata

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200			75	60000	30000	60000	CC	$ 399,750,016	39,453,976	$ 904,104,256	0.149	0.45	93,253,696	5,873
0.400			75	60000	30000	60000	CC	$ 399,750,016	58,257,128	$ 1,144,471,680	0.189	0.45	93,719,832	5,855
0.600			75	60000	30000	60000	CC	$ 399,750,016	77,580,152	$ 1,391,484,672	0.230	0.44	94,420,864	5,892
0.800			100	60000	30000	60000	CC	$ 491,000,000	88,526,216	$ 1,622,662,272	0.268	0.51	82,640,760	5,178

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	37,315,084	$ 691,512,064	0.114	0.36	79,341,552	6,291

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	58,061,040	$ 956,715,008	0.158	0.36	78,812,816	6,235

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		75	40000			CC	80000	$ 305,750,016	70,389,984	$ 1,205,570,304	0.199	0.46	65,379,392	5,186

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		100	40000			CC	80000	$ 397,000,000	80,579,320	$ 1,427,074,176	0.236	0.53	56,319,732	4,468

At Diesel Price 0.80 $/L

10. Murgub

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)		PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200				50	60000	30000	60000	CC	$ 308,500,000	41,968,120	$ 844,993,472	0.140	0.35	109,925,520	6,832
0.400				50	60000	30000	60000	CC	$ 308,500,000	63,900,832	$ 1,125,367,168	0.186	0.34	110,120,760	6,763
0.600				75	60000	30000	60000	CC	$ 399,750,016	77,311,744	$ 1,388,053,632	0.229	0.44	94,049,368	5,833
0.800				100	60000	30000	60000	CC	$ 491,000,000	88,129,264	$ 1,617,587,840	0.267	0.51	82,322,552	5,158

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	37,401,496	$ 692,616,704	0.114	0.36	78,565,664	6,227

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	58,174,120	$ 958,160,512	0.158	0.36	77,894,416	6,156

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			75	40000			CC	80000	$ 305,750,016	70,375,008	$ 1,205,378,816	0.199	0.46	65,164,832	5,171

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			100	40000			CC	80000	$ 397,000,000	80,394,168	$ 1,424,707,328	0.235	0.53	56,228,484	4,470

At Diesel Price 0.80 $/L

11. Tripoli

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)		PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200				75	60000	30000	60000	CC	$ 399,750,016	39,397,520	$ 903,382,528	0.149	0.45	93,188,872	5,850
0.400				100	60000	30000	60000	CC	$ 491,000,000	54,760,200	$ 1,191,019,264	0.197	0.52	81,820,664	5,130
0.600				100	60000	30000	60000	CC	$ 491,000,000	71,783,720	$ 1,408,636,928	0.233	0.51	82,479,312	5,166
0.800				100	60000	30000	60000	CC	$ 491,000,000	88,626,808	$ 1,623,948,160	0.268	0.51	82,751,880	5,181

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	37,309,888	$ 691,445,632	0.114	0.36	79,056,320	6,266

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	58,045,848	$ 956,520,768	0.158	0.36	78,573,920	6,215

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			75	40000			CC	80000	$ 305,750,016	70,411,744	$ 1,205,848,448	0.199	0.46	65,348,020	5,183

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			100	40000			CC	80000	$ 397,000,000	80,602,424	$ 1,427,369,600	0.236	0.53	56,269,956	4,462

At Diesel Price 0.80 $/L

12. Jafara

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)		PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200				75	60000	30000	60000	CC	$ 399,750,016	39,397,520	$ 903,382,528	0.149	0.45	93,188,872	5,850
0.400				100	60000	30000	60000	CC	$ 491,000,000	54,760,200	$ 1,191,019,264	0.197	0.52	81,820,664	5,130
0.600				100	60000	30000	60000	CC	$ 491,000,000	71,783,720	$ 1,408,636,928	0.233	0.51	82,479,312	5,166
0.800				100	60000	30000	60000	CC	$ 491,000,000	88,626,808	$ 1,623,948,160	0.268	0.51	82,751,880	5,181

