Department of Mechanical and Aerospace Engineering

Supplying El-Munawara Town by Renewable Energy; Feasibility Study

Author: OSAMA HAMOUDA

Supervisor: DR. CAMERON JOHNSTONE

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This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: OSAMA HAMOUDA Date: AUG 2018

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Contents

Table of figures

1 Abstract

This thesis aims to investigate the possibility of supplying El-Munawara town in Khartoum, Sudan by renewable energy. The demand in the town was estimated through quantitative and qualitative surveys and then has been optimized through the consultation of an expert.

The SWOT analysis of the renewable energy systems in there was made and included in this thesis.

The renewable supply analysis was made to find the potential of the renewables in the town. The applicability of supplying the town by hydro, wind or solar power was analysed and solar and photovoltaic options were the most optimum solutions.

The effect of increasing the storage of the electricity was checked on wind and photovoltaic power supply systems. Furthermore, the effect of increasing the renewable system output capacity was checked and the results are shown in the results section.

Keywords; Renewable energy, Wind power, photovoltaic panels, Renewable energy in Africa, Sudan.

2 Introduction

When it comes to sustainable energy supply for remote areas, many challenges need to be overcome to enable a sustainable energy supply without any power cuts or blackouts. Constructing a strong energy grid that would cover a whole country with immense area and dissimilar population densities distributed across the whole country is a difficult challenge. Furthermore, when the country has few power stations to supply its energy needs with a wide area, the transmission costs, losses and greenhouse gases emissions will significantly increase. For ages, in many countries with immense area, small remote municipalities survived by depending on fossil fuel electricity generation which is very expensive, poses unique reliability challenge and leave residents vulnerable to fuel shortages, adds to greenhouse gas emissions, and increases environmental and public health risks from air pollution and the possible storage tank leaks.

Today, the greater part of the world population lives in urban areas and over 30% of every single urban inhabitant live in slums or slum like minimized quarters. Against this background, the arrangement of decent housing keeps on being one of the fundamental difficulties of our urbanizing world. This is universally perceived by the Sustainable Development Goals, endorsed in 2015, which set up as the principal focus of its Sustainable Development Goal 11 to ensure, by 2030, access for all to sufficient, sheltered and moderate housing and in addition to ensure access to fundamental services and to redesign slums. (Obermayr, C., 2013).

The question of "what a sustainable city is?" has been a topic of research for many years and it has been answered several times by many researchers. Breaking down the city into many sections, the city physical dimensions of urban form may include its size, shape, land uses, configuration and distribution of open space and the associated energy consumption – a composite of a multitude of characteristics, including a city's transportation system and urban design features - (Handy, 1996; Llewelyn-Davies, 2000).

The right policy and energy management plans have a significant effect on how the city is sustainable. The implementation of policy and practising it has, to some extent, overtaken the knowledge and evidence needed to assure the success of sustainable urban forms. (M. Jenks 2010). Generally, developmental experts agree that "*a sustainable city should meet the needs of the present without sacrificing the ability of future generations to meet their own needs. The ambiguity within this idea leads to a great deal of variation in terms of how cities carry out their attempts to become sustainable*".

collaboration and scavenging between the different sectors and pillars in every community would result in a sustainable city, which could be defined as a city that will feed itself with minimal reliance on the surrounding rural area, and power itself with renewable sources of energy. The crux of this is often to make the tiniest possible ecological footprint, and to supply rock bottom amount of pollution possible, to with efficiency use land; compost used materials, recycle it or convert waste-to-energy, and therefore the city's overall contribution to global climate change are least, if such practices are adhered to. And when it comes to energy consumption, this collaboration would have a great effect in reducing the green-house gases emissions and enhance the living quality and reduce the environmental footprint. The scavenging between these sectors can be in forms of using the dump heat of factories in residential heating which is known as a *cogeneration*. Also, the use of the agricultural wastes like bagasse, silage waste and biomass wood chip can be used for biomass power generation to produce energy. In addition, using food wastes to produce methane gas for either residential or industrial use is a form of that collaboration. On the other hand, there are many obstacles that need to be tackled to make a city more sustainable. Table 1 shows the different collaboration ways that can lead to a sustainability in cities and the obstacles need to be dealt with as well.

Table 1: Aspects of a sustainable built environment (CABE, 2008)

Land use and build form	Environmental – energy conservation	Environmental – recycling and re-use	Communication and transport
• **Networks of green corridors (which decrease the energy consumption in buildings)** • **Community buildings,** • **self-managed** • **Mixture of land uses at relatively high density** • **Affordable homes** • **Local identity** • **Sustainable building materials** • **Flexible design and good space standards** • **Improved noise** • **insulation**	• Combined heat and power (CHP) – local power generation • Micro power generation (helps in reducing emissions from transmission) • Renewable energy • Reduced energy consumption and embodied energy • High levels of insulation (which decreases the heating loads) • Intelligent lighting and integrated security, heating, and IT systems • 'A' rated white Goods (which have less energy consumption) • Eco-rating e.g.	• 'Grey' water systems • Using recycle water for gardening and car washing • Reuse water and filter, to be directed to ecology parks or green spaces • Waste recycling, and use for production of biogas • Reduced domestic and construction waste • Carbon-neutral lifestyle	• Light transit • routes, eco-friendly buses and bikeways • Car clubs and cycle facilities • Pedestrian-friendly infrastructure • Restricted car parking • Environmental advice – bus/transit times, energy and water monitoring • IT enabled

The mentioned points in table 1 are based on a consensus that these many initiatives that are claimed to contribute to sustainability. (M. Jenks 2010). The easiest aspects those can incorporate into developments include Combined heat and power, Networks of Green Corridors, Light transit routes, eco-friendly buses, and bikeways, Pedestrian-friendly infrastructure and Restricted car parking.

Environmental advantages are claimed to accrue from additional compact urban forms wherever concentration of uses means that less need to travel and so lower emissions from vehicles. Additionally, cities concerning higher population densities are recommended to take advantages in energy savings through combined heat and power (CHP), however that advantages may be outweighed by the loss of open house.

The use of renewable energy is one of the main points that can result in a sustainable city and that is due to the almost zero carbon emissions environmental footprint and the closeness of the load to the supply which result in decreasing the transmission emissions.

2.1 Sudan Power Current Figures

In Sudan, where this study is done, the total power generation is equal to more than 17338 Kilo tonne of equivalent oil (Ktoe). (*A. Rabah, 2016*). More than 8900 Ktoe of this power (56%) comes from biomass resources such as charcoal which is widely used in the rural areas of Sudan for cooking, bakeries and lighting. In the second place, oil represents about %36 of the country power generated, with 6167 Ktoe, oil is used in wide sectors in Sudan such as transportation, residential, power generation and industry. Hydro power represents only 5% of the power generation in Sudan which is relatively low. The rest of the power generation in Sudan is covered by imports from abroad.

On the demand side, a total of more than 730 Ktoe shapes the energy demand in Sudan which is shared by residential, transportation, services, industry and agriculture sectors.

The high difference between the demand and generation is due to the high transmission and transportation losses due to the low grid efficiency and low transport facilities' efficiency.

A common solution to the issue of the high losses is to break down the power generation into several power stations which are nearer to the load in which is known as "Microgrid". These power stations could be either renewable or not. But in the first case the associated carbon dioxide emissions will reduce as well.

2.2 Literature related to the research:

The most common barrier for renewable supply for cities is the high CAPEX (capital expenditure). The cost which is always significantly higher than the ordinary power supply.

Reliance and transmission also shape constraints to renewable energy supply. Because the natural resources that the renewable energy always harnessed from are not stable and always fluctuate according to the climate and weather, the predictions of how much energy would be harnessed are always obscure.

Many cities in the world have switched to renewables, whether partially or completely as the new policies and regulations in many countries encourage to. One of the model examples in the turning from an unsustainable to a sustainable city is Cape Town, South Africa. Before the city switching to renewable energy, the availability and accessibility of coal as an energy source has made electricity generation heavily dependent on coal; 88% of electricity used to be generated through burning low grade coal. Another reason that shaped this high percentage of depending on coal is the affordability of this substance. On the other hand, 6% of electricity is produced through nuclear power stations and 2.3% is by hydroelectric stations and pumped storage stations assist with load management. (Ward et al 2011). The environmental costs of burning coal to produce power have not been figured into the cost of electricity. This, along with the abundance of coal, has made power in South Africa being amongst the cheapest in the world. This has driven to poor efficiencies in energy utilization, and the value added to the economy per unit of energy is lower than many in other nations. South Africa utilized more than double the sum of vitality as Germany in 2006 to produce the same financial impact. (Ward et al 2011).

Cape Town launched a road map in 2010 to reduce the greenhouse emissions and to make the city more sustainable. The road map has 10 goals which are:

- City wide reduction in electricity consumption
- Enable 10% renewable energy supply
- New demand will be met by renewable supply
- Resources' efficiency development
- Sustainable transport system
- Adapting to and building resilience to climate change impacts
- Greening low-income housing units
- Development of carbon sales potential of all projects
- Local economic development in energy sector
- Awareness, E&CC communications and education programmes

Because of this plan, the carbon dioxide emissions in South Africa decline since 2010. Figure (1) shows the declination of the CO_2 emissions in South Africa.

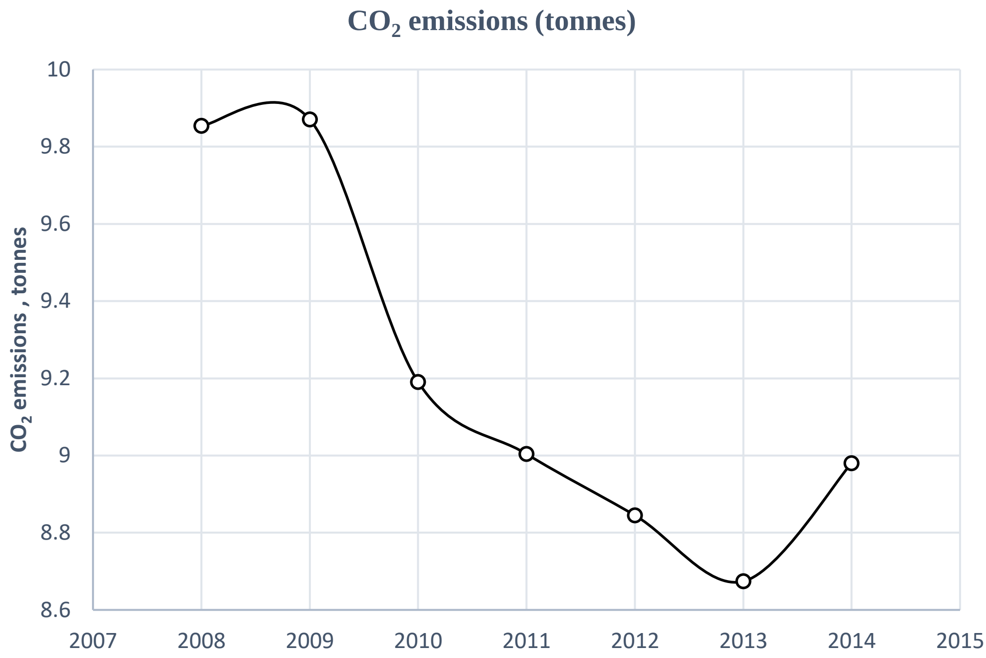


Figure 1: Carbon Dioxide Emissions from South Africa (World Bank Data, 2018)

Another example of the sustainable city phenomenon is the BedZED project in the London Borough of Sutton. A project that has been developed to be carbon dioxide free zone in London. The ninety-nine homes, and 1,405 sq. metres of work area were designed between 2000 and 2002. it's the UK's largest and 1st carbon-neutral eco-community. The buildings are made of materials that store heat throughout warm conditions and unleash heat at cooler times, and wherever possible. The buildings have been designed from natural, recycled or rescued materials. The primary residents moved in (to the Helios Road a part of the development) throughout March 2002.

The buildings were established using material specially designed to store heat when it is warm and release heat when it gets colder - and there is additionally the advantage of insulation around all the buildings. The building site was chosen due to its south facing position - that maximises the quantity of daylight reaching every property. The project has a unique transport system that encourage people to use the public transport and cycling.

The BedZED eco community is constructed using renewable or recycled materials, sourced from sustainable forests and alternative sources. This helps to minimise the environmental footprint that went into the making of the homes. Furthermore, the project considered the efficiency of every appliance in the houses and the power that they consume using the smart metering technologies, factors which resulted in a significant reduction in the power consumption.

Another example of the renewable energy projects is the Hywind floating wind farm. The farm is in Peterhead, Aberdeenshire in the north-eastern side of Scotland. The project was built by Statoil Norwegian Energy Company between 2012 and 2017. The wind farm capacity is 30 MW and it is powering 20,000 households. It is operated by Hywind (Scotland) Limited, a joint venture of Equinor (75%) and Masdar.

2.3 Terms and scope of the research:

This study aims to investigate the feasibility of covering the demand of the El-Munawara town in Khartoum, Sudan by renewable energy resources to supply a stable electricity to the town avoiding the regular occurring blackouts and to reduce the environmental footprint. Once renewable energy generation does not require any fuel transportation to the generation site, renewable generation has a least transportation impacts and significantly satisfactory to the demand of the town in which the study is proposed.

2.4 Evaluation for the current situation

The current environmental footprint of Sudan is 0.38 Tonne CO_2/Capita a year (IEA 2018). The urbanization rate is 63% percent with 21% of electrification in rural areas. The population of the country are 40.3 million persons with a GDP 72.73 billion USD. (IEA 2018)
El-Munawara town is consisted of 610 house, 3 schools, 3 retails and 2 restaurants with a total power consumption of nearly 4.1 Gwh a year. The town population is almost 3200 persons living in terraces and semi-detached houses with average power consumption between 3600 – 4800 Kwh a year. The nature of the buildings in there is terrace, semi-detached and detached houses with yard spaces in the fronts and backs of the houses. The building materials are bricks and cement with no insulation as the climate in there is a tropical climate. The average high temperature degree in the summer is 41 degrees Celsius and the average low temperature degree during the winter is 23 degrees Celsius.

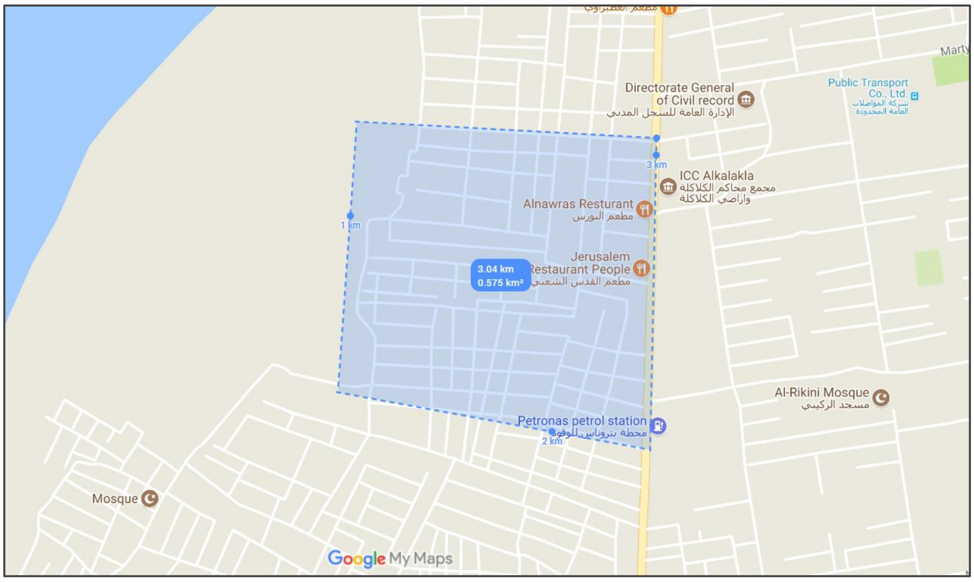


Figure 2: The project location map, Khartoum, Sudan

Figure 3: Khartoum, Sudan where El-Munawara town is.

Figure 4: El-Munawara map, in where this project is supposed to be done

2.5 *The importance renewable energy to cities*

The research undertaken in this study aims to investigate the feasibility of totally or partially supplying El-Munawara town by renewable energy to avoid the regular occurring blackouts and electricity cuts. In addition, the research aims to decrease the associated CO_2 emissions in the area which are linked with the electricity consumption, generation and transmission.

To estimate the power demand in the town, some considerations have been considered to find the approximate value of the average household daily power consumption. The first consideration is the random human behaviour of consumption which has been distributed in fixed terms of times throughout the 24 hours of the day. Furthermore, the average Kwh (Kilo Watt Hour) consumption for the electrical appliances has been taken from the manufacturers dara to calculate the daily consumption in order to calculate the demand.

The dependence on fossil fuels to produce electricity in Sudan makes electricity one of the most polluting energy resources in there. Electricity fossil fuel stations require huge quantities of coal, oil or gas. These fuels may need to be transported over long distances which require power as well and results in increasing the environmental footprint. Furthermore, the price of fuels can rise sharply at times of shortage, leading to unstable generation costs and high environmental footprints.

2.6 The research questions

Unstable electricity supply causes lots of problems particularly in this era of urbanization when almost everything needs electricity to work. The research undertaken needs to answer the following questions:

- Can El-Munawara town be supplied totally or partially by renewable energy?
- Can the intermittent renewable energy supply cover the town supply during the blackouts and the electricity cuts?
- Does it require storage facilities to facilitate the intermittent renewable energy supply?
- By how much would the air pollution be reduced if the town is on renewable energy supply?

2.7 Research objectives

Electricity cuts and blackouts shape a regular obstacle in Khartoum, Sudan which cause lots of discomfort and malaise to the residents who live there and cause problems to school students and patients in hospitals as well. Providing a stable electricity supply through renewable energy means is the main objective of this study. Due to the high solar radiation rates and wind speeds in Sudan, renewable energy has a promising future in there.

The air pollution associated with the electricity generation, whether in the power stations or in the small-scale electricity generators is one of the issues that this study is targeting to reduce.

Global warming abatement would be implicitly included in this study as a result of reducing the CO_2 associated with the electricity consumption, generation and transmission.

The objectives of this study can be summarized in:

1. To estimate the demand in El-Munawara town in Khartoum, Sudan
2. To analyse the renewable supply in the town
3. To find the most optimum renewable supply means through the software modelling tools

2.8 The order of information in the thesis

This thesis is a study of the feasibility of supplying El-Munawara town in Khartoum, Sudan by renewable energy. A SWOT analysis for the renewable energy in El-Munawara town was made to determine the strengths, weaknesses, opportunities and threats of the project in there.

The study contains two surveys that were made in the town in Sudan to estimate the electricity demand in there. The first survey is a quantitative survey and shows that the average monthly electricity household consumption is 350 to 450 Kwh in the winter, whilst this value can increase up to 600 Kwh a month in summer due to the high cooling loads.

The second survey is a qualitative survey and it was done to acquire data about the human behaviour to optimize the monthly demand data distribution throughout the day. Data about the consumption in the community centres premises and schools were also acquired to estimate the demand in these premises.

The renewable energy supply was analysed in the “renewable resources analysis section” in this study. In the “results” section in this study the results of the supply from different renewable means are shown and the illustrating graphs and figures as well.

The final section of the study is the “conclusion” which shows the key findings of the study and the recommended way of the renewable supply to the town.

2.9 The methodology of the research

The research started by data collection through quantitative and qualitative surveys. The data collected was optimized through the qualitative data that was collected from the town residents to get an idea about the human behaviour. For schools and the mosque, all the Muslims habits and traditions were considered in the human behaviour.

The renewable resources in the town from which energy can be harnessed were analysed to find the most appropriate energy supplies those can be added in the modeller to check their applicability. Data from The National Aeronautics and Space Administration “NASA”, Meteoblue meteorological service and other references was used to analyse the wind and solar energy potential in Khartoum, Sudan.

HOMER simulation modeller was used to simulate the town supply from renewable means and demand to calculate the best possible renewable energy supply to the town.

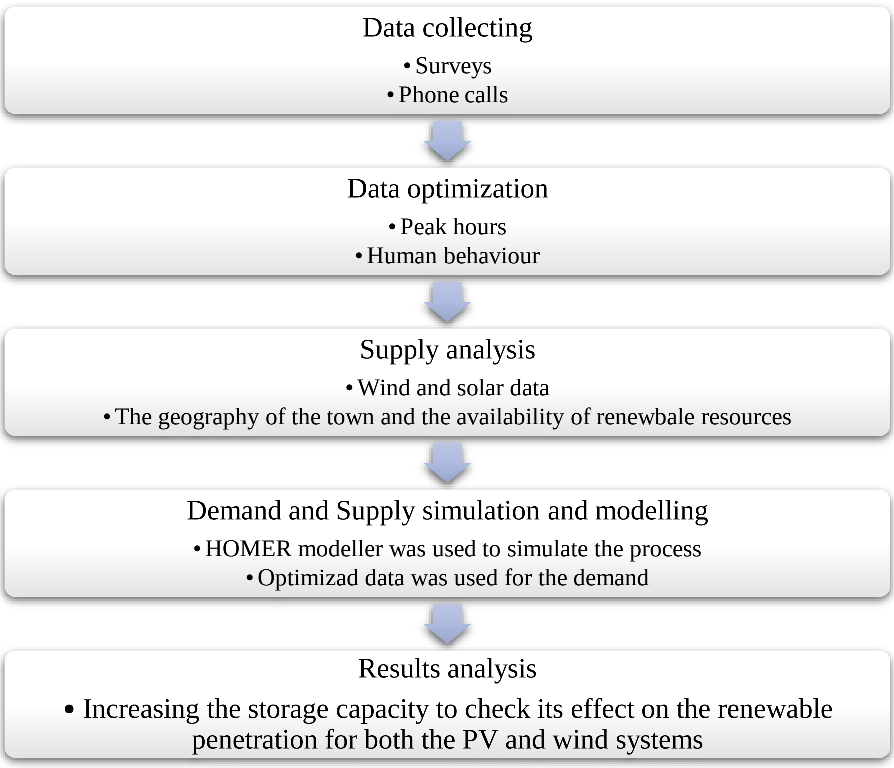
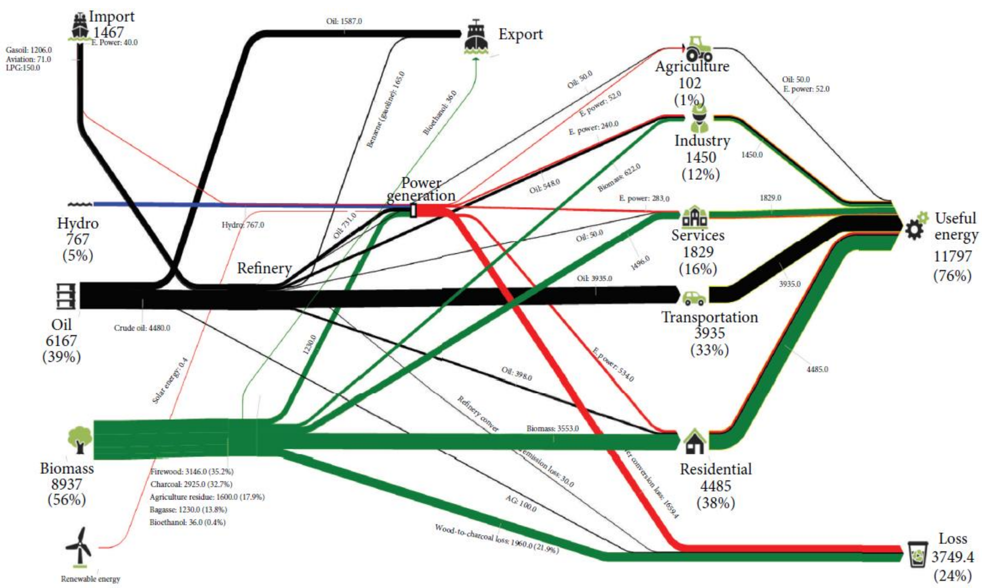


Figure 5: Research methodology

Apart from the methodology is to increase the storage capacity in renewable energy systems to check the effect of increasing the energy storage capacity on the power output and the renewable energy penetration as well.

To well understand how power in Sudan is produced, Sankey diagram of Sudan is shown in figure (6)



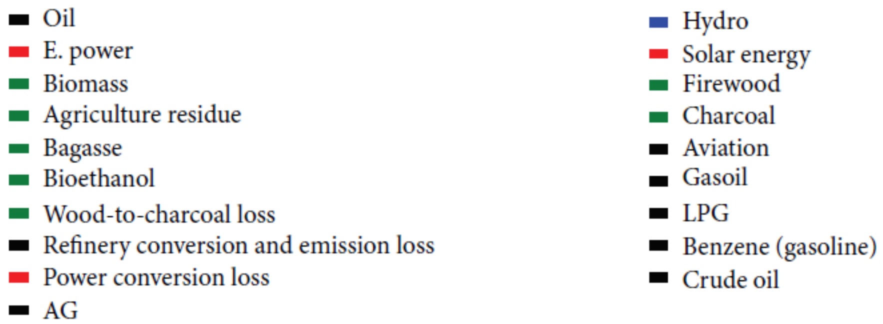


Figure 6: Sankey Diagram for Sudan (A. Rabah, 2016)

2.10 Energy purchasing power in Khartoum

Due to the relatively low electricity prices in Sudan many people in the residential sector are not concerned about their appliances' efficiency. The chart below shows the Purchasing Power Parity factor (PPP factor) of throughout the last 30 years is shown in figure (7).

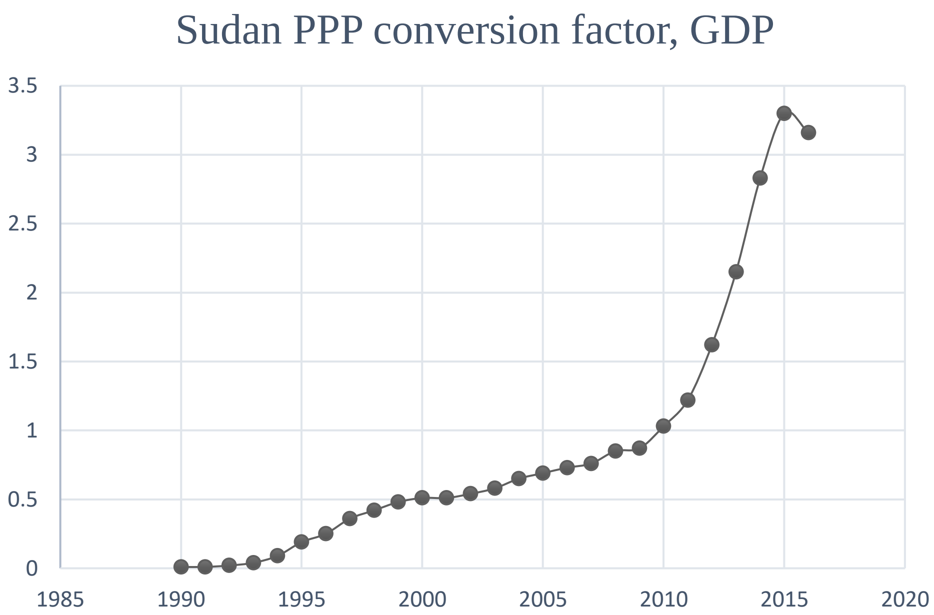


Figure 7: PPP conversion factor for Sudan (Definition: Purchasing power parity conversion factor is the number of units of a country's currency required to buy the same amounts of goods and services in the domestic market as U.S. dollar would buy in the United States, (EIA, 2018))

2.11 Electricity prices in Sudan

The Sudanese currency is pound (SDG) which is very low comparing with the British Pound (GBP), (1 SDG = 23.60). After the separation of South Sudan in 2011, the SDG collapsed dramatically. Just before the separation of South Sudan in January 2011, 1 GBP used to equal 3.88 SDG. The decrease in the currency exchange rate led to the decrease of the electricity prices comparing with the foreign currencies.

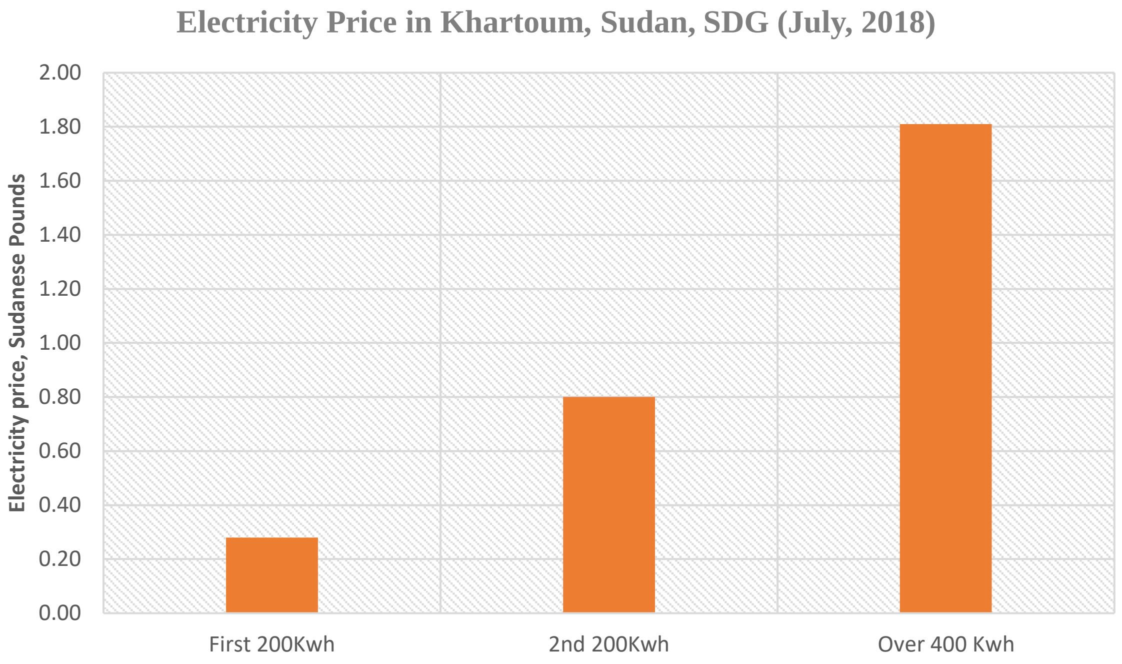


Figure 8: Electricity Prices in Khartoum, Sudan. From the shown prices, it can be clearly seen that the electricity prices are too low comparing with the UK. The first 200 Kwh of electricity costs 56 SDG, which equals to 2.37 GBP

3 Objectives

The study has main five objectives:

- To estimate the demand in the town through the possible reliable ways
- To analyse the renewable supply in the town
- To investigate the possibility of supplying the town by renewable energy
- To model the demand and the renewable energy supply while the town is connected to the grid
- Carbon auditing

From a wide range of available renewable supplies which includes:

- Wind
- Solar
- Hydro
- Biomass
- Bioenergy,
- Wave
- Geothermal
- Rains

In this study, the analysis that was carried out has conclude wind and solar energies are the optimum renewable supply systems due to the availability of wind and solar in the location of this study. Solar power intensity in Sudan is substantial and estimated to be about 277 watt per square metre per day. (Omer. A, M, 1994)

4 Scope and Methodology

4.1 Methodology

The research is investigating the possibility of supplying El-Munawara town in Khartoum, Sudan by renewable energy to sustain a reliable electrical supply and avoid the regularly happening blackouts and electricity cuts.

Quantitative surveys which are used to quantifying the problem by way of generating numerical data or data can be transformed into usable statistics were used to estimate the demand in this study with qualitative surveys as well which is primarily exploratory research.

A quantitative survey that includes 15 homes was made to collect the monthly residential electrical consumption data throughout the summer and winter.

Another qualitative survey was made for the same 15 homes sample to get the data of the used appliances in every house and their running times to help in indicating the human behaviour.

The data acquired from the first survey was optimized by effect of the human behaviour that was indicated by the second qualitative survey to give a demand profile which was used in the software modeller.

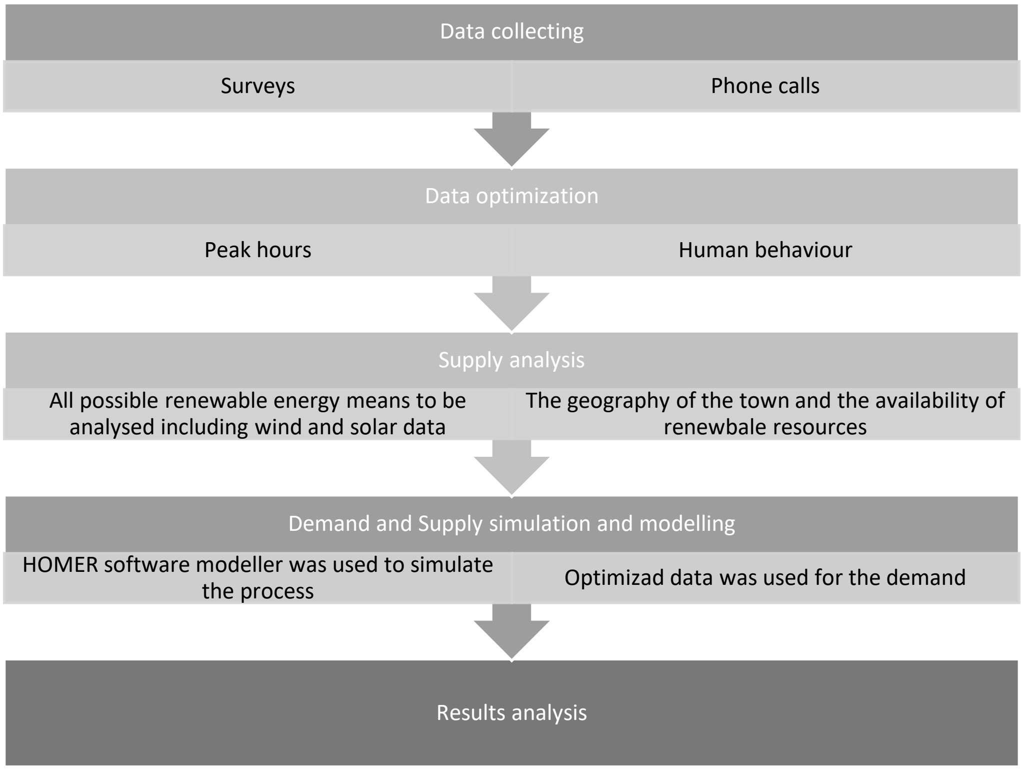


Figure 9: Research methodology of the study

Apart from hydropower generation, power from renewable resources is always has a high rates of non-dispatchability and depending on the weather and climate situations.

Due to the stochastic supply from renewable energy facilities generally and the PV panels and wind turbines particularly, an appropriate reliable modelling software that gives reliable results must be used to simulate the supply and demand with the profiles of the solar radiation and wind. From a list of the available energy modelling software, a modeller has to be used to simulate the demand and supply process. The available software modellers include:

- EnergyPLAN (University of Aalborg, 2017a) is a national and regional planning tool which has bee n used to model a 100% renewable energy future for Denmark (Lund & Mathiesen, 2009) and for many other studies (University of Aalborg, 2017b).
- HOMER; a community scale software that was developed originally to model the off-gird renewable energy schemes, but lately includes on-grid as well.
- TRNSYS (TRNSYS, 2017) is a modelling software that has smaller timesteps that can reach up to 1 second and can be used to model hybrid systems which include solar PV panels and thermal systems.

A research on “how to select the optimum modelling tool” was published by the University of Strathclyde in 2018 summarising the process of choosing the optimum software in a table that includes all almost all the available renewable energy modelling software modellers and the modelling factors those affect them.

Table 2: The available software modellers to select from and the affecting factors, (Lyden, A et all 2018)

Modeller	Criteria met?	Community scale?	Case study	Planning level design	LZCT	Storage/ DSM	Time step	Electrical	Thermal
EnergyPlan	Yes	National/ Regional	yes	yes	yes	yes	yes	yes	yes
HOMER	yes	yes	-	yes	yes	yes	Minutes	yes	yes
TRNSYS	No	Yes	-	No	yes	yes	Seconds	yes	yes

From table (2), following the methodology in Lyden, A study on how to choose the optimum renewable energy software modeller and due to the availability and the ease of access and use, HOMER software was selected as a modelling tool to simulate the demand and supply in this study.

The options considered for the renewable energy supply included solar photovoltaic panels (PV panels), wind turbines and the biomass that can be got from the wastes of the town and particularly wastes of a fire wood shop that is in the town.

Due to the high solar radiation in the Khartoum which can reach more than 2200 w/m^2, PV panels solar systems have a good potential in there. Furthermore, the availability of the barren plains gives a good area to install these systems. Furthermore, due to the closeness of the town to the White River Nile (figure 10) and the wide areas on the both sides of the river, wind has long unrestricted areas to run on in there, a factor which gives the wind turbines a high potential to be installed in there.

4.2 SWOT Analysis

To well understand the possibility of success of installing renewable energy facilities in the town of El-Munawara, SWOT analysis (Strengths, Weaknesses, Opportunities and Threats analysis) was done to determine whether more specific research questions will be introduced and investigated in the study.

Strengths	**Weaknesses**
• Free resource of energy • Sustainable resource of energy • Not depletable • Very low environmental footprint	• Non-dispatchable energy • Supply-demand matching problems • Weather dependent • High CAPEX cost • Long payback periods • Low consistency of resources

• renewable energy produces little or no waste products such as carbon dioxide or other chemical pollutants • Create new jobs • No need for fuel transportation to run the turbines	• Require storages
Opportunities	**Threats**
• Can be used for grid-connected areas to create hybrid networks • In weak electricity transmission grids, renewable energy projects can be built near the loads which lower the load on the grid • High wind speeds in Khartoum, Sudan • High solar radiation rates in Khartoum	• Governmental corruption • No feed-in-tariff projects • Sand storms in Khartoum • Excessive temperature degrees • Transportation and logistics difficulties • Weak infrastructure in Khartoum, Sudan

4.3 Understanding the demand in El-Munawara town:

Empirical studies on residential electricity consumption have received respectable attention in both developed and developing countries. Designers usually place confidence in benchmarks to tell predictions of small power consumption, power demand and internal gains. These are usually out of date and fail to account for the variability in equipment evolution and usage patterns in several offices. (Menezes, A.C., 2014). On the other hand, many designers use surveys to obtain the data which is required to estimate the demand in the targeted cities and towns.

Table (3) summarizes some previous studies on residential electricity demand that chiefly target the estimates of financial gain and value elasticities. Most of those studies use aggregated statistic information, and only a couple of small studies use the offered household-level information.

Table 3: List of previous studies that show how to estimate demands

Sources	Price elasticity	Income elasticity	Study period	Countries
Donatos and Mergos (1991)	−0.56	1.5	1961–1986	Greece
Ang et al. (1992)	−0.35	1	1972–1990	Singapore
Beenstock et al. (1999)	−0.52	1	1973–1994	Israel
Bose and Shukla (1999)	−0.65	0.88	1985–1993	India
Berkhout et al. (2004)	−0.55	0.61	1994–1999	Netherlands
Hondroyiannis (2004)	−0.41	1.56	1986–1996	Greece
Holtedahl and Joutz (2004)	−0.15	1.57	1955–1995	Taiwan
Narayan and Smyth (2005)	Short-run:-0.26, Long-run:-0.54	Short-run:0.012, Long-run: 0.41	1969–2000	Australia
Halicioglu (2007)	−0.52	0.7	1968–2005	Turkey
Ziramba (2008)	−0.01	0.87	1978–2005	S. Africa
Filippini and Pachauri (2004)	−0.42 to −0.29	0.60–0.64	1993–1994	India
Yoo et al. (2007)	−0.25	0.06–0.11	2005	Seoul, Korean
Dilaver and Hunt (2011)	Short-run: −0.09, Long-run:−0.38	Short-run:0.38, Long-run:1.57	1960–2008	Turkish

Breaking loads into small segments is a popular method to estimate demand in the residential areas. A study published by the New Buildings Institute suggest that plugs loads can represent up to 50% of the electricity use in buildings with high efficiency systems. (NBI 2012)
Office and residential buildings are seemingly to have higher cooling demands within the future because of global climate change, emphasising the necessity to higher perceive (and reduce) the impact of internal gains from IT equipment.

Detailed estimates of small power consumption are rarely undertaken, and designers usually rely on the available benchmarks so as to account for small power demand in residential and workplace buildings. (BCO, 2009). A more systematic and theoretical analysis is required to estimate the electricity consumption in residential buildings through the combination of quantitative and qualitative data.

The widely used document which is known as Energy Consumption Guide (ECG 19), provides typical and smart follow benchmarks for workplace and line of work equipment electricity consumption. Table (1) shows the ECG guide.