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	37,309,888	$ 691,445,632	0.114	0.36	79,056,320	6,266

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	58,045,848	$ 956,520,768	0.158	0.36	78,573,920	6,215

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			75	40000			CC	80000	$ 305,750,016	70,411,744	$ 1,205,848,448	0.199	0.46	65,348,020	5,183

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			100	40000			CC	80000	$ 397,000,000	80,602,424	$ 1,427,369,600	0.236	0.53	56,269,956	4,462

At Diesel Price 0.80 $/L

13. Zawiya

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200			75	60000	30000	60000	CC	$ 399,750,016	39,453,976	$ 904,104,256	0.149	0.45	93,253,696	5,873
0.400			75	60000	30000	60000	CC	$ 399,750,016	58,257,128	$ 1,144,471,680	0.189	0.45	93,719,832	5,855
0.600			75	60000	30000	60000	CC	$ 399,750,016	77,580,152	$ 1,391,484,672	0.230	0.44	94,420,864	5,892
0.800			100	60000	30000	60000	CC	$ 491,000,000	88,526,216	$ 1,622,662,272	0.268	0.51	82,640,760	5,178

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	37,315,084	$ 691,512,064	0.114	0.36	79,341,552	6,291

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	58,061,040	$ 956,715,008	0.158	0.36	78,812,816	6,235

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		75	40000			CC	80000	$ 305,750,...	70,389,984	$ 1,205,570,304	0.199	0.46	65,379,392	5,186

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		100	40000			CC	80000	$ 397,000,000	80,579,320	$ 1,427,074,176	0.236	0.53	56,319,732	4,468

At Diesel Price 0.80 $/L

14. Nuqat al Khams

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200			75	60000	30000	60000	CC	$ 399,750,016	40,379,336	$ 915,933,440	0.151	0.43	96,187,888	6,052
0.400			75	60000	30000	60000	CC	$ 399,750,016	59,727,320	$ 1,163,265,664	0.192	0.43	96,605,744	6,022
0.600			75	60000	30000	60000	CC	$ 399,750,016	79,623,800	$ 1,417,609,472	0.234	0.42	97,385,616	6,065
0.800			100	60000	30000	60000	CC	$ 491,000,000	91,452,640	$ 1,660,071,808	0.274	0.49	85,822,744	5,382

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	38,153,336	$ 702,227,712	0.116	0.34	81,572,512	6,455

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	59,449,920	$ 974,469,568	0.161	0.34	81,052,304	6,400

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		75	40000			CC	80000	$ 305,750,016	72,391,872	$ 1,231,161,216	0.203	0.44	67,886,288	5,384

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		100	40000			CC	80000	$ 397,000,000	83,101,328	$ 1,459,313,920	0.241	0.51	58,630,048	4,652

At Diesel Price 0.80 $/L

15. Jabal al Gharbi

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)	System	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200				75	60000	30000	60000	CC	$ 399,750,016	40,698,648	$ 920,015,296	0.152	0.43	97,103,688	6,124
0.400				75	60000	30000	60000	CC	$ 399,750,016	60,058,392	$ 1,167,497,856	0.193	0.42	97,249,056	6,061
0.600				75	60000	30000	60000	CC	$ 399,750,016	80,195,128	$ 1,424,912,896	0.235	0.42	98,192,192	6,125
0.800				100	60000	30000	60000	CC	$ 491,000,000	92,272,384	$ 1,670,550,784	0.276	0.49	86,693,528	5,445

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

System	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	38,378,796	$ 705,109,888	0.116	0.34	82,037,816	6,487

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

System	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	59,819,464	$ 979,193,536	0.162	0.34	81,622,208	6,443

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

System	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			75	40000			CC	80000	$ 305,750,016	72,886,048	$ 1,237,478,272	0.204	0.44	68,489,648	5,433

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

System	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			100	40000			CC	80000	$ 397,000,000	83,697,384	$ 1,466,933,504	0.242	0.50	59,165,848	4,696