Table 4: ECG electrical consumption guide

	Electricity consumption (kWh/m^2)		**Power load density (W/m^2)**	
	Good practice	**Typical**	**Good practice**	**Typical**
Type 1: Naturally ventilated cellular	14	21	10	12
Type 2: Naturally ventilated open plan	23	32	12	14
Type 3: Air-conditioned standard	28	37	14	16
Type 4: Air-conditioned prestige	36	47	15	18

To calculate the peak loads, usually power load density is used to assess the expected peak power demand, commonly being used to calculate internal heat gains, affecting the design of cooling systems. (Menezes, A.C., 2014). The Building Services Research and Information Association (BSRIA) suggests that a value of 15 w/m^2 can be used to represent the electrical consumption value in residential buildings.

Figure 10: The map of the town in which this study was carried out

The town of El-Munawara is consisted from the more than 600 houses and some other premises, table (1) shows the structures in the town. The population of the town is estimated to be more than 3000 people.

Table 5: The premises in El-Munawara town

El-Munawara town premises	
Premises	Number
Houses	610
Schools	3
Restaurants	3
Mosques	1
Supermarkets	3
Bakeries	2
Firewood and charcoal shops	1

Through a questionnaire that was filled by an expert who works in the Sudanese Company for Electricity Distribution (H. Ibrahim, 2018); the governmental company responsible for selling electricity, table (6) was created which include the average electrical consumption for the premises in El-Munawara town.

Table 6: Electrical consumption for each structure in El-Munawara town, data was estimated through expert opinion.

Premises	Average summer monthly consumption - Kwh	Average winter monthly consumption -Kwh	Hourly value range - Summer	Hourly value range - Winter	Summer Average Hourly consumption - Kwh	Winter Average Hourly Consumption Kwh
Average home	450 - 600	350 - 450	0.625 - 0.833	0.486 - 0.625	0.729	0.556
Mosque	2500 - 3000	1000 - 1500	3.472 - 4.167	1.389 - 2.083	3.82	1.74
School	2100 - 2400	1700 - 2000	2.916 - 3.333	2.36 - 2.778	3.125	2.569
Restaurant	1850 - 1950	1700 - 1800	2.569 - 2.708	2.361 - 2.50	2.638	2.43
Bakery - Electric	20,000 – 20,200	20,000 – 20,200	27.397 – 27.671	27.397 – 27.671	27.523	27.523
Bakery - Biomass	850 - 950	700 - 800	1.180 - 1.319	0.972 - 1.111	1.5	1.042
Supermarket	1500 - 1700	1200 - 1400	2.054 – 2.328	1.643 – 1.917	2.191	1.780

4.4 Demand from the collected data:

Through a quantitative survey that was made in this study to calculate the demand in the El-Munawara town, smart meters bills and readings have been collected to find the average monthly residential demand in the town.

The data of 15 houses That was collected includes:

- Electricity bills for the last 12 months
- Household equipment and energy ratings
- Consumption behaviour
- Lighting types
- Cooker fuels

- Fridge and freezer types and power consumption

From the survey, the monthly electricity bills were varying between 450 – 600 Kwh in summer and 350 – 450 Kwh in winter. According to the data available the Sudanese Company for Electricity Distribution, the demand in summer is always higher than that in winter.

Table 7: the quantitative data survey that was made to collect the data

Home No.	**summer low average, Kwh**	**summer high average, Kwh**	**winter low average, Kwh**	**Winter high average, Kwh**
Home 1	449	603	345	458
Home 2	447	607	360	449
Home 3	457	603	349	456
Home 4	457	595	350	454
Home 5	459	595	348	455
Home 6	444	604	350	442
Home 7	450	604	340	452
Home 8	449	590	355	449
Home 9	455	600	348	458
Home 10	447	599	345	451
Home 11	451	604	343	452
Home 12	440	595	357	447
Home 13	447	596	343	441
Home 14	440	601	345	447
Home 15	452	606	352	452

The qualitative part of the survey included the number of the bedrooms in each house and the equipment and the operation time of each equipment to indicate the human behaviour which was used later to optimize the electrical demand data to a proper hourly consumption rate. Most of the houses included in the survey have the same equipment and roughly a similar number of bedrooms and living rooms.

The survey focused on the lighting types and energy rating of the equipment, but only one of the house owners was aware about the energy ratings of his equipment and the others answered the survey as they have no clue. Table (8) shows the qualitative part of the survey.

Table 8: The qualitative part of the survey which used to indicate the human behaviour to optimize the demand data

	Household appliances and energy ratings,	**Lighting types**
Home 1	3 Ceiling fans, 5 lamps, fridge, freezer, washing machine, iron, blender, PC, TV, Laptop, oven	1 Tungsten, 4 Fluorescent
Home 2	5 Ceiling fans, 8 lamps, fridge, freezer, washing machine, iron, blender, PC, TV, Laptop, oven, microwave	2 Tungsten, 6 Fluorescent
Home 3	4 Ceiling fans, 6 lamps, fridge, freezer, washing machine, iron, blender, PC, TV, Laptop, oven, microwave	2 Tungsten, 4 Fluorescent
Home 4	3 Ceiling fans, 5 lamps, fridge, freezer, washing machine, iron, blender, TV, Laptop, oven, microwave	2 Tungsten, 3 Fluorescent
Home 5	4 Ceiling fans, 6 lamps, fridge, freezer, washing machine, iron, blender, PC, TV, Laptop, oven, microwave	2 Tungsten, 6 Fluorescent
Home 6	3 Ceiling fans, 5 lamps, fridge, freezer, washing machine, iron, blender, PC, TV, Laptop, oven, microwave	2 Tungsten, Fluorescent
Home 7	3 Ceiling fans, 5 lamps, fridge, freezer, washing machine, iron, blender, PC, TV, Laptop, oven	2 Tungsten, 3 Fluorescent

Home 8	3 Ceiling fans, 5 lamps, fridge, freezer, washing machine, iron, blender, PC, TV, Laptop, oven, microwave	2 Tungsten, 3 Fluorescent
Home 9	3 Ceiling fans, 5 lamps, fridge, freezer, washing machine, iron, blender, PC, TV, Laptop, oven	1 Tungsten, 4 Fluorescent
Home 10	5 Ceiling fans, 10 lamps, fridge, freezer, washing machine, iron, blender, PC, TV, 3 Laptop, oven, microwave	2 Tungsten, 10 Fluorescent
Home 11	3 Ceiling fans, 5 lamps, fridge, freezer, washing machine, iron, blender, PC, TV, Laptop, oven, microwave	2 Tungsten, 3 Fluorescent
Home 12	3 Ceiling fans, 5 lamps, fridge, freezer, washing machine, iron, blender, PC, TV, 2 Laptop, oven, microwave	1 Tungsten, 4 Fluorescent
Home 13	3 Ceiling fans, 5 lamps, fridge, freezer, washing machine, iron, blender, PC, TV, Laptop, oven, microwave	1 Tungsten, 4 Fluorescent
Home 14	3 Ceiling fans, 5 lamps, fridge, freezer, washing machine, iron, blender, PC, TV, Laptop, oven, microwave	1 Tungsten, 4 Fluorescent
Home 15	3 Ceiling fans, 5 lamps, fridge, freezer, washing machine, iron, blender, TV, 2 Laptop, oven, microwave	1 Tungsten, 4 Fluorescent

According to the data acquired from the quantitative survey and according to the questionnaire that was filled by the expert from the Sudanese Electricity Distribution Company, the data was created and optimized. Table (9) was created based on random values between the low and the high average values of the demand in the summer and winter which was gathered from the qualitative questionnaire.

Table 9: Optimized residential data; from the quantitative survey that was made, the overall consumption data was acquired, and for the qualitative survey, the data was optimized

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	9625	10834	12024	13480	13610	11632	14171	12672	12330	11742	9524	10744
2	9032	10640	13906	14180	14138	13450	14880	14841	15234	12102	9429	11100
3	10116	11429	14233	12628	13108	15302	13681	15440	14997	12653	10478	9667
4	10604	9987	14117	13767	13907	12158	14999	13664	14891	14876	9277	10556
5	10969	10126	11849	14790	11923	14986	13788	14357	12645	13613	9586	11452
6	10934	9769	15054	14139	14546	12893	14238	15107	11880	15185	11348	9206
7	10622	10221	13997	11916	15101	15031	12238	13495	12213	14715	11458	9298
8	10331	11414	13062	12600	13155	15402	13885	11620	15311	11876	10229	9828
9	10193	9713	15177	13725	14513	15133	12814	12812	14622	13179	10995	9813
10	10523	9674	11620	12484	14805	14521	14382	11891	12960	11684	9972	10728
11	9315	9724	14368	12904	13391	12462	12244	14336	11937	11734	10903	9601
12	9158	9387	14083	14152	11826	12164	11773	12864	11698	13006	10810	9318
13	9228	11205	13737	13345	11751	13006	15269	14548	12558	15009	10942	11221
14	10221	11473	12582	13499	12335	13051	14058	11831	14667	12704	11375	9690
15	9380	9093	14326	14523	13810	13442	11735	13428	14995	15298	10704	9632
16	9875	10570	12959	12638	13536	12478	13858	15297	15181	13473	11170	10237
17	9541	9657	13007	13000	11915	12866	13145	15126	11886	15047	9611	9106
18	11374	11467	12416	15122	14583	15393	13554	13409	13029	13924	9398	10633
19	11179	9205	12114	14971	13281	13858	12200	13617	14633	12411	10001	9153
20	9298	10781	14761	14113	13538	15202	14986	13308	15319	12765	9625	10371
21	10214	10437	14873	13406	12829	12693	12437	12866	13020	13376	11120	9071
22	9445	10949	14928	14167	13975	12148	15118	13109	13119	13128	10638	10751
23	10132	9345	12609	14556	13385	14909	13365	13078	13974	13982	9517	10531
24	11100	9581	12644	14614	11783	14578	14773	13888	14236	14747	9838	10402

Comparing the residential annual demand with the temperature degrees throughout the year it is no doubt that the high-power consumption between March and October is due to the high cooling loads. Table (10) shows the average temperature degrees throughout the year in Khartoum, Sudan.

The data in table (2) is considering the whole monthly consumption distributed throughout the day between fixed ranges varies in summer and winter. Another data processing has been done to make the data more accurate is to consider the different operating hours of the different equipment.

In the beginning of the day until 6 AM in the morning, there is fridge, freezer and might be some fans working in summer. From 6 AM, the TV starting to work, with the kettle and cooking facilities which not all of it is electric.

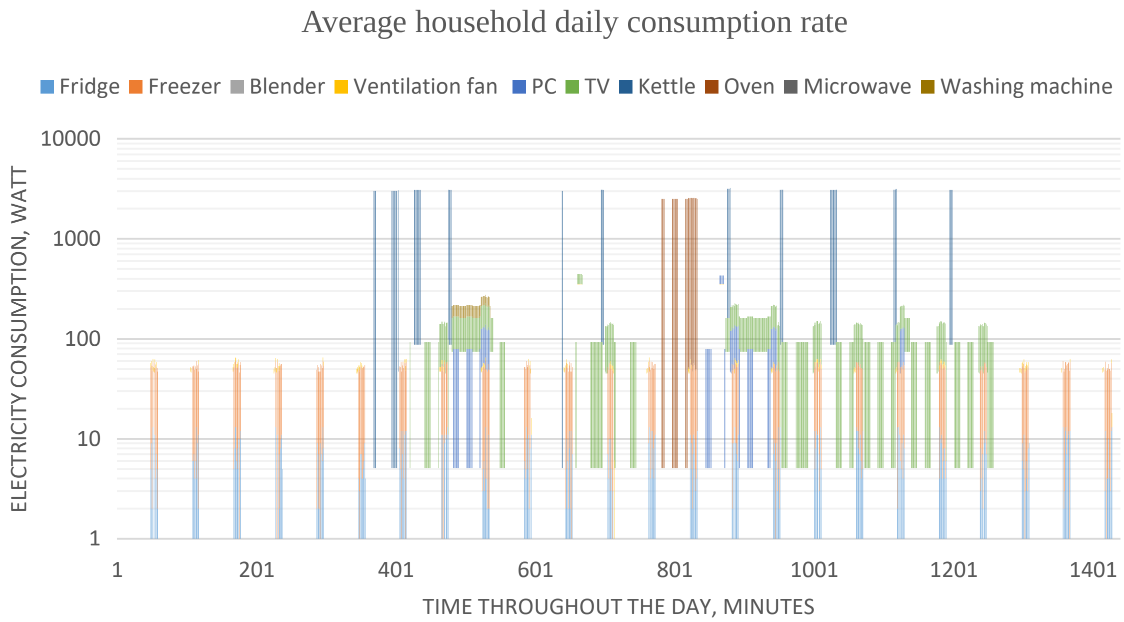


Figure 11: (Household Equipment consumption along the 24 hours' time)

The demand in El-Munawara town is highly affected by the high temperature degrees in Khartoum, Sudan. The average temperature degree in summer can reach up to 41.9 degree Celsius in May, which put lots of pressure on the electricity grid by the high cooling loads. Table (10) shows the temperature degrees in Khartoum throughout the year.

Table 10: Temperature degrees throughout the year in Khartoum, Sudan, where El-Munawara town is, from the table it could be clearly seen that the high temperature degrees cause the high cooling loads in the summer

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	39.7 -103.5	42.5 -108.5	45.2 -113.4	46.2 -115.2	46.8 -116.2	46.3 -115.3	44.5 -112.1	43.5 -110.3	44 -111.2	43 -109.4	41 -105.8	39 -102.2	46.8 -116.2
Average high °C (°F)	30.7 -87.3	32.6 -90.7	36.5 -97.7	40.4 -104.7	41.9 -107.4	41.3 -106.3	38.5 -101.3	37.6 -99.7	38.7 -101.7	39.3 -102.7	35.2 -95.4	31.7 -89.1	37 -98.6
Daily mean °C (°F)	23.2 -73.8	25 -77	28.7 -83.7	31.9 -89.4	34.5 -94.1	34.3 -93.7	32.1 -89.8	31.5 -88.7	32.5 -90.5	32.4 -90.3	28.1 -82.6	24.5 -76.1	29.9 -85.8
Average low °C (°F)	15.6 -60.1	16.8 -62.2	20.3 -68.5	24.1 -75.4	27.3 -81.1	27.6 -81.7	26.2 -79.2	25.6 -78.1	26.3 -79.3	25.9 -78.6	21 -69.8	17 -62.6	22.8 -73
Record low °C (°F)	8 -46.4	8.6 -47.5	12.6 -54.7	12.7 -54.9	18.5 -65.3	20.2 -68.4	17.8 -64	18 -64.4	17.7 -63.9	17.5 -63.5	11 -51.8	6.2 -43.2	6.2 -43.2

4.5 Estimated Demand

Almost, every house in the town is consisted of two bedrooms, one living room, a kitchen, and two bathrooms. The most used building materials are cement and bricks. The average area of the houses in there is between 300 and 500 square metres.

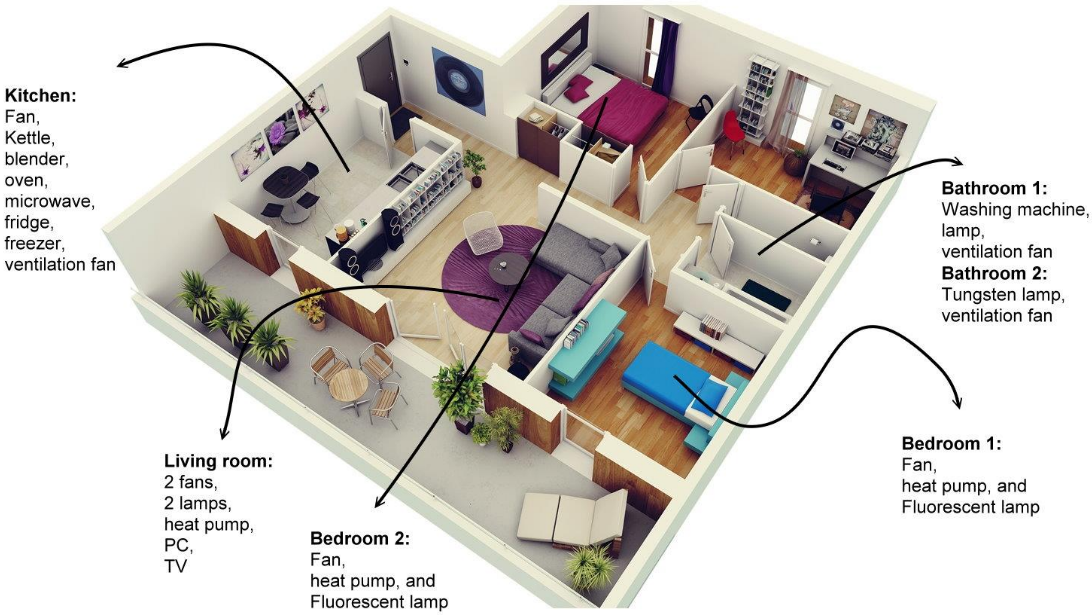


Figure 12: Average house map in El-Munawara town

The residential demand is affected by the appliances in the houses, the weather, and the human behaviour. The appliances in every house could be summarized roughly for every house as table (11) shows. But the human behaviour is something that could not be easily predicted, and it is usually happens in a random manner.

The appliances in residential use in there are various but the most common used ones can be summarized in table (11). To estimate the demand in the town, many considerations have been considered. First, the average size of houses has been taken to be a 2 bedrooms house with living room, 2 bathrooms and a kitchen. Secondly, the average appliances consumption has been taken to estimate the daily residential consumption.

Table 11: Average equipment demand from manufacturers' websites

Appliance	Electricity consumption (Wh)	Average
Ceiling fan	72	72
Tungsten lamp	70 - 100	85
Fluorescent lamp	6 - 10	8
Air conditioner	1500 - 3500	2500
Fridge	12 - 15	13.5
Freezer	44 - 50	47

Blender	350	350
Ventilation fan	3.4 – 6.8	5.1
PC	68 - 80	74
TV	75 - 100	87.5
Kettle	2900 - 3100	3000
Oven	2400 - 2600	2500
Microwave	2400 - 2600	2500
Washing machine	40 - 60	50

To estimate the demand in either a residential or office premises, a simple bottom-up approach can be used to do that. The approach is inspired by the methodology set out in CISBSE guide F and TM54, addressing the needs of designers and the wider industry more closely. (Menezes, A.C et all, 2014)

The data of the equipment demand has been used with the homes maps data to obtain the hourly residential demand in the town. Table (8) shows the demand in every part of the home according to the appliances in there.

Table 12: Homes appliances in each structure in the home

Component	Appliances	Power consumption Kwh
Bedroom No.1	Fan, heat pump, Tungsten lamp	72 + 2500 + 85 = 2657
Bedroom No.2	Fan, heat pump, lamp	72 + 2500 + 8 = 2580
Living room	2 fans, 2 lamps, heat pump, PC, TV	2(72) + 2(8) + 2500 + 74 + 87.5 = 2821.5
Kitchen	Fan, Kettle, blender, oven, microwave, fridge, freezer, ventilation fan	72 + 3000 + 350 + 2500 + 2500 + 13.5 + 47 + 5.1 = 8487.6
Bathroom 1	Washing machine, lamp, ventilation fan	50 + 85 + 5.1 = 140.1
Bathroom 2	lamp, ventilation fan	85 + 5.1 = 90.1

The human behaviour of consumption which is almost follow a stochastic manner was arranged in typical fixed periods of consumption that take the total power consumption and distribute it throughout the day. Figure (3) shows the average electricity consumption in houses in El-

Munawara town. Figure (12) shows a map of a typical house in El-Munawara town and the appliances in there.