At Diesel Price 0.80 $/L

16. Nalut

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)		PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200				75	60000	30000	60000	CC	$ 399,750,016	40,628,064	$ 919,113,024	0.152	0.43	96,854,744	6,113
0.400				75	60000	30000	60000	CC	$ 399,750,016	59,933,928	$ 1,165,906,816	0.193	0.43	96,985,168	6,051
0.600				75	60000	30000	60000	CC	$ 399,750,016	79,889,320	$ 1,421,003,648	0.235	0.42	97,773,928	6,096
0.800				100	60000	30000	60000	CC	$ 491,000,000	91,952,568	$ 1,666,462,464	0.275	0.49	86,341,552	5,423

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	38,318,760	$ 704,342,400	0.116	0.34	81,981,880	6,485

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	59,722,848	$ 977,958,464	0.162	0.34	81,433,680	6,427

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			75	40000			CC	80000	$ 305,750,016	72,693,840	$ 1,235,021,312	0.204	0.44	68,465,032	5,433

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			100	40000			CC	80000	$ 397,000,000	83,430,584	$ 1,463,522,944	0.242	0.51	59,129,192	4,695

At Diesel Price 0.80 $/L

17. Jufra

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)		PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200				75	60000	30000	60000	CC	$ 399,750,016	40,600,040	$ 918,754,752	0.152	0.43	96,856,480	6,098
0.400				75	60000	30000	60000	CC	$ 399,750,016	59,999,352	$ 1,166,743,040	0.193	0.42	97,134,528	6,054
0.600				75	60000	30000	60000	CC	$ 399,750,016	79,917,000	$ 1,421,357,440	0.235	0.42	97,832,664	6,092
0.800				100	60000	30000	60000	CC	$ 491,000,000	92,002,128	$ 1,667,096,064	0.275	0.49	86,487,616	5,424

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	38,273,480	$ 703,763,584	0.116	0.34	81,971,072	6,481

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	59,654,144	$ 977,080,192	0.161	0.34	81,366,360	6,417

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			75	40000			CC	80000	$ 305,750,016	72,753,360	$ 1,235,782,272	0.204	0.44	68,670,720	5,444

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			100	40000			CC	80000	$ 397,000,000	83,622,816	$ 1,465,980,288	0.242	0.50	59,511,320	4,722

At Diesel Price 0.80 $/L

18. Wadi al Shatii

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200			75	60000	30000	60000	CC	$ 399,750,016	39,900,600	$ 909,813,568	0.150	0.44	94,635,768	5,963
0.400			75	60000	30000	60000	CC	$ 399,750,016	58,985,128	$ 1,153,777,920	0.191	0.44	95,123,768	5,943
0.600			75	60000	30000	60000	CC	$ 399,750,016	78,401,368	$ 1,401,982,592	0.232	0.43	95,700,592	5,967
0.800			100	60000	30000	60000	CC	$ 491,000,000	89,829,056	$ 1,639,316,864	0.271	0.50	84,107,128	5,276

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	37,686,056	$ 696,254,336	0.115	0.35	80,183,640	6,342

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	58,678,696	$ 964,610,688	0.159	0.35	79,606,576	6,281

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		75	40000			CC	80000	$ 305,750,016	71,327,600	$ 1,217,556,096	0.201	0.45	66,663,904	5,284

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		100	40000			CC	80000	$ 397,000,000	81,815,912	$ 1,442,882,048	0.238	0.52	57,641,868	4,573

At Diesel Price 0.80 $/L

19. Sabha

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200			50	60000	30000	60000	CC	$ 308,500,000	41,603,600	$ 840,333,632	0.139	0.36	108,452,744	6,795
0.400			50	60000	30000	60000	CC	$ 308,500,000	63,333,648	$ 1,118,116,608	0.185	0.35	108,773,728	6,748
0.600			75	60000	30000	60000	CC	$ 399,750,016	76,135,232	$ 1,373,013,760	0.227	0.45	92,369,624	5,779
0.800			100	60000	30000	60000	CC	$ 491,000,000	86,552,344	$ 1,597,429,504	0.264	0.53	80,547,640	5,085

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	36,863,856	$ 685,743,808	0.113	0.37	77,598,464	6,147

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	57,306,032	$ 947,063,488	0.156	0.37	77,012,320	6,085