After the data optimization for the human behaviour and the hourly equipment operation times the last residential demand profile can be seen in table (13)

Table 13: Optimized data according to the high consumption rates and the home appliances running times

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	5775	6500.4	7214.4	8088	8166	6979.2	8502.6	7603.2	7398	7045.2	5714.4	6446.4
2	5419.2	6384	8343.6	8508	8482.8	8070	8928	8904.6	9140.4	7261.2	5657.4	6660
3	6069.6	6857.4	8539.8	7576.8	7864.8	9181.2	8208.6	9264	8998.2	7591.8	6286.8	5800.2
4	6362.4	5992.2	8470.2	8260.2	8344.2	7294.8	8999.4	8198.4	8934.6	8925.6	5566.2	6333.6
5	6581.4	6075.6	7109.4	8874	7153.8	8991.6	8272.8	8614.2	7587	8167.8	5751.6	6871.2
6	6560.4	5861.4	9032.4	8483.4	8727.6	7735.8	8542.8	9064.2	7128	9111	6808.8	5523.6
7	10622	10221	13997	11916	15101	15031	12238	13495	12213	14715	11458	9298
8	14463.4	15979.6	18286.8	17640	18417	21562.8	19439	16268	21435.4	16626.4	14320.6	13759.2
9	14270.2	13598.2	21247.8	19215	20318.2	21186.2	17939.6	17936.8	20470.8	18450.6	15393	13738.2
10	14732.2	13543.6	16268	17477.6	20727	20329.4	20134.8	16647.4	18144	16357.6	13960.8	15019.2
11	13041	13613.6	20115.2	18065.6	18747.4	17446.8	17141.6	20070.4	16711.8	16427.6	15264.2	13441.4
12	12821.2	13141.8	19716.2	19812.8	16556.4	17029.6	16482.2	18009.6	16377.2	18208.4	15134	13045.2
13	12919.2	15687	19231.8	18683	16451.4	18208.4	21376.6	20367.2	17581.2	21012.6	15318.8	15709.4
14	14309.4	16062.2	17614.8	18898.6	17269	18271.4	19681.2	16563.4	20533.8	17785.6	15925	13566
15	13132	12730.2	20056.4	20332.2	19334	18818.8	16429	18799.2	20993	21417.2	14985.6	13484.8
16	13825	14798	18142.6	17693.2	18950.4	17469.2	19401.2	21415.8	21253.4	18862.2	15638	14331.8
17	13357.4	13519.8	18209.8	18200	16681	18012.4	18403	21176.4	16640.4	21065.8	13455.4	12748.4
18	15923.6	16053.8	17382.4	21170.8	20416.2	21550.2	18975.6	18772.6	18240.6	19493.6	13157.2	14886.2
19	11179	9205	12114	14971	13281	13858	12200	13617	14633	12411	10001	9153
20	5578.8	6468.6	8856.6	8467.8	8122.8	9121.2	8991.6	7984.8	9191.4	7659	5775	6222.6
21	6128.4	6262.2	8923.8	8043.6	7697.4	7615.8	7462.2	7719.6	7812	8025.6	6672	5442.6
22	5667	6569.4	8956.8	8500.2	8385	7288.8	9070.8	7865.4	7871.4	7876.8	6382.8	6450.6
23	6079.2	5607	7565.4	8733.6	8031	8945.4	8019	7846.8	8384.4	8389.2	5710.2	6318.6
24	6660	5748.6	7586.4	8768.4	7069.8	8746.8	8863.8	8332.8	8541.6	8848.2	5902.8	6241.2

Figure (13) and (14) shows the optimized demand data distribution in both cases of winter and summer.

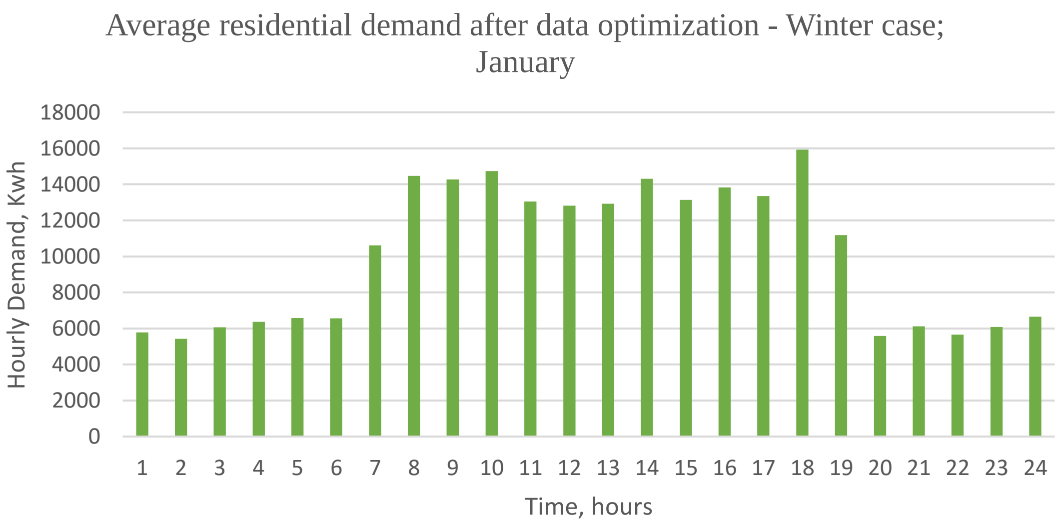


Figure 13: data after correction for the human behaviour and the operation times for the different household equipment – winter case

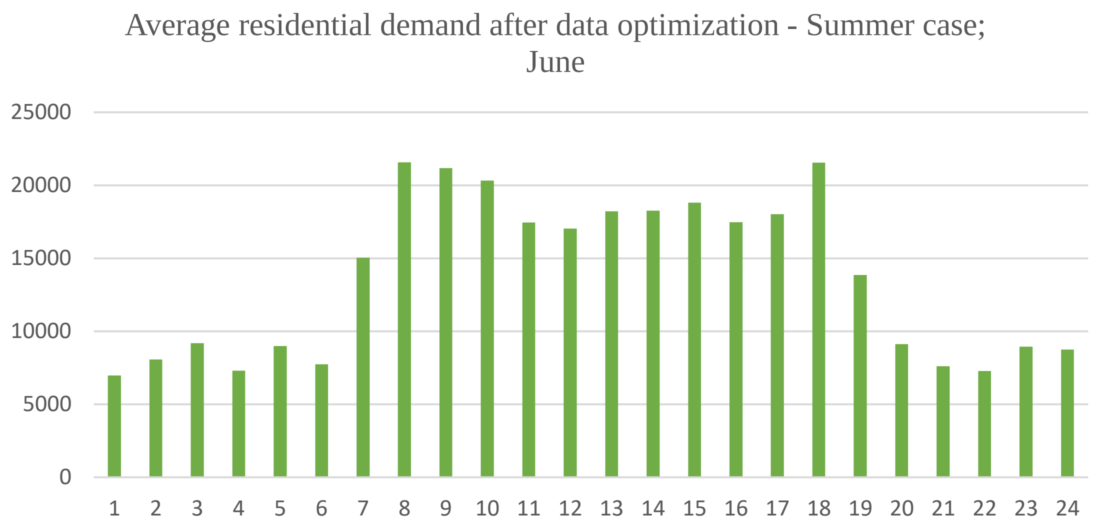


Figure 14: Data after correction for the human behaviour and the operation times for the different household equipment – Summer case

5 Schools and mosque demand profile:

The electrical demand in schools was calculated using a data that was collected through a survey from one of the schools. And due to the difficulty in getting in touch with the 2 other schools' staff who would have support us with the required data, the demand was estimated.

The school which the survey was made to is called "El-Munawara Boys Primary School". Note that in Sudan the primary education level is consisted out of 8 classes, not 6 like the British primary school system.

El-Munawara Boys Primary School is consisted of 8 classrooms, 6 offices, buffet room and 25 toilet and a very big yard. The estimations of the demand for the 3 schools are given in table (14)

Table 14: Electricity demand in 3 schools in El-Munawara town in Kilo watt hours

Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
00:00	248	231	303	297	270	269	267	287	303	277	235	251
01:00	217	230	284	301	282	298	285	272	295	292	223	237
02:00	249	242	283	283	275	275	270	271	272	273	246	232
03:00	244	247	281	275	278	284	294	280	278	297	239	235
04:00	239	229	298	275	286	272	276	301	297	269	225	226
05:00	237	228	290	298	303	281	300	295	271	280	229	229
06:00	228	253	285	292	292	280	294	281	302	286	237	246
07:00	246	216	274	288	279	296	299	292	296	289	227	238
08:00	243	227	273	285	268	286	285	283	300	268	244	232
09:00	237	218	300	276	299	293	288	293	270	268	221	219
10:00	248	232	269	283	269	299	273	304	292	296	245	250
11:00	230	226	273	268	281	297	289	300	278	274	227	222
12:00	227	238	291	290	284	275	298	291	269	273	237	250
13:00	216	220	287	281	291	302	304	290	286	298	226	216
14:00	217	248	273	278	293	291	301	273	285	287	250	235
15:00	222	231	295	297	277	284	289	289	268	277	248	238
16:00	233	226	277	269	289	275	285	287	273	285	219	237
17:00	231	218	267	294	294	280	300	275	277	267	249	248
18:00	221	251	270	304	301	282	268	280	300	291	251	248
19:00	223	244	292	288	283	280	288	269	288	269	243	246
20:00	249	232	302	289	298	283	285	299	281	282	234	220
21:00	217	249	280	269	298	287	281	278	304	276	245	234
22:00	227	230	290	277	273	286	285	274	289	273	230	244
23:00	221	235	299	275	267	289	300	282	290	272	251	224

According to El-Munawara Primary School manager Mahmud, A (Mahmud, A. 2018), the electricity consumption in the schools is 70% higher in peak hours when the school is open than the consumption when the school is closed at the evening times. From this point table (15) was made.

Table 15: Optimized schools electricity demand

Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	74.4	69.3	90.9	89.1	81	80.7	80.1	86.1	90.9	83.1	70.5	75.3
2	65.1	69	85.2	90.3	84.6	89.4	85.5	81.6	88.5	87.6	66.9	71.1
3	74.7	72.6	84.9	84.9	82.5	82.5	81	81.3	81.6	81.9	73.8	69.6
4	73.2	74.1	84.3	82.5	83.4	85.2	88.2	84	83.4	89.1	71.7	70.5
5	71.7	68.7	89.4	82.5	85.8	81.6	82.8	90.3	89.1	80.7	67.5	67.8
6	402.9	387.6	493	506.6	515.1	477.7	510	501.5	460.7	476	389.3	389.3
7	387.6	430.1	484.5	496.4	496.4	476	499.8	477.7	513.4	486.2	402.9	418.2
8	418.2	367.2	465.8	489.6	474.3	503.2	508.3	496.4	503.2	491.3	385.9	404.6
9	413.1	385.9	464.1	484.5	455.6	486.2	484.5	481.1	510	455.6	414.8	394.4
10	402.9	370.6	510	469.2	508.3	498.1	489.6	498.1	459	455.6	375.7	372.3
11	421.6	394.4	457.3	481.1	457.3	508.3	464.1	516.8	496.4	503.2	416.5	425
12	391	384.2	464.1	455.6	477.7	504.9	491.3	510	472.6	465.8	385.9	377.4
13	385.9	404.6	494.7	493	482.8	467.5	506.6	494.7	457.3	464.1	402.9	425
14	367.2	374	487.9	477.7	494.7	513.4	516.8	493	486.2	506.6	384.2	367.2
15	368.9	421.6	464.1	472.6	498.1	494.7	511.7	464.1	484.5	487.9	425	399.5
16	66.6	69.3	88.5	89.1	83.1	85.2	86.7	86.7	80.4	83.1	74.4	71.4
17	69.9	67.8	83.1	80.7	86.7	82.5	85.5	86.1	81.9	85.5	65.7	71.1
18	69.3	65.4	80.1	88.2	88.2	84	90	82.5	83.1	80.1	74.7	74.4
19	66.3	75.3	81	91.2	90.3	84.6	80.4	84	90	87.3	75.3	74.4
20	66.9	73.2	87.6	86.4	84.9	84	86.4	80.7	86.4	80.7	72.9	73.8
21	74.7	69.6	90.6	86.7	89.4	84.9	85.5	89.7	84.3	84.6	70.2	66
22	65.1	74.7	84	80.7	89.4	86.1	84.3	83.4	91.2	82.8	73.5	70.2
23	68.1	69	87	83.1	81.9	85.8	85.5	82.2	86.7	81.9	69	73.2
24	66.3	70.5	89.7	82.5	80.1	86.7	90	84.6	87	81.6	75.3	67.2

Another factor that affects the demand in the schools in the summer holiday which lasts for three months and takes a place in Sudan between March and May. The demand in the summer break is usually less the normal demand by 80% because the schools are normally fully closed in summer and rarely they open them for 1 or 2 staff meetings. Table (16) was made according to the effect of the summer break:

Table 16: Final optimised schools electricity demand in Kwh, the demand is optimized according to the peak hours in the schools and the summer holiday which lasts for 3 months.

Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
00:00	74.4	69.3	60.6	59.4	54	80.7	80.1	86.1	90.9	83.1	70.5	75.3
01:00	65.1	69	56.8	60.2	56.4	89.4	85.5	81.6	88.5	87.6	66.9	71.1
02:00	74.7	72.6	56.6	56.6	55	82.5	81	81.3	81.6	81.9	73.8	69.6
03:00	73.2	74.1	56.2	55	55.6	85.2	88.2	84	83.4	89.1	71.7	70.5
04:00	71.7	68.7	59.6	55	57.2	81.6	82.8	90.3	89.1	80.7	67.5	67.8
05:00	402.9	387.6	58	59.6	60.6	477.7	510	501.5	460.7	476	389.3	389.3
06:00	387.6	430.1	57	58.4	58.4	476	499.8	477.7	513.4	486.2	402.9	418.2
07:00	418.2	367.2	54.8	57.6	55.8	503.2	508.3	496.4	503.2	491.3	385.9	404.6
08:00	413.1	385.9	54.6	57	53.6	486.2	484.5	481.1	510	455.6	414.8	394.4
09:00	402.9	370.6	60	55.2	59.8	498.1	489.6	498.1	459	455.6	375.7	372.3
10:00	421.6	394.4	53.8	56.6	53.8	508.3	464.1	516.8	496.4	503.2	416.5	425
11:00	391	384.2	54.6	53.6	56.2	504.9	491.3	510	472.6	465.8	385.9	377.4
12:00	385.9	404.6	58.2	58	56.8	467.5	506.6	494.7	457.3	464.1	402.9	425
13:00	367.2	374	57.4	56.2	58.2	513.4	516.8	493	486.2	506.6	384.2	367.2
14:00	368.9	421.6	54.6	55.6	58.6	494.7	511.7	464.1	484.5	487.9	425	399.5
15:00	66.6	69.3	59	59.4	55.4	85.2	86.7	86.7	80.4	83.1	74.4	71.4
16:00	69.9	67.8	55.4	53.8	57.8	82.5	85.5	86.1	81.9	85.5	65.7	71.1
17:00	69.3	65.4	53.4	58.8	58.8	84	90	82.5	83.1	80.1	74.7	74.4
18:00	66.3	75.3	54	60.8	60.2	84.6	80.4	84	90	87.3	75.3	74.4
19:00	66.9	73.2	58.4	57.6	56.6	84	86.4	80.7	86.4	80.7	72.9	73.8
20:00	74.7	69.6	60.4	57.8	59.6	84.9	85.5	89.7	84.3	84.6	70.2	66
21:00	65.1	74.7	56	53.8	59.6	86.1	84.3	83.4	91.2	82.8	73.5	70.2
22:00	68.1	69	58	55.4	54.6	85.8	85.5	82.2	86.7	81.9	69	73.2
23:00	66.3	70.5	59.8	55	53.4	86.7	90	84.6	87	81.6	75.3	67.2
Total schools electricity consumption	**4931.6**	**4908.7**	**1367.2**	**1366.4**	**1366**	**6113.2**	**6174.6**	**6116.6**	**6047.8**	**5962.3**	**4984.5**	**4968.9**
Average schools consumption	*1643.87*	*1636.23*	*455.733*	*455.467*	*455.333*	*2037.73*	*2058.2*	*2038.87*	*2015.93*	*1987.43*	*1661.5*	*1656.3*

The appliances and equipment in each school are almost the same. Table (17) shows the appliances in each school.

Table 17: School appliances and equipment, (Hisham, I. 2018)

Appliance	**Number**	**Electricity consumption wh/1000hr**
Fridge	4	13.5
Freezer	4	47
Microwave oven	6	2500
Ceiling fan	34	72
Water-based air conditioner	20	2060

Microphone sound system	1	15000
Cookers (in the school buffet)	2	810

The mosque demand is affected by the daily five prayers that the residents do every day in there. The mosque is always open for an hour for every prayer. Table (18) shows the five prayers and their times.

Table 18: Muslim prayers and its time, the mosque is nearly open for an hour at any prayer

Prayer	Time
Fajr	5:00
Zhuhr	13:30
Asr	16:30
Magrib	19:15
Isha	20:30

The appliances and equipment in the mosque can be seen in table (19), (Al-sadiq, 2018). The equipment operation times in the mosque are controlled by the prayers times and the Ramadan month.

Table 19: Mosque equipments

Appliance	Number	Electricity consumption wh/1000hr
Fridge	1	13.5
Microwave oven	1	2500
Ceiling fan	34	72
Heat pumps (Air conditioner)	20	3000
Microphone sound system	1	15000

The average monthly mosque electricity consumption is 1000 to 1500 Kwh in the winter and 2500 to 3000 Kwh in the summer. The human behaviour has not a significant effect in the mosque case, because the mosque is open in regular times and the consumption is nearly fixed.

Another factor that affect the demand in the mosque is Ramadan month, the month in which a huge electricity consumption happens throughout the day due to the high cooling loads.

Table 20: Mosque electricity consumption optimized to the opening times during the 5 Muslims prayers and Ramadan month

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
00:00	4.1	6.2	11	12.2	112	12.1	12.1	11.9	11.2	12.1	4.3	6.1
01:00	5.7	4.4	11	10.4	116	10.8	11.3	10.9	11.3	11.7	5.4	5.5
02:00	5.3	4.4	11	12	124	11.9	11	12	12.3	12.4	4.2	5.3
03:00	5.7	5.4	12	10.4	108	10.5	10.7	11.1	11.7	12.4	5.8	4.9
04:00	4.3	5.7	12	11.9	104	12	11	10.4	12.1	10.4	5.1	5.6
05:00	147.5	132.5	310	295	287.5	272.5	310	295	277.5	280	150	120
06:00	4.7	4.8	12	10.4	307.5	10.4	11.8	11.2	12	11.1	5.7	6.1
07:00	4.2	5.5	12.2	10.4	295	11	10.9	11.8	10.4	11.9	5.9	6.1
08:00	6.1	5.4	11.8	11.7	290	12.5	10.6	10.9	12	10.5	4.8	5.7
09:00	5.8	5.8	10.8	12.1	270	10.5	11.8	12.5	12.4	11.5	5.8	5.6
10:00	4.8	4.3	10.7	11.6	277.5	10.7	11.2	10.6	11.1	10.8	5.4	5.6
11:00	4.2	4.9	12.3	11.1	312.5	12.5	11	11.7	11.2	10.4	5.8	6.1
12:00	4.2	4.5	11	10.6	262.5	11.4	11.4	10.5	10.7	10.8	5.6	6.1
13:00	155	122.5	290	312.5	292.5	267.5	265	302.5	275	290	140	125
14:00	59	53	120	125	295	125	125	121	121	104	41	49
15:00	54	46	117	104	277.5	122	117	111	106	111	46	54
16:00	150	137.5	265	267.5	292.5	312.5	310	267.5	310	270	117.5	147.5
17:00	43	46	112	107	285	125	122	113	116	111	50	60
18:00	48	59	104	118	292.5	108	104	117	111	113	55	41
19:00	102.5	125	277.5	307.5	267.5	307.5	282.5	292.5	275	265	107.5	140
20:00	120	102.5	290	285	275	265	270	312.5	275	302.5	125	130
21:00	105	102.5	310	265	260	272.5	282.5	277.5	305	277.5	142.5	155
22:00	43	52	105	110	297.5	120	111	119	116	116	44	47
23:00	54	58	113	121	280	105	119	116	111	107	42	50
Monthly consumption	1140.1	1097.8	2551.3	2552.3	5981.5	2538.8	2552.8	2580	2536.9	2483	1124.3	1187.2

5.1 *Restaurants, supermarkets and bakeries demand:*

The town has 3 restaurants, 3 supermarkets and 2 bakeries. The demand of each was estimated through the average daily consumption and the expert consultation who works in the Sudanese Electricity Distribution Company.

The average restaurant hourly consumption varies between 1850 to 1950 Kwh in the summer and 1700 to 1800 Kwh in the winter. The effect of the opening hours and the peak times was estimated. All the 3 restaurants open at 10 o'clock in the morning and closes at 11 PM in the evening.

Restaurant name	*Opening hours*	*Cooking facilities type*	*Capacity*
Al-Nawras resaurant	10:00 – 23:00	Electric	400 meals per day
Jerusalem Restaurant	10:00 – 00:00	Gas	500 meals per day

Al-Shaygi Restaurant	10:00 – 00:00	Biomass	250 meals per day

According to the restaurants opening hours for every restaurant and cooking facilities type. The demand profile was made as in table (21).

Most of the demand in the restaurant is by the fridges and freezers in the food storage area and due to the electric cooking facilities.

Due to the “partially” stochastic manner that the demand follows in restaurants which can be affected by the nearby events and the weather and many factors beyond mention, random number between the lowest and highest demands in summer and winter were taken to shape the demand for the restaurants in order to simulate the demand in the software modeller.

Table 21: Restaurants estimated demand, the demand was estimated according to the highest and lowest demand values in summer and winter. The effects of peak hours and opening hours were considered as well.

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
00:00	181.6	175.2	194.4	191.2	196.8	190.4	194.4	188.8	197.6	192	180	180
01:00	182.4	177.6	192	192.8	188	192.8	191.2	192	190.4	192.8	179.2	176
02:00	176.8	178.4	189.6	193.6	190.4	188.8	193.6	196	192.8	192.8	180	180.8
03:00	182.4	173.6	195.2	196	196	189.6	193.6	197.6	191.2	192.8	181.6	181.6
04:00	175.2	176.8	192	194.4	191.2	196.8	191.2	191.2	195.2	194.4	182.4	180.8
05:00	173.6	178.4	195.2	194.4	188.8	191.2	192.8	193.6	189.6	192.8	176	178.4
06:00	180.8	182.4	195.2	196.8	195.2	188.8	189.6	196	192	192	176.8	173.6
07:00	175.2	177.6	188.8	189.6	192	188	193.6	188.8	193.6	195.2	180.8	176
08:00	174.4	172.8	193.6	197.6	194.4	192.8	194.4	188	192	192.8	176.8	172.8
09:00	287.3	295.1	319.8	318.5	315.9	310.7	321.1	309.4	317.2	308.1	286	282.1
10:00	282.1	291.2	310.7	310.7	315.9	318.5	310.7	312	312	306.8	292.5	296.4
11:00	287.3	292.5	305.5	318.5	309.4	306.8	317.2	319.8	309.4	313.3	282.1	283.4
12:00	288.6	280.8	315.9	318.5	312	309.4	319.8	315.9	315.9	317.2	282.1	292.5
13:00	291.2	286	315.9	317.2	318.5	317.2	305.5	319.8	309.4	308.1	282.1	280.8
14:00	289.9	284.7	317.2	308.1	312	321.1	305.5	318.5	313.3	318.5	284.7	293.8
15:00	289.9	287.3	314.6	306.8	321.1	318.5	312	314.6	319.8	310.7	296.4	284.7
16:00	282.1	284.7	319.8	308.1	314.6	315.9	321.1	305.5	309.4	318.5	288.6	293.8
17:00	293.8	287.3	309.4	319.8	319.8	309.4	314.6	319.8	306.8	309.4	292.5	283.4
18:00	284.7	292.5	315.9	305.5	319.8	321.1	305.5	308.1	308.1	306.8	293.8	291.2
19:00	286	283.4	306.8	305.5	321.1	319.8	305.5	313.3	310.7	308.1	286	287.3
20:00	287.3	296.4	319.8	313.3	306.8	317.2	309.4	315.9	319.8	318.5	291.2	295.1
21:00	288.6	295.1	321.1	305.5	308.1	318.5	315.9	315.9	305.5	321.1	287.3	286
22:00	292.5	289.9	306.8	313.3	314.6	312	318.5	315.9	308.1	305.5	293.8	280.8
23:00	194.4	203.4	211.5	211.5	215.1	212.4	222.3	216	212.4	221.4	198.9	199.8
Total consumption	**5828.1**	**5843.1**	**6346.7**	**6327.2**	**6357.5**	**6347.7**	**6339**	**6352.4**	**6312.2**	**6329.6**	**5851.6**	**5831.1**
Average restaurant monthly consumption	*1942.7*	*1947.7*	*2115.57*	*2109.07*	*2119.17*	*2115.9*	*2113*	*2117.47*	*2104.07*	*2109.87*	*1950.53*	*1943.7*

On top of the opening times, the supermarkets’ demand patter is controlled by the high number of the fridges and freezers in each supermarket, the lighting and the HVAC systems as well.

Table (22) shows the number of the fridges and freezers in each supermarket and the HVAC systems.

Table 22: Supermarkets appliances in El-Munawara town, Khartoum, Sudan

Supermarket	*Number of fridges*	*Number of freezers*	*Opening times*	*HVAC system*
Sarah Centre	24	10	8:00 – 00:00	3 Heat pumps
Intifadah Supermarket	10	4	9:00 – 23:00	1 heat pump and 2 ceiling fans
Mohammed Supermarket	18	8	8:00 – 23:00	4 Ceiling fans and 1 heat pump

According to the average daily consumption of the Super market and from the expert consultation that was made through the phone call, the average monthly supermarket electricity consumption is 1500 to 1700 Kwh in summer and 1200 to 1400 Kwh in winter.

According to the average monthly consumption and the opening hours, the demand for the 3 supermarkets was estimated. From 8:00 until one hour before the midnight the demand is always 40% higher than the average hourly demand. And between 8:00 AM and 9:00 an increase of 10% in the demand was predicted according to the appliances and equipment operation times.

All the supermarkets in the town use fluorescent lights and none of them is taking advantage of the natural sunlight. Two of the owners of these supermarkets do not measure and track their supermarket energy consumption and efficiency as they said, they just know the overall energy consumption. One owner said they established an effective operations and maintenance program to identify and address equipment issues before they become energy-wasting problems.

The LED lighting in the supermarkets is expected to reduce the lighting energy consumption by 40 to 50%.

Table (23) shows the values of the electricity consumption in the 3 supermarkets in El-Munawara town.

Table 23: Supermarkets electricity demand in Kwh, the data is optimized to the opening hours of the shops.

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
00:00	407.4	379.2	454.2	478.8	479.4	480.6	484.2	450	476.4	456.6	393.6	375
01:00	377.4	381.6	457.8	469.2	469.2	476.4	478.2	453	480.6	455.4	380.4	397.2
02:00	392.4	399.6	451.2	486	472.8	478.2	465.6	466.8	486	485.4	402	393.6
03:00	400.2	388.2	476.4	474.6	483	476.4	476.4	482.4	465.6	464.4	376.2	396.6
04:00	385.2	403.2	474.6	476.4	473.4	465	457.8	478.2	473.4	469.2	391.8	393.6
05:00	396.6	391.8	469.2	472.8	465.6	472.2	462	453.6	450.6	477.6	397.2	411
06:00	403.8	381	486.6	476.4	470.4	484.2	463.2	457.2	472.2	483.6	408.6	411
07:00	384.6	384.6	454.8	475.8	467.4	457.2	470.4	477	474.6	476.4	397.2	385.8
08:00	687.5	702.9	863.5	884.4	829.4	848.1	876.7	869	878.9	860.2	742.5	740.3
09:00	956.2	911.4	1107.4	1096.2	1085	1097.6	1114.4	1048.6	1052.8	1085	918.4	922.6
10:00	931	953.4	1111.6	1071	1068.2	1125.6	1108.8	1104.6	1079.4	1059.8	925.4	956.2
11:00	926.8	887.6	1068.2	1128.4	1069.6	1121.4	1096.2	1120	1096.2	1122.8	926.8	952
12:00	918.4	884.8	1093.4	1080.8	1113	1115.8	1108.8	1079.4	1127	1131.2	929.6	939.4
13:00	877.8	960.4	1117.2	1065.4	1117.2	1085	1076.6	1086.4	1113	1125.6	953.4	928.2
14:00	949.2	894.6	1113	1132.6	1085	1069.6	1061.2	1085	1129.8	1085	915.6	961.8
15:00	884.8	943.6	1079.4	1079.4	1124.2	1059.8	1110.2	1076.6	1079.4	1052.8	952	954.8
16:00	875	910	1083.6	1113	1134	1061.2	1066.8	1106	1093.4	1122.8	961.8	956.2
17:00	890.4	929.6	1079.4	1094.8	1094.8	1061.2	1066.8	1066.8	1134	1083.6	926.8	908.6
18:00	886.2	925.4	1110.2	1059.8	1115.8	1048.6	1071	1104.6	1051.4	1059.8	883.4	905.8
19:00	933.8	932.4	1103.2	1083.6	1075.2	1110.2	1129.8	1114.4	1062.6	1129.8	918.4	903
20:00	875	925.4	1111.6	1066.8	1089.2	1135.4	1050	1048.6	1113	1132.6	922.6	953.4
21:00	910	900.2	1052.8	1111.6	1093.4	1136.8	1089.2	1124.2	1073.8	1125.6	887.6	907.2
22:00	950.6	918.4	1066.8	1061.2	1122.8	1087.8	1080.8	1111.6	1122.8	1050	915.6	875
23:00	684	687	780	768	754	750	803	789	806	790	642	641
Total supermarkets consumption	**17284.3**	**17376.3**	**20666.1**	**20707**	**20752**	**20704.3**	**20668.1**	**20653**	**20792.9**	**20785.2**	**17468.9**	**17569.3**
Average supermarket consumption	*5761.43*	*5792.1*	*6888.7*	*6902.33*	*6917.33*	*6901.43*	*6889.37*	*6884.33*	*6930.97*	*6928.4*	*5822.97*	*5856.43*

There are 2 bakeries in the town, one works by electricity and the other one works by biomass. The electric oven that is used to bake bread in the electric bakery is 4.5 KW load. Both bakeries open at 8:00 until 22:00, but they started baking the bakeries since 4:00 AM in the morning. When the bakery is closed at the evening, only 2 % of the day electrical consumption is required to run the equipment in there which are represented by 2 small fridges for the staff snack and some fly's repellents.

Table 24: 3 Bakeries optimized electricity demand in El-Munawara town, the demand was optimized to the opening hours of the bakeries

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
00:00	16.7	16.66	16.8	16.7	16.84	16.84	16.72	16.68	16.74	16.76	16.66	16.8
01:00	16.76	16.78	16.76	16.8	16.84	16.78	16.84	16.76	16.66	16.82	16.82	16.66
02:00	16.82	16.8	16.66	16.76	16.7	16.7	16.76	16.68	16.84	16.68	16.76	16.68
03:00	16.7	16.68	16.68	16.72	16.78	16.74	16.8	16.72	16.82	16.82	16.66	16.72
04:00	841	837	842	835	833	842	836	837	838	840	837	841
05:00	833	836	835	835	842	836	842	835	839	838	838	833
06:00	834	841	841	840	840	840	838	835	834	840	838	836
07:00	833	839	839	838	840	837	837	835	833	842	840	837
08:00	839	833	838	833	836	834	836	840	840	839	840	837
09:00	839	840	841	841	839	839	838	839	838	833	837	835
10:00	836	840	835	833	833	841	840	835	835	842	842	839
11:00	833	835	842	841	836	840	835	836	835	840	838	841
12:00	840	838	842	835	839	835	839	840	837	838	842	833
13:00	834	833	834	833	834	841	837	842	839	837	836	837
14:00	841	835	836	840	833	833	834	833	840	835	833	836
15:00	838	835	842	836	833	836	839	842	841	841	841	842
16:00	833	837	840	838	834	835	835	841	840	839	839	840
17:00	835	839	835	842	835	836	835	840	842	834	840	837
18:00	838	840	842	833	833	835	833	833	838	842	836	837
19:00	841	841	833	837	842	840	835	835	841	836	833	835
20:00	836	834	836	838	835	842	835	838	835	841	839	837
21:00	836	835	839	839	837	835	835	842	835	841	841	834
22:00	16.76	16.82	16.7	16.84	16.74	16.74	16.76	16.72	16.78	16.76	16.68	16.82
23:00	16.76	16.74	16.82	16.8	16.82	16.76	16.74	16.68	16.8	16.68	16.82	16.78
Bakery Monthly consumption	**15160.5**	**15168.48**	**15192.42**	**15167.62**	**15154.72**	**15177.56**	**15159.62**	**15178.24**	**15180.64**	**15198.52**	**15190.4**	**15167.46**

The biomass bakery uses biomass to bake it bakeries which reduces its electricity consumption to be as that of a house. The electricity consumption is occurring by lighting and some small fridges in the working place. This consumption was added to the consumption of the electric bakery to shape the total demand of the bakeries. Table (25) shows the total bakeries demand in the town.

Table 25: Bakeries total demand, 2 electric bakeries and biomass bakery

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
00:00	32.5	34.4	36.5	38.8	39.2	35.9	40.0	37.5	37.0	36.0	32.3	34.4
01:00	31.6	34.2	39.6	40.0	40.0	38.8	41.2	41.1	41.6	36.7	32.3	34.9
02:00	33.4	35.5	40.0	37.5	38.2	41.8	39.2	42.0	41.4	37.4	33.9	32.5
03:00	34.1	33.1	39.8	39.3	39.6	36.7	41.4	39.1	41.2	41.2	31.9	34.0
04:00	859.0	853.6	861.4	859.2	852.5	866.6	858.6	860.5	858.7	862.3	852.7	859.8
05:00	850.9	852.0	859.7	858.2	865.8	857.1	865.3	859.8	858.5	862.9	856.6	848.1
06:00	851.4	857.8	863.9	859.5	864.8	864.6	858.1	857.1	854.0	864.1	856.8	851.2
07:00	849.9	857.7	860.4	858.7	861.6	862.2	859.8	854.0	858.1	861.5	856.8	853.1
08:00	855.7	848.9	862.9	855.5	859.8	858.8	857.0	861.0	864.0	860.6	858.0	853.1
09:00	856.3	855.9	860.0	861.5	863.3	862.8	861.6	858.5	859.2	852.2	853.3	852.6
10:00	851.3	855.9	858.6	854.2	855.0	861.4	860.1	858.5	854.6	861.2	859.9	854.7
11:00	848.0	850.4	865.1	864.2	855.4	859.9	854.3	857.1	854.2	861.3	855.7	856.3
12:00	855.1	856.4	864.5	856.9	858.3	856.3	864.0	863.8	857.6	862.6	859.9	851.4
13:00	850.8	851.8	854.6	855.1	854.2	862.4	860.0	861.4	863.0	857.8	854.6	852.9
14:00	856.4	849.9	859.5	863.8	855.6	855.0	853.2	855.0	864.6	860.1	850.5	851.8
15:00	854.2	852.3	863.2	856.7	855.2	856.5	861.7	867.1	865.9	863.1	859.3	858.8
16:00	848.6	852.8	861.3	859.3	853.5	856.1	856.5	865.8	859.5	863.7	854.8	854.9
17:00	853.6	857.8	855.4	866.8	858.9	861.2	857.2	862.0	863.4	856.8	855.4	854.4
18:00	856.3	855.1	861.9	857.5	854.8	857.7	853.0	855.3	862.0	862.3	852.4	852.0
19:00	856.2	858.7	857.2	860.1	864.2	864.9	859.6	856.8	866.1	856.9	848.8	852.0
20:00	852.7	851.1	860.4	860.0	856.0	862.8	855.4	859.1	856.3	862.9	857.2	851.9
21:00	851.5	852.9	863.5	862.2	859.9	854.9	859.8	863.5	856.5	862.5	858.4	851.6
22:00	33.4	32.1	37.4	40.7	38.7	41.2	38.7	38.2	39.7	39.7	32.3	34.1
23:00	35.0	32.4	37.5	40.8	36.1	40.7	41.0	39.4	40.1	40.9	32.9	33.8
Total bakeries' demand	**15557.9**	**15572.9**	**15724.3**	**15706.5**	**15680.5**	**15716.5**	**15696.7**	**15713.7**	**15717.3**	**15726.8**	**15596.9**	**15564.4**
Average bakery consumption	7778.9	7786.4	7862.1	7853.3	7840.3	7858.3	7848.3	7856.8	7858.6	7863.4	7798.4	7782.2

5.2 The total demand:

By taking the summation of all the demands, the total demand was estimated. Table (26) shows the total demand for El-Munawara town. This demand would be used in the software simulator as a load with the reasonable and available renewable energy resources to find the optimum supply means. The total demand would be subjected to variation value between 5 to 10% which expresses about the possible fluctuations in the values of the consumption.

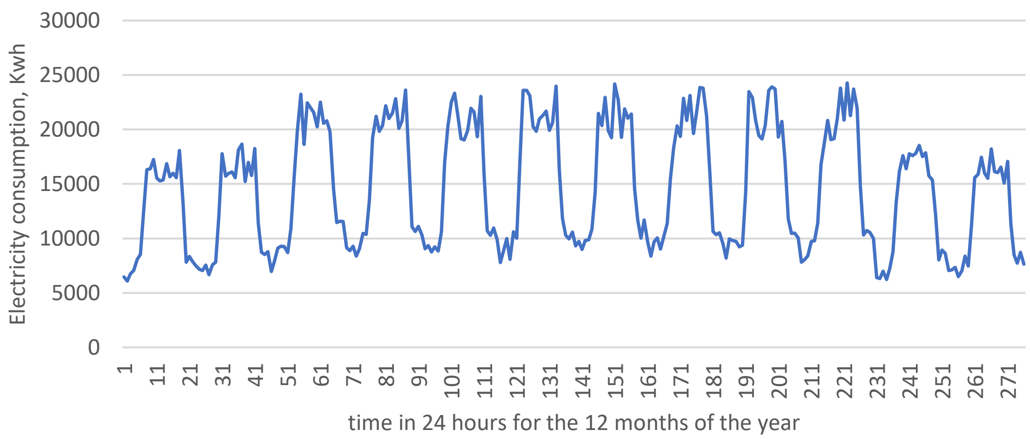


Figure 15: Demand fluctuations in El-Munawara town in the 12 months of the year

Table 26: Total estimated demand for El-Munawara town

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
00:00	6475.0	7164.7	7971.1	8868.4	9047.4	7778.9	9313.4	8377.5	8211.1	7825.0	6395.1	7117.2
01:00	6081.4	7050.8	9100.8	9280.6	9352.4	8878.2	9735.4	9683.2	9952.8	8045.4	6321.6	7344.7
02:00	6752.2	7547.9	9288.2	8362.5	8745.2	9984.4	8999.0	10062.1	9812.3	8401.7	6980.7	6482.0
03:00	7058.0	6666.6	9249.8	9035.5	9226.4	8093.2	9809.7	9012.6	9727.7	9725.5	6233.4	7021.2
04:00	8076.8	7583.6	8709.0	10470.9	8832.1	10613.6	9874.2	10244.8	9215.5	9784.8	7251.1	8378.8
05:00	8531.9	7803.7	10924.5	10363.4	10595.9	10006.5	10882.9	11367.7	9364.9	11400.3	8777.9	7470.4
06:00	12450.3	12077.1	15611.7	13517.5	16997.3	17055.0	14260.5	15494.2	14256.6	16752.0	13308.8	11158.1
07:00	16295.5	17772.2	19857.8	19232.1	20288.8	23584.4	21482.0	18296.0	23475.3	18662.7	16147.2	15584.8
08:00	16407.0	15714.1	23234.2	21221.2	22545.4	23584.6	20362.8	20346.8	22927.7	20830.3	17589.9	15904.5
09:00	17240.7	15982.4	18626.0	19821.1	23321.0	23109.1	22933.3	19374.5	20844.6	19070.0	16400.0	17454.4
10:00	15531.8	16112.8	22460.6	20369.7	21317.8	20271.3	19896.5	22872.9	19465.3	19169.4	17763.9	15979.3
11:00	15278.5	15561.4	22021.9	22188.6	19159.5	19835.1	19252.2	20828.2	19120.8	20982.0	17590.3	15520.4
12:00	15371.4	18118.1	21574.8	21007.8	19054.0	20968.8	24187.2	23131.5	20349.7	23798.5	17798.9	18223.8
13:00	16851.4	18656.9	20249.9	21505.0	19909.6	21316.9	22705.1	19626.5	23580.4	20873.7	18539.3	16120.1
14:00	15655.4	15234.0	22520.7	22817.3	21940.2	21684.2	19285.6	21642.8	23906.2	24272.7	17502.4	16040.7
15:00	15974.5	16996.5	20575.8	20099.5	21583.8	19911.2	21888.8	23871.8	23704.9	21282.9	17866.1	16555.5
16:00	15583.0	15772.6	20794.9	20801.7	19333.4	20640.6	21042.9	23807.3	19294.6	23726.3	15743.8	15071.9
17:00	18073.7	18239.9	19792.0	23618.0	23033.5	23991.0	21426.2	21216.7	20743.9	21934.5	15356.6	17067.0
18:00	13320.5	11412.3	14560.0	17372.6	15924.1	16278.0	14613.9	16086.0	17055.5	14840.2	12160.9	11317.4
19:00	7824.2	8741.3	11459.7	11082.1	10707.4	11807.6	11655.4	10642.5	11792.2	10299.5	8008.6	8478.7
20:00	8338.1	8507.2	11566.0	10626.5	10284.0	10281.1	10032.5	10345.4	10460.4	10726.7	8938.2	7739.0
21:00	7887.2	8794.8	11560.2	11098.3	10966.0	9957.6	11702.5	10529.9	10503.4	10546.3	8632.1	8720.6
22:00	7466.8	6968.4	9139.4	10314.2	9859.2	10592.2	9653.5	9513.7	10057.7	9982.3	7064.9	7628.7
23:00	7693.7	6799.9	8788.2	9964.7	8408.4	9941.6	10139.1	9577.8	9798.1	10089.1	6893.9	7233.0
Monthly	286219.0	291279.4	369637.2	373039.2	370432.7	380165.3	375134.6	375952.5	377621.7	373021.9	295265.8	285612.3

5.3 *Software selection*

From a plethora available software, a modeller has to be selected to simulate the demand and supply and to analyse them for this study.