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		75	40000			CC	80000	$ 305,750,016	68,971,776	$ 1,187,440,896	0.196	0.47	64,306,952	5,106

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		100	40000			CC	80000	$ 397,000,000	78,554,632	$ 1,401,191,936	0.231	0.54	55,332,184	4,406

At Diesel Price 0.80 $/L

20. Wadi al Hayaa

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)		PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200				75	60000	30000	60000	CC	$ 399,750,016	37,095,288	$ 873,952,256	0.144	0.49	85,781,472	5,416
0.400				75	60000	30000	60000	CC	$ 399,750,016	54,335,304	$ 1,094,337,536	0.181	0.49	86,113,696	5,390
0.600				75	60000	30000	60000	CC	$ 399,750,016	71,978,600	$ 1,319,878,144	0.218	0.49	86,589,080	5,405
0.800				100	60000	30000	60000	CC	$ 491,000,000	81,860,680	$ 1,537,454,336	0.254	0.56	75,440,328	4,760

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	35,207,692	$ 664,572,480	0.110	0.40	73,634,968	5,850

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	54,583,104	$ 912,255,296	0.151	0.40	72,916,360	5,774

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			75	40000			CC	80000	$ 305,750,016	65,464,980	$ 1,142,612,224	0.189	0.50	59,867,556	4,753

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			100	40000			CC	80000	$ 397,000,000	74,416,312	$ 1,348,290,304	0.223	0.57	51,312,740	4,074

At Diesel Price 0.80 $/L

21. Ghat

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)		PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200				75	60000	30000	60000	CC	$ 399,750,016	38,044,672	$ 886,088,576	0.146	0.48	88,722,376	5,607
0.400				75	60000	30000	60000	CC	$ 399,750,016	56,021,528	$ 1,115,893,120	0.184	0.47	89,293,872	5,609
0.600				75	60000	30000	60000	CC	$ 399,750,016	74,442,744	$ 1,351,378,176	0.223	0.47	89,924,392	5,638
0.800				100	60000	30000	60000	CC	$ 491,000,000	84,321,704	$ 1,568,914,432	0.259	0.54	78,042,784	4,927

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	36,045,720	$ 675,285,312	0.112	0.38	76,344,520	6,072

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			50	40000			CC	80000	$ 214,500,000	55,971,736	$ 930,006,656	0.154	0.38	75,701,880	6,004

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			75	40000			CC	80000	$ 305,750,016	67,301,968	$ 1,166,095,104	0.193	0.48	62,169,952	4,941

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
			100	40000			CC	80000	$ 397,000,000	76,594,232	$ 1,376,131,456	0.227	0.55	53,235,540	4,229

At Diesel Price 0.80 $/L

22. Murzuq

Stand-Alone System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Diesel ($/L)	PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
0.200			50	60000	30000	60000	CC	$ 308,500,000	39,647,192	$ 815,324,160	0.135	0.40	102,292,232	6,412
0.400			50	60000	30000	60000	CC	$ 308,500,000	60,239,904	$ 1,078,568,192	0.178	0.39	102,731,904	6,390
0.600			75	60000	30000	60000	CC	$ 399,750,016	72,080,688	$ 1,321,183,104	0.218	0.49	86,609,120	5,441
0.800			100	60000	30000	60000	CC	$ 491,000,000	81,543,184	$ 1,533,395,584	0.253	0.56	75,056,280	4,750

Grid-Connected System

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	35,095,316	$ 663,135,936	0.110	0.40	73,699,648	5,864

At Diesel Price 0.20 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		50	40000			CC	80000	$ 214,500,000	54,403,160	$ 909,955,008	0.150	0.40	73,019,072	5,792

At Diesel Price 0.40 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		75	40000			CC	80000	$ 305,750,016	65,120,180	$ 1,138,204,544	0.188	0.50	59,536,688	4,727

At Diesel Price 0.60 $/L

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

PV (kW)	E-101	E-82	DG (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)
		100	40000			CC	80000	$ 397,000,000	73,940,624	$ 1,342,209,408	0.222	0.57	51,170,864	4,069

At Diesel Price 0.80 $/L

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