In a study that was done in The University of Strathclyde, a methodology of how to select the most appropriate modelling tool for energy supply designs. The study considers four steps to identify the optimum software modeller: (A. Lyden, et al)

- An Initial screening to find the potential optimum software
- Categorization and filtering of software characteristics and capabilities
- Development of software selection using tables
- Demonstrating of software selection through a case study

More than 50 modelling tools were tested according to a set of criteria to find the potential suitability for all of them. A tool passes the criteria if it could pass the test criteria (A. Lyden, et al)

The study ended up with 15 software modellers to be the most suitable modellers for community scale projects. Two of these 15 were discarded because of the lack and difficulty of accessing the required information. Table (17) shows the most suitable software that the study found:

Table 27: The 13 Software modellers those were passed the study criteria (A. Lyden et al)

Tools	Demand profile generator	Resource assessor	Supply profile generator
Biomass decision support tool	Yes	No	Modeller
COMPOSE	No	No	Database and input
DER-CAM	No	S, T, Wi	Modeller
EnergyPLAN	No	No	Database and input
EnergyPRO	Yes	B, H, S, T, Wi	Modeller
eTransport	Yes	Yes[a]	Modeller
H2RES	No	B, H, S, Wi	Modeller
HOMER	Yes	B, H, S, T, Wi	Modeller
Hybrid2	Yes	S, Wi	Modeller
iHOGA	Yes	H, S, Wi	Modeller
MARKAL/TIMES	No	B, H, S, T, Wi	Modeller
Merit	Yes	S, T, Wi	Modeller
SimREN	Yes	Yes[a]	Modeller

Resource Assessor Key: Biomass (B); Hydro (H); Solar radiation (S); Temperature (T); Wind (Wi).

[a] indicates that a resource assessor exists but the specifics were unable to be determined.

6 Supply Analysis

This study examines the possibility of supplying the town by power from wind and solar due to the high GHI radiation in Khartoum which can reach up to 2500 watt per square metre per annum and the relatively high wind speeds which can reach up to 30 mph. (Bluemeteo 2018).

6.1 Wind Turbine

According to Renewables First UK, a speed over 7 mph would increase the power by more than 60% which would increase the energy output from wind turbines by 36%. Figure (16) shows the wind speeds in Khartoum throughout the year.

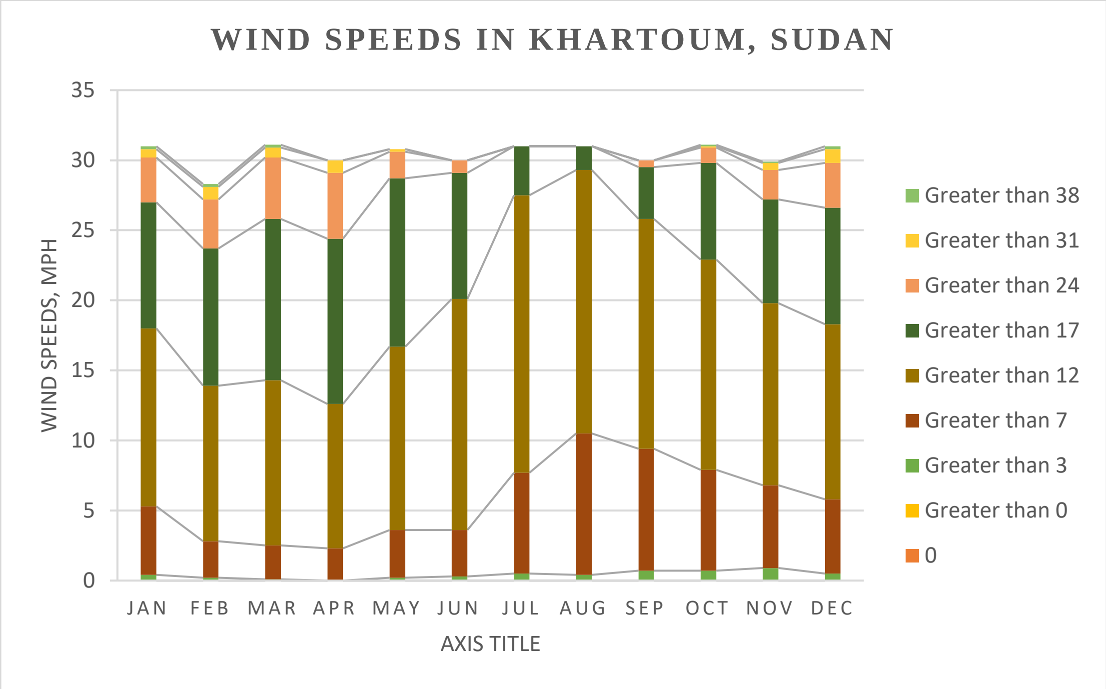


Figure 16: Wind speeds in Khartoum, Sudan (Bluemetoe, 2018)

Figure (17) shows more detailed wind speeds in Khartoum. Wind storms are common in Khartoum, Sudan. The thing which can explain the excessive wind speeds in the figure.

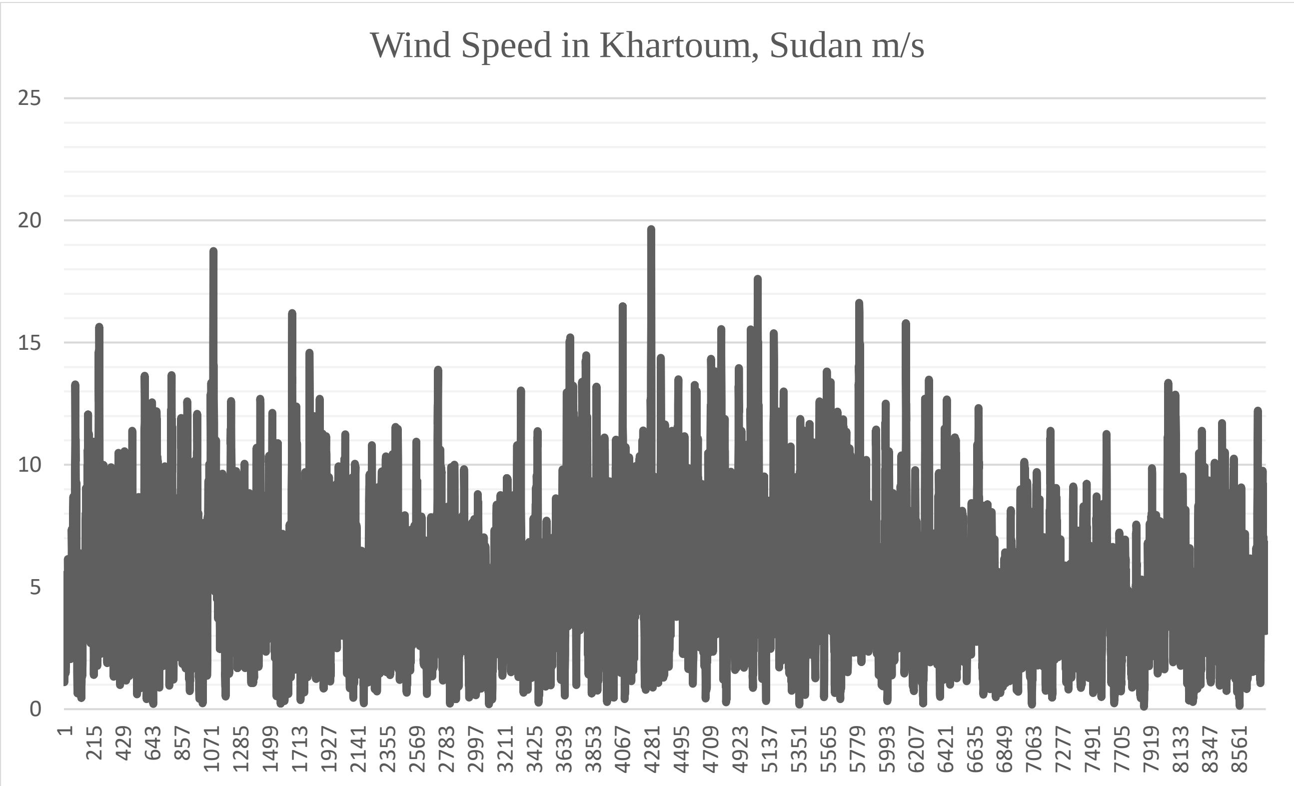


Figure 17: Wind speeds in Khartoum, Sudan by NASA data (NASA, 2018)

Wind speeds in Khartoum vary between 1 and 12 metre per second and can reach up to over 22 metre per second (meteoblue meteorological service, 2018). According to the to equation (1), there is a positive proportionality between the wind cubic value of the wind speed.

$$P = \frac{1}{2} \rho A V^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where

- P ≡ Power output of the wind turbine
- ρ ≡ Air density
- A ≡ Circular ring area
- V ≡ Wind velocity

From equation (1), a small increase in the wind velocity can result in a big change in the power output. The average wind velocity in the UK is between 6 and 7 mph whilst in Khartoum the average wind speed is between 9 and 11 mph. The difference in the velocities would result in 8 to 27 more power output from the wind turbines according to equation (1).

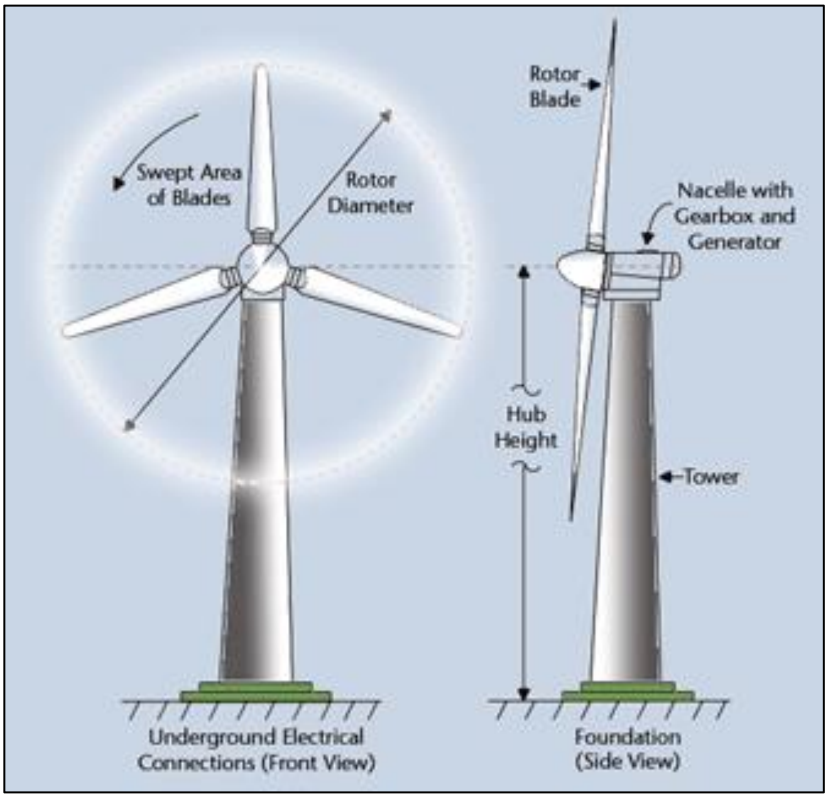


Figure 18: Wind turbine facing wind and the required variables to calculate the power output

A typical power output that can be harnessed from 95 Kw wind turbine that is placed in Khartoum city can be shown in figure (19).

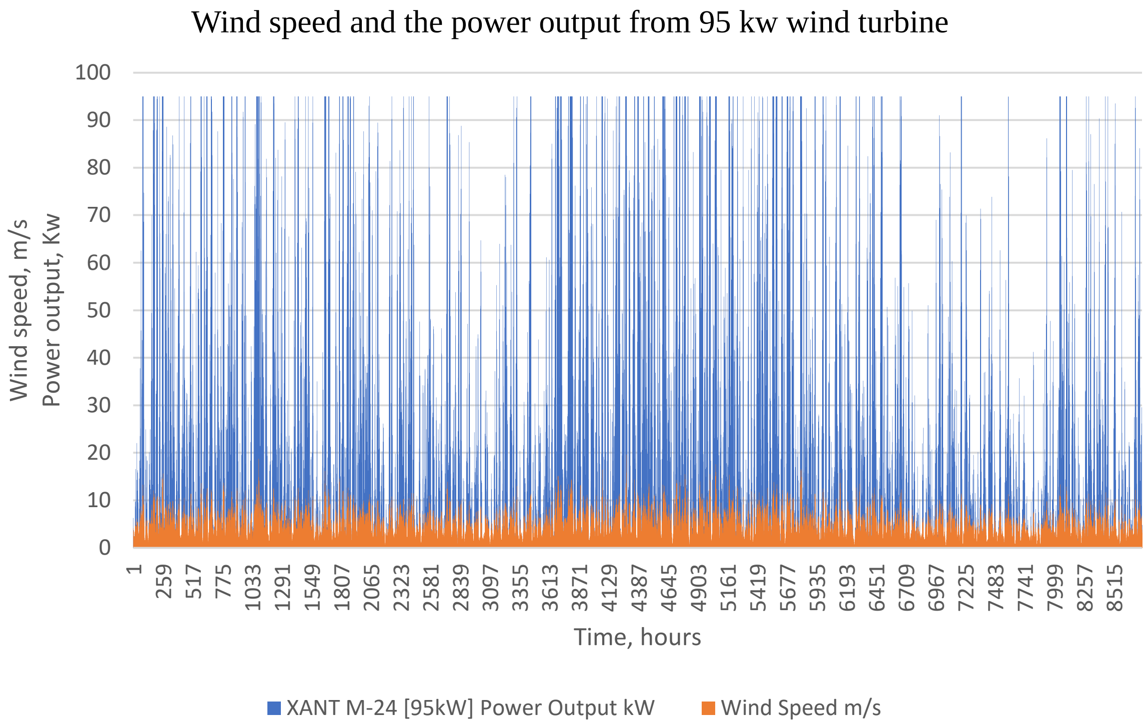


Figure 19: Wind speed and wind turbine output, it can be clearly seen that there is a positive proportionality between them

By taking the 50 hours period of the annual period in figure (19), the effect of the cubic value of the wind velocity and plotting it versus the power output, the outcome can be seen in figure (20).

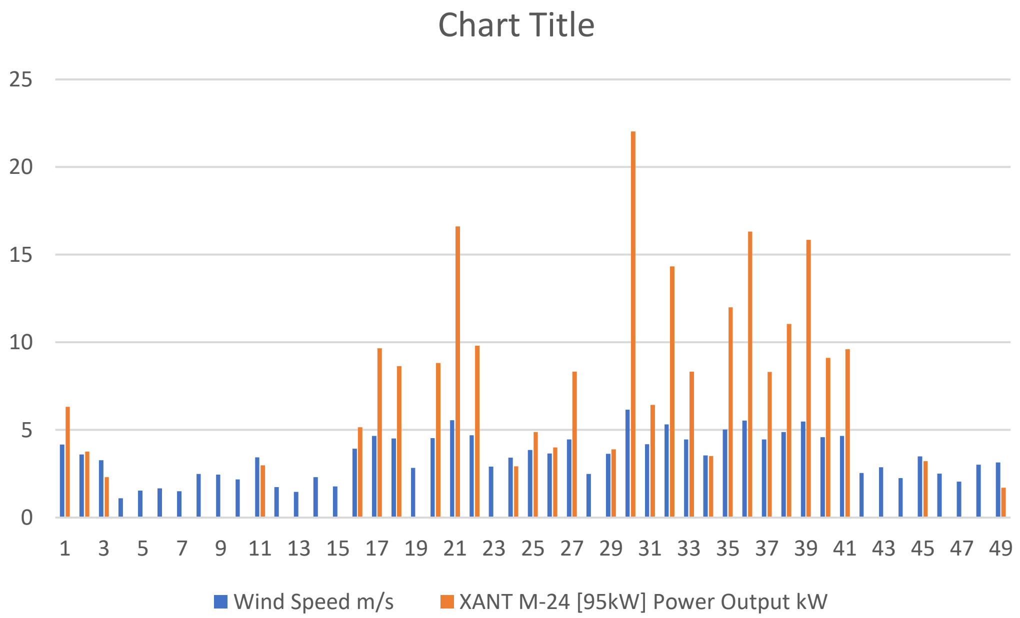


Figure 20: Wind speed vs the wind turbine output in the first 50 hours in the year to show the proportionality between the wind speed and the power output which is dominated by the effect of the cubic value of the velocity, which makes a small increase in the velocity result in a significant change

in the power output. In the time period between hour 29 and hour 30, this effect could be clearly seen, as the power output increases from 4 to 23 Kw when the velocity increase from around 4 to 6 m/s.

6.2 Solar PV panels

During the past 36 years in order to estimate global radiation on the surface on each daily and monthly mean daily basis, varied empirical models have been developed for many locations in Africa. As a result, numerous input parameters are used, and many different forms are used. (Chukwujindu, N.S., 2017)

Identifying the exact values of solar rates and the climate in a continent could be challenging. solely some mensuration sites area unit available with semi-permanent time-series of correct measurements. For such a web site, the time structure is also derived that characterizes the star climate. The monthly mean of the daily clearness index $(KT_d)_m$ is an acceptable variable in that respect. It's outlined by the quantitative relation of the monthly mean daily global irradiation $(G_d)_m$ and also the monthly mean daily extra-terrestrial irradiation $(G_{0d})_m$ following the notations of the European Union radiation atlas. (ESRA 2000).

$$(KT_d)_m = (G_d)_m / (G_{0d})_m$$

The difficulty in solar climate lies within the comprehension of the abstraction dimension. due to the inadequacy of the network, the boundaries of a climatic area are tough to draw. However, partition helps in a very higher understanding of the distribution of the clearness index in area. It conjointly guides the choice of acceptable measuring stations for a given geographical location. Incidentally, it additionally helps with the Ångström coefficients by shaping the geographical limits of the validity of a given set of coefficients. (Diabate, L *et al* 2004)

The Photovoltaic Geographical Information System (PVGIS) is a web application for the estimation of the performance of photovoltaic (PV) systems in Europe and Africa, which has become widely used by the PV community in Europe.

HOMER energy modeller uses the Photovoltaic Geographical Information System (PVGIS) to estimate the solar radiation in the coordinates that have been entered to it.

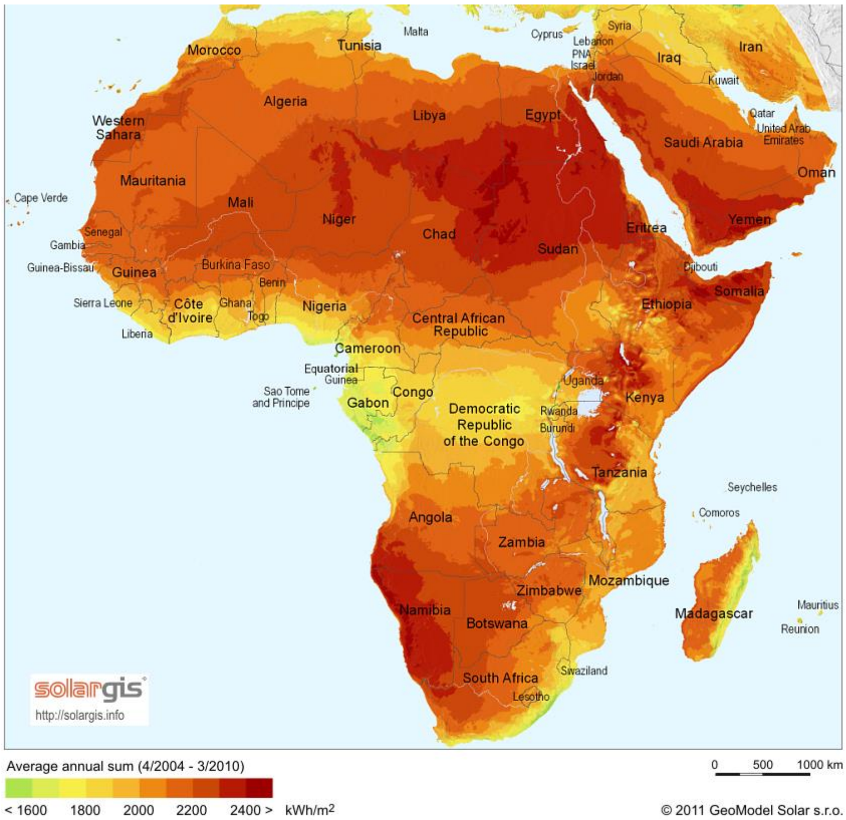


Figure 21: GHI solar radiation in Africa (GeoModel, 2011)

In this study, NASA global radiation data was used to simulate the solar resources quantity and the output of the PV panels that were used to represent part of the power supply.

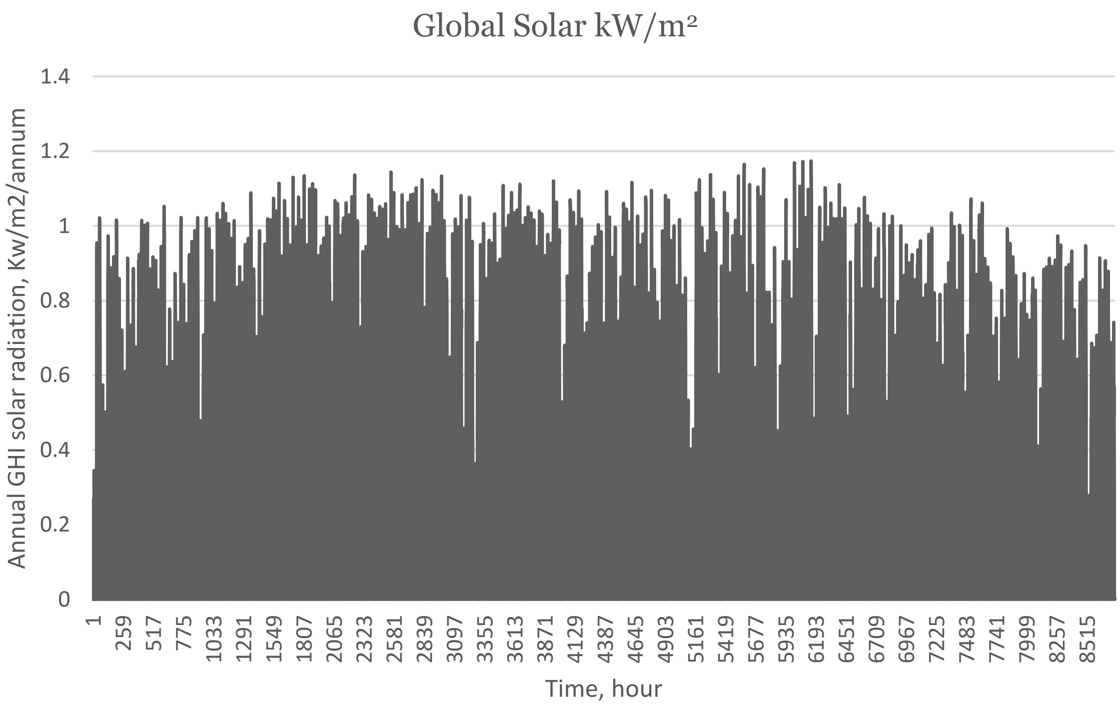


Figure 22: Solar GHI radiation data for Khartoum, Sudan (NASA, 2018)

The average direct solar radiation rate in Sudan is 2200 watt per metre square per annum according to solar energy local. (solar energy local, 2018), but the GHI radiation varies between 800 – 1200 w/m/yr.

6.3 Biomass as alternative fuel for bakeries and restaurant

Biomass is organic material that comes from plants and animals, and it is a renewable source of energy. (EIA, 2018). Biomass can be used as an energy in different forms; the processing wastes of Wood can be burned to heat buildings, to produce process heat in industry, and to generate electricity as well. Furthermore, agricultural crops and waste materials can be burned as a fuel or converted to liquid biofuels like biodiesel. On the food side, food, yard, and wood waste in garbage can be burned to generate electricity in power plants or converted to biogas in landfills. Lastly, animal manure and human sewage can be converted to biogas, which can be burned as a fuel for cooking, transport or generating electricity. (EIA, 2018)

The woodchip disposed from the fire wood shops can be used as a fuel for cooking or baking. According to a call to the woodchips owner, the shop dispose around 85 – 100 kg of woodchip every week. This amount of wood should be used in cooking or baking in one of the biomass restaurants or the bakery.

The energy content of dry Acacia firewood is between 21,000 – 21,6000 Kj/Kg, a value equals to 5.8 kwh of power. A quantity of 100 kg every week equals to 580 kwh of energy that can be used to cook in the restaurant to cook instead of electricity and butane gas.

6.4 The electricity grid in Sudan

The Sudanese electricity grid consists of various kilo volts lines. Moving electricity between cities is always done via 440 KV transmission towers. The transmission tower within the city are 33 KV towers. And the distribution towers are always 230 KV. There are no buried cables in Sudan. Figure (23) shows the 440KV transmission lines electricity grid in Sudan between the generation stations and the main loads which are represented by the main cities. The long distants of the transmissions lines results in high carbon emissions which plays an important part in the environmental footprint of the country. Despite the fact that this study is for a small town in Sudan, but scaling up the study can gives indications about the conversion of the conventional power generating to renewable energy from environmental perspective.

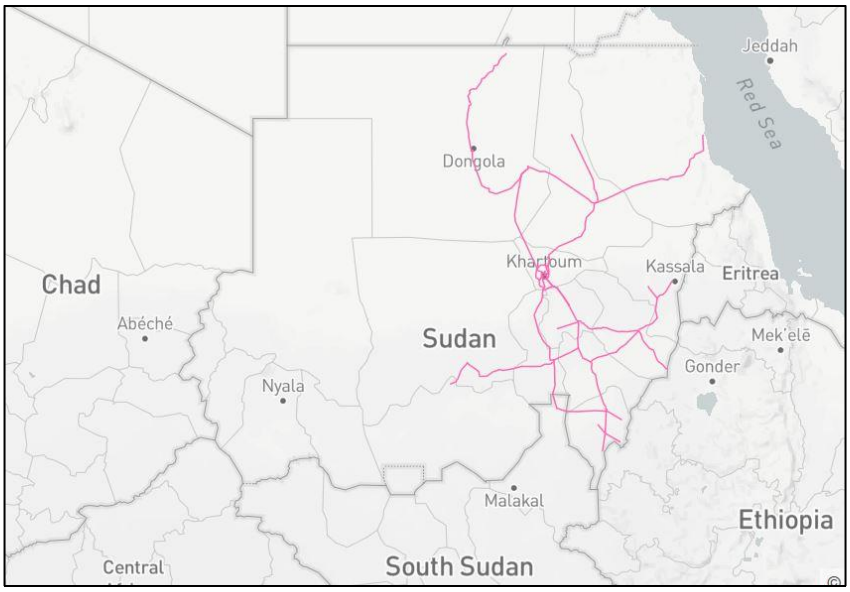


Figure 23: Sudanese electricity grid transmission lines between the generation stations and the main cities (energydata.info, 2017)

The produced electricity in El-Munawara town in this study is supposed to be from the PV panels or the Wind turbines which are meant to be in near the town. Therefore, the required transmission lines to transmit electricity are the 33KV towers and the for the PV panels, the electr icity would be transmitted from the panels to the inverter and then to the load directly.

7 Critical literature review

There are many cities that turn to renewable energy instead of the ordinary means of power generation. Cape Town in South Africa can be a good example for that. The city of 3.74 million persons is has been turning to renewable energy since 2010, which resulted in decreasing the environmental footprint by almost 10%. The city is gaining a reputation for decisive actions and pioneering measures in sustainable energy development. Figure (24) shows the carbon emissions decrease in the last decade in the Cape Town.

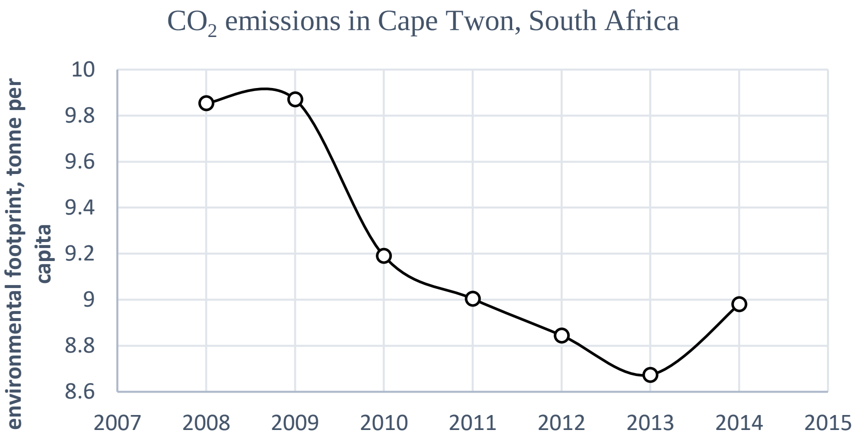


Figure 24: the declination in CO_2 emissions in Cape Town, South Africa

Another example of renewable energy projects is Hywind farm which was built in Aberdeenshire, Scotland and it is the first floating wind farm in the world. The farm is administrated by Statoil Norwegian energy company. The farm has very high efficiency of harnessing power from wind and Statoil states that this efficiency reaches values over 59% which is unbelievable because it exceeds Betz limit.

7.1 El-Munawara Size, Demographics and Economics:

El-Munawara is a town that is in the Sudanese capital, Khartoum. The town has 610 house and some shopping facilities and 3 schools. The population of El-Munawara is consisted of 3100 capita. The vast majority of the males of the population are middle working class meanwhile the majority of the females are house wives.

The income per capita has been increasing since 1991, in contrast the inflation has been increasing as well. Figure (25) shows the average annual per capita income for Sudan.

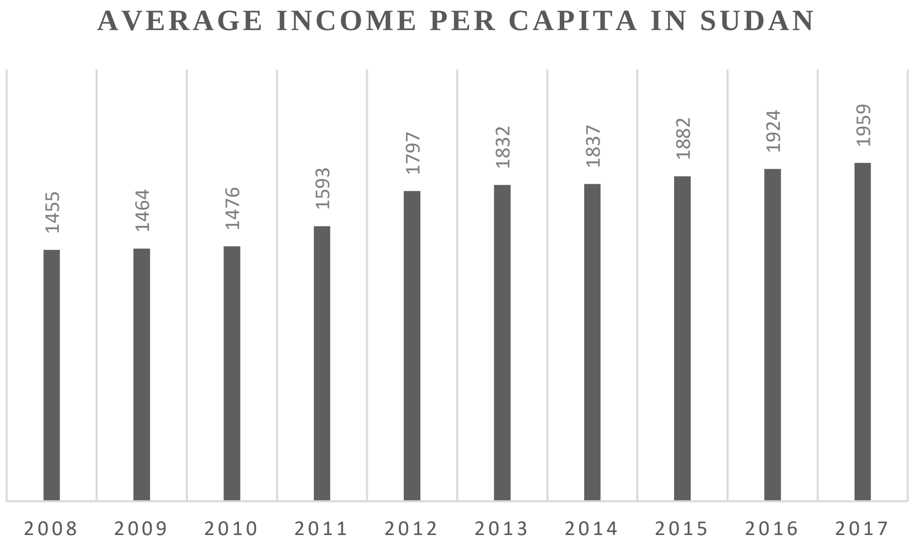


Figure 25: Average per capita income for Sudan in USD (World Bank Data, 2017)

According the EIA, the greenhouse gases emissions in Sudan are in the average countries zone, which have less than 0.5 tonnes of CO_2 emissions per capita per annum. Figure (26) shows the carbon emissions in Sudan.

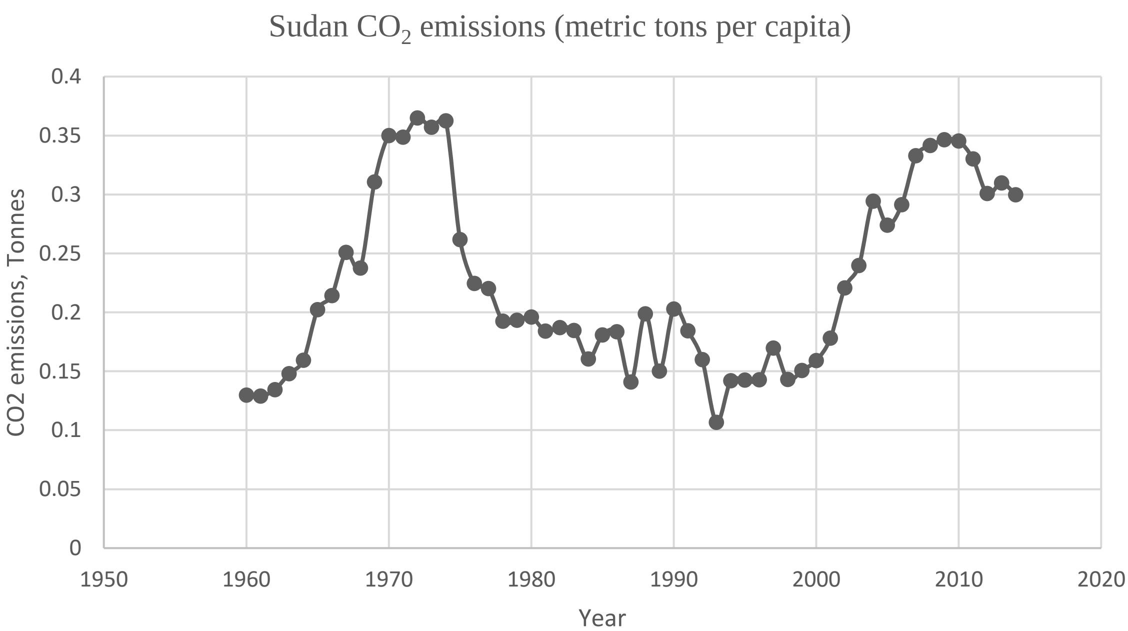


Figure 26: CO_2 emissions trend in Sudan (Data source: World Bank Group)

7.2 *El Munawara Town Current Energy Picture*

The supply of the electricity in the town is from the Sudanese national grid which the majority of its supply comes from fossil fuels and hydropower as well. Figure (27) shows the percentages of the power generation in Sudan.

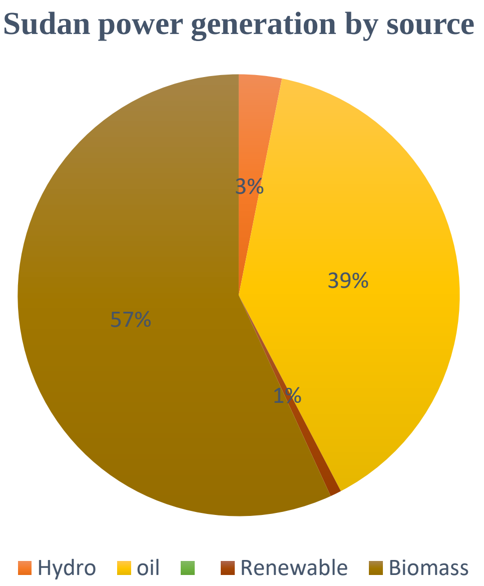


Figure 27: Sudanese power generation percentages (A. Rabah, 2016)

The percentage of the population who have access to electricity in Sudan is 44% and the environmental footprint is 0.38 tonne per capita (RCREEE, 2018). The electrical power generation represent 3% of the power consumption in Sudan. There are no data from the government to tell about the environment footprint of the electricity generation in Sudan.

7.3 *Energy Supply and Consumption*

The fuels of the energy in El-Munawara town can be divided into three sections:

- Electricity
- Gasoline
- Diesel
- Gas

The electricity is bought from the grid which is generated as figure (27) shows. The demand for energy in El-Munawara town is highly controlled by the high cooling loads during the summer and the human behaviour which has been considered in the total final demand as table (16) shows. Figure (28) shows the monthly electricity consumption in summer and winter that was estimated according to a quantitative survey that was made to 15 houses in the town and expert advice.

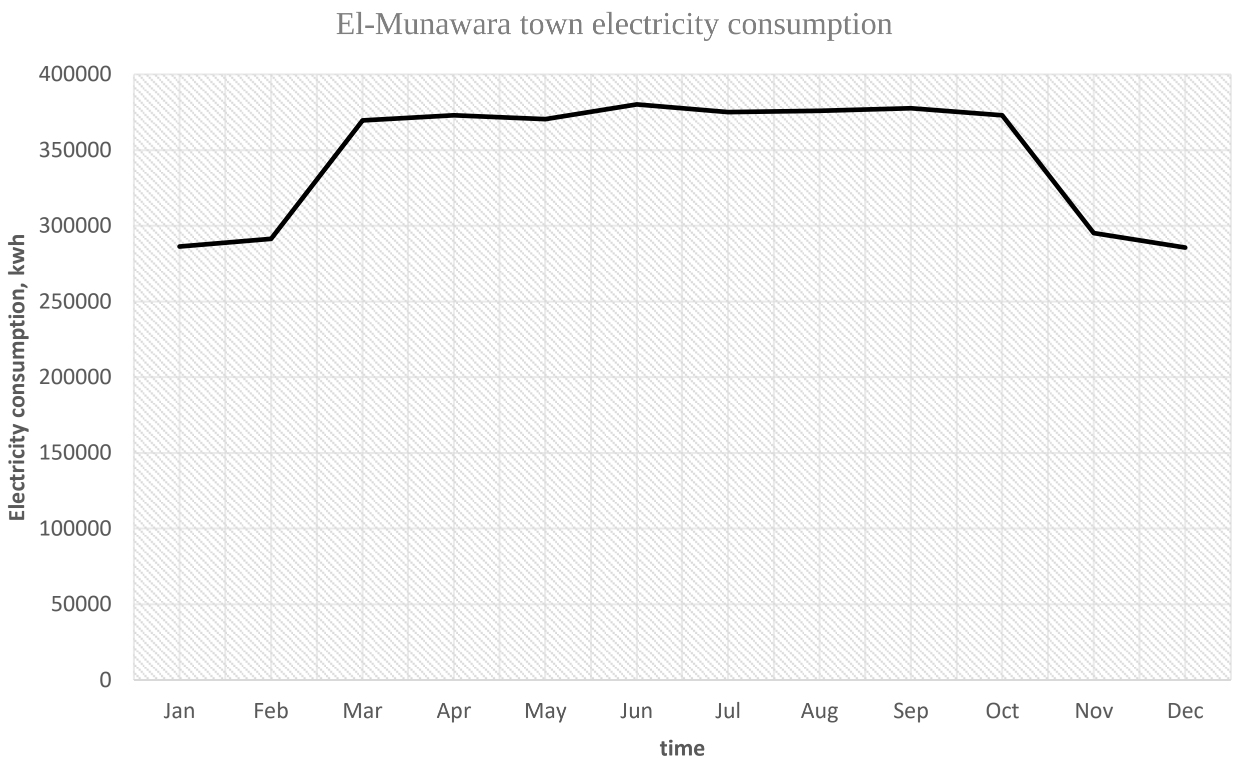


Figure 28: El-Munawara town estimated electricity consumption throughout the year

7.4 Sectoral energy consumption

There are three sectors for energy consumption in El-Munawara:

- Residential
- Commercial
- Transport

Table 28: Demand rations in El-Munawara town in Khartoum, Sudan

Sector	*Consumption, kwh*	*Percent, %*
Residential	**3573279.8**	**86.03%**
Bakeries	187974.2	4.53%
Restaurants	74066.2	1.78%
Supermarket	235427.4	5.67%

Commercial total	**497467.8**	**12%**
Mosque	28326	0.68%
Schools	54307.8	1.31%
Governmental total	**82633.8**	**1.99%**
Total Annually Demand	**4153381.4**	

The residential sector power demand shapes the majority of the power consuming sectors by about 85%, meanwhile the commercial sectors comes second by 12% and lastly the schools and community centres come in the bottom by slightly more than 2%. Table (28) shows the sectoral power consumption in El-Munawara town in Khartoum, Sudan.

7.4.1 Residential Electricity Demand

The residential sector shapes the majority of the power consumption in the town. The consumption behaviour is controlled by the high cooling loads that are required in the summer when the temperature degrees reach up to 47^0 C. Another factor that play a significant role in the human behaviour is the sleeping times for the population in there. Correspondingly, the school times have a significant effect of the electricity consumption manner.

The data of the demand in this research was acquired through a quantitative survey which includes questions about the monthly electrical consumption. Together with, a qualitative survey was done to examine the effect of the human behaviour in the residential sector.

The two surveys were used to indicate the hourly electricity consumption in the town which can be seen in table (7) and (8). Figure (29) shows the residential power demand in El-Munawara town.

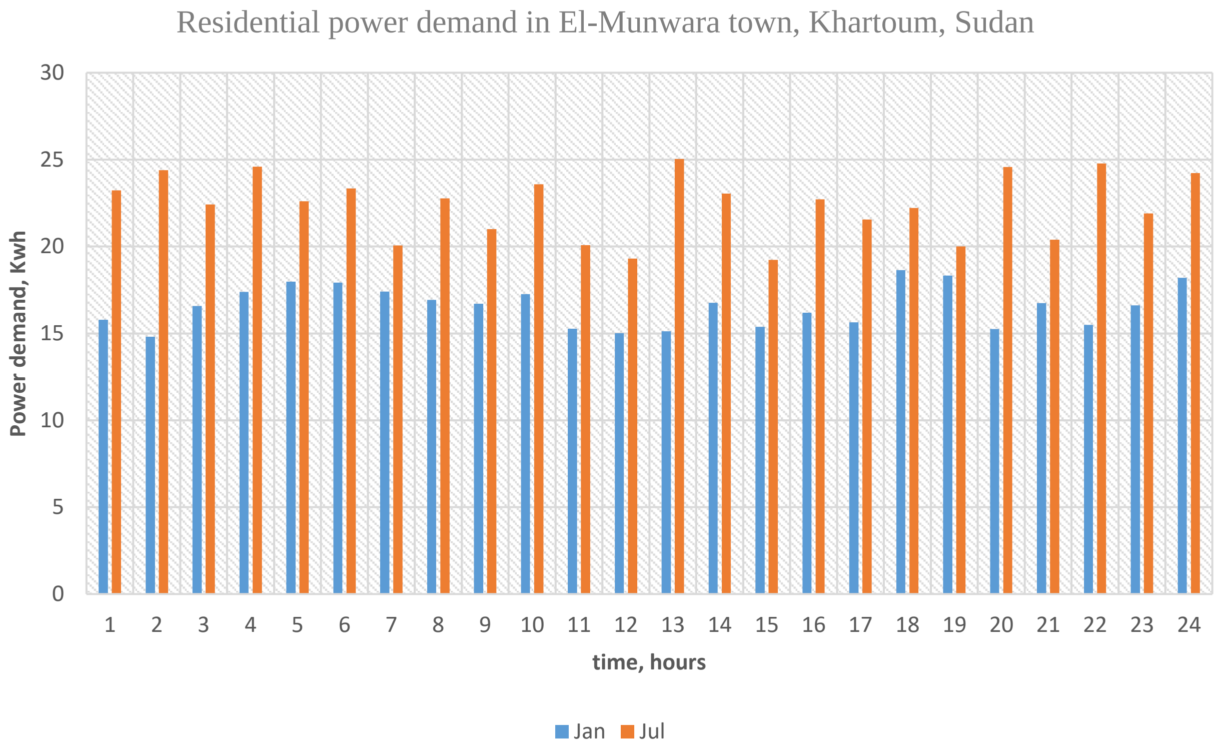


Figure 29: Residential power demand in El-Munawara, Khartoum, Sudan

7.4.2 Industrial and Commercial

The electrical power consumption in El-Munawara town by the commercial sector is dominated by 3 supermarkets in the town, 2 bakeries and 3 restaurants. The total power consumed by them is nearly 500 Mwh per annum which shapes almost 12% of the total demand in the town. The demand in the commercial sector is controlled by the opening hours and the demand rates as well. Figure (30) shows the commercial power demand in El-Munawara town.

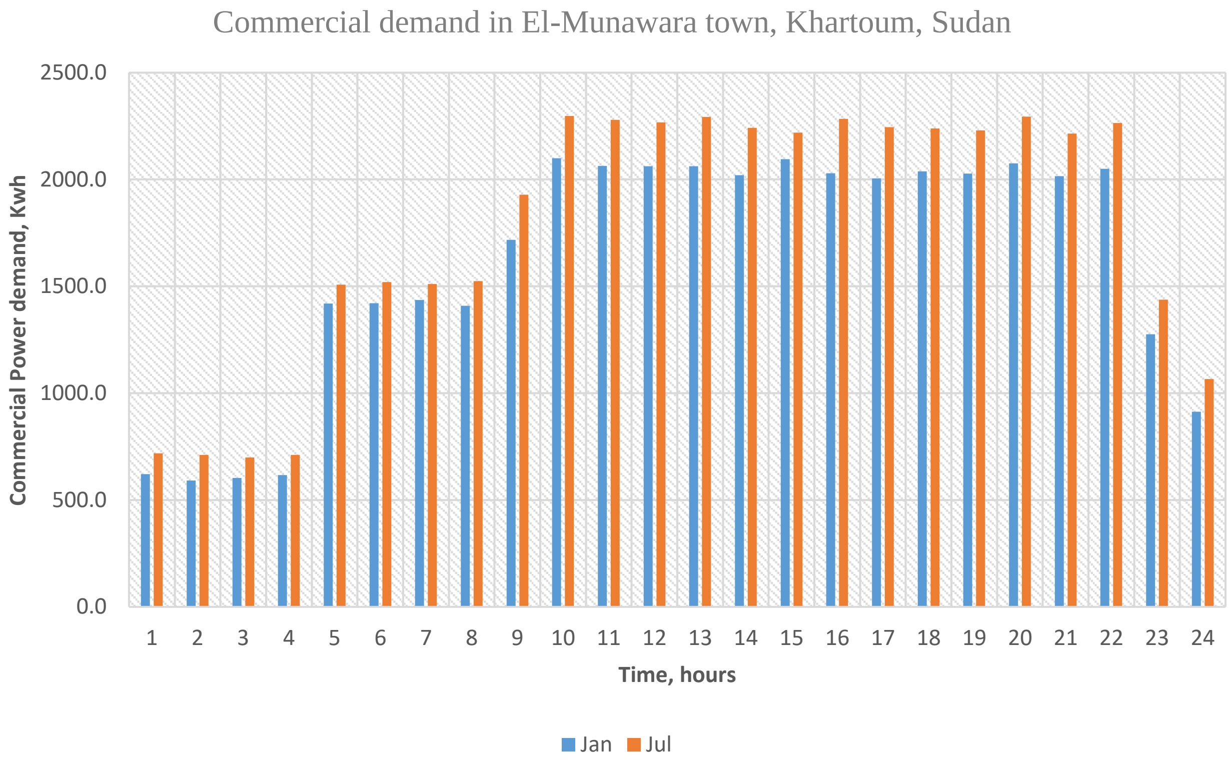


Figure 30: Commercial power demand in El-Munawara town, Khartoum, Sudan

7.4.3 Governmental Electricity Demand

The governmental demand in El-Munawara town is shaped by the 3 schools in the town and the mosque. The governmental consumption in the town is dominated by the school peak hours and the prayers times in the mosque. In Ramadan month, the mosque consumes electricity more than other months during the day, which makes the consumption in May taking a plateau trend in most of the day.

In January the schools are open, which makes the governmental electricity consumption higher than may during the day hours. In January the schools are open as well, but because of the lower cooling loads, the demand is not as high as in July.

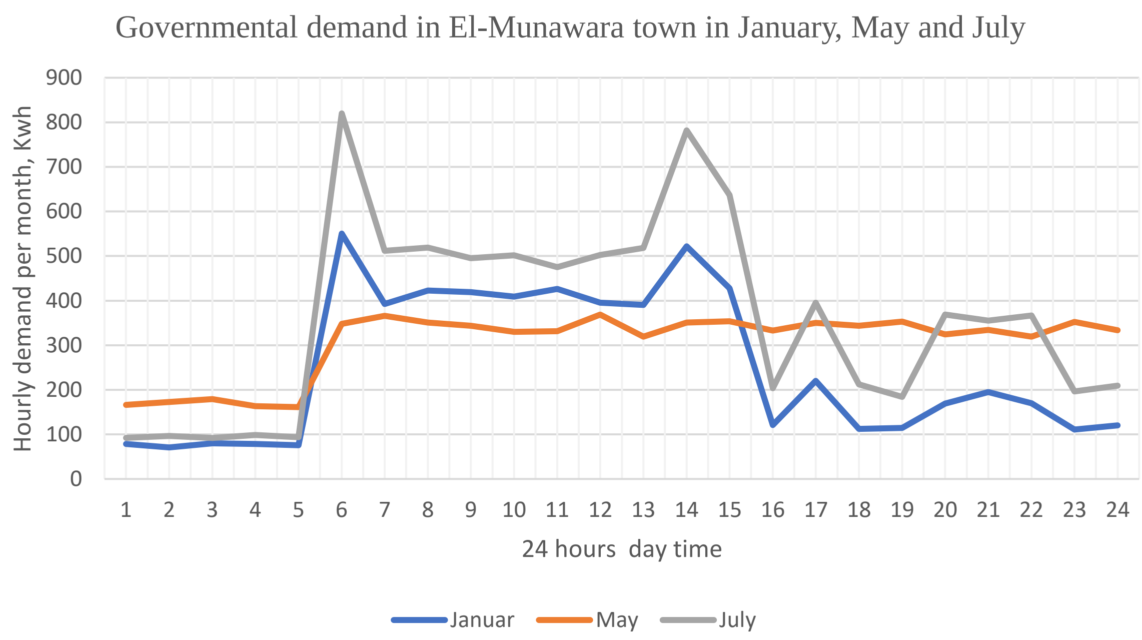


Figure 31: Governmental electricity consumption in January, May and July

7.4.4 Transport Power Demand

The citizens in the town depend highly on the public transport system which almost all its vehicles use diesel. Albeit, almost %25 of the population have their own cars to transport. The research undertaken does not include the transport system because of the lack of the electric cars in Africa and if they could be imported from outside they will cost lots of money which the citizens would not be able to afford. For the mentioned reasons, the transport power consumption is outside the vision of this research because there are no electric power in the town that can be considered to be fuelled by renewable energy from wind or solar.

8 Research Undertaken

The research undertaken is proposed to investigate the applicability of supplying El-Munawara town by renewable energy. Due to the availability of the renewable resources in Khartoum, Sudan, the research is examining by HOMER simulator the possibility of installing of wind turbines and PV panels. Notwithstanding, the White River Nile is less than 1 kilo metre from the town, but the huge width of the river makes it very hard to install any hydro turbines in there. Furthermore, the base of the White River Nile is unconsolidated mud which makes it highly difficult to build a base for the turbines in there. In addition, the water flow rate of the river is very low because the Nile in the area of Khartoum is in its old age stage (lower course) and the confluence of the Blue River Nile with the White River Nile in the area of Al-Mogran plays an extra factor in lowering the speed of the White River Nile in this area because the Blue Nile is running too fast in this area. Considering the fact that the Blue Nile contributing by more than 80% of the River Nile (Verhoeven, H., 2011) is a convincing fact that the White River Nile is in its very old stages when it comes in Khartoum City which makes the possibility of harnessing energy from hydropower very low. Figures (31) and (32) show how the White river Nile in Khartoum is very wide which hardening the installation of any hydropower turbines.

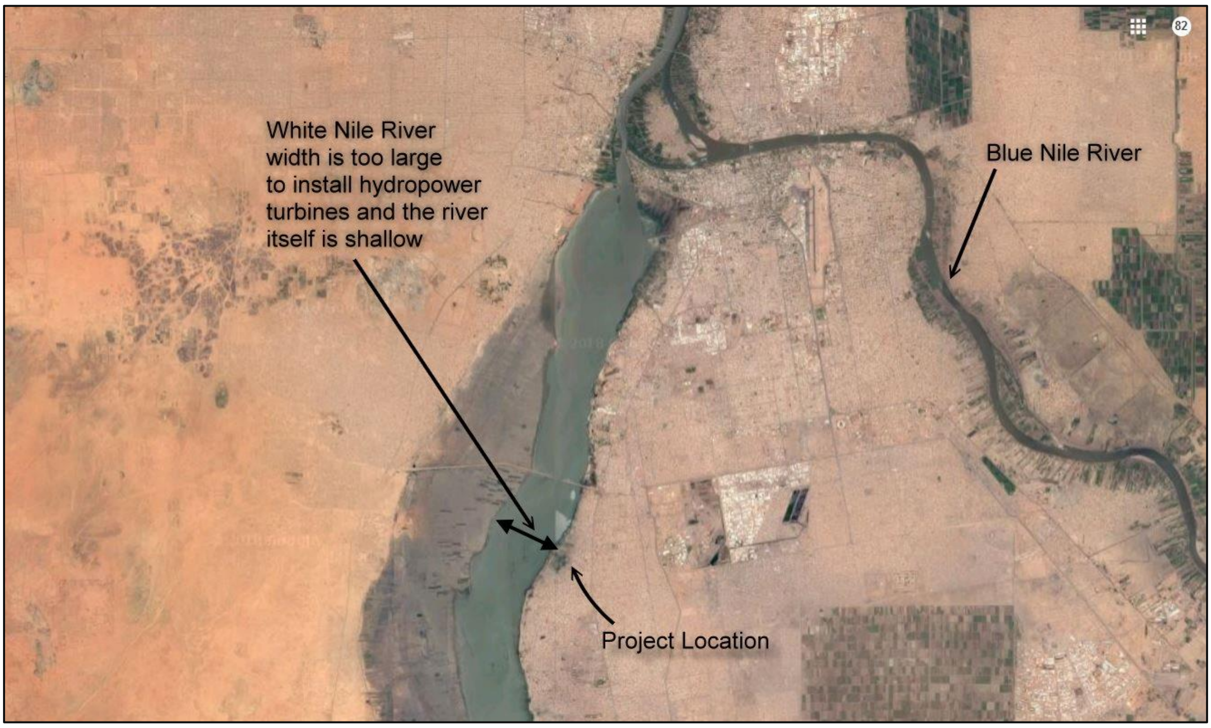


Figure 32: The figure shows the wide width of the White River Nile which makes it difficult to install hydro turbines for electricity

Figure 33: The map shows how the White Nile River is wide which add difficulties in installing hydropower turbines in the river

The waves of the White river Nile have short heights which makes harnessing energy from them very difficult and have a low potential. The short waves come as a result of the shallow depth of the river.

The renewable resources surrounding the town of El-Munawara can be summarized in:

- **Solar energy:** Solar radiation in Khartoum can reach up to 2500 w/m^2 per annum which is a high value comparing with many other countries.
- **Wind energy:** Wind speeds can reach up to 30 mph in Khartoum, Sudan. Which makes it a resource with high potential to be harnessed. The town in which this study is undertaken, there is large barren planes in the western side of it, which makes it optimum for wind energy harnessing projects. The distance between the river and the first terrace of houses in the town is more than 700 metres, this is in addition to the width of the river itself and the distance between the river and the other side in the river as well

8.1 Wind energy analysis

Wind energy has a good potential in plane flat areas where there are no obstructions to the wind hitting the turbine blades. Similarly, in EL-Munawara town in the western side of the town which faces the White Nile.

The distance between the first residential premises and the White River Nile is almost greater than half a kilo metre in addition to the width of the Nile itself and the area on the other coast of the Nile which gives a significant area to harness wind energy from there.

Table 29: Wind direction data in the era between 2000 and 2018 in Khartoum, Sudan (Weather Online, 2018)

Wind direction	Ration
N	43 %
NE	5 %
E	2 %
SE	3 %
S	14 %
SW	12 %
W	5 %
NW	15 %

Wind energy can be fit into 7 classes from which the potential of wind energy can be predicted.

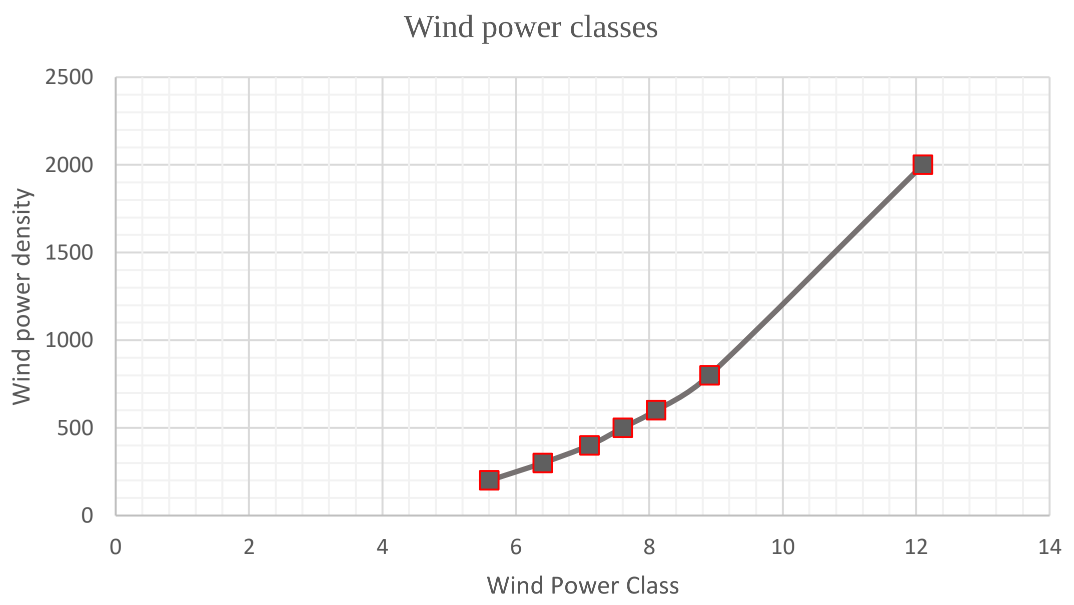


Figure 34: Wind power classes, from the left the classes start by class 1 which gives 200 watt per square metre wind power density from 5.6 m/s wind speed and increase

The large area between the town of El-Munawara and the river gives a large range to the wind to run without any constraints which will gives a stead gusts of wind those can sustain the output of wind turbines.

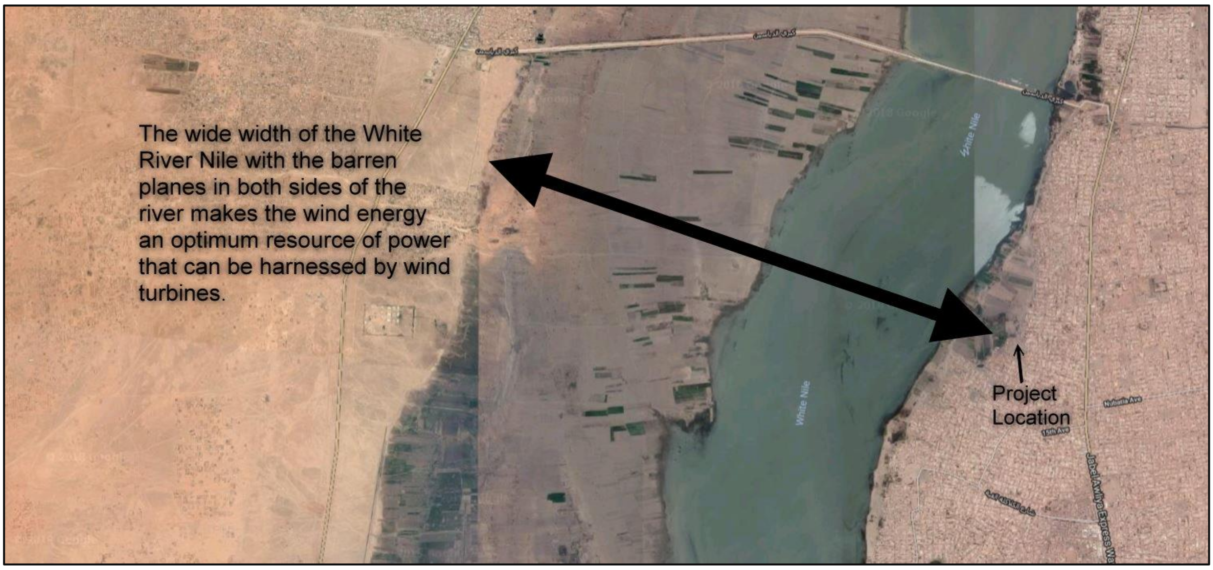


Figure 35: The wide area between where the wind turbine is suggested to be and the buildings in there, the absence of the building gives a good potential for the wind turbines to be installed in there.

Another factor that can affect the wind energy in Khartoum is the effect of the direction of the wind, figure (36) shows the wind directions by percentages in Khartoum, Sudan.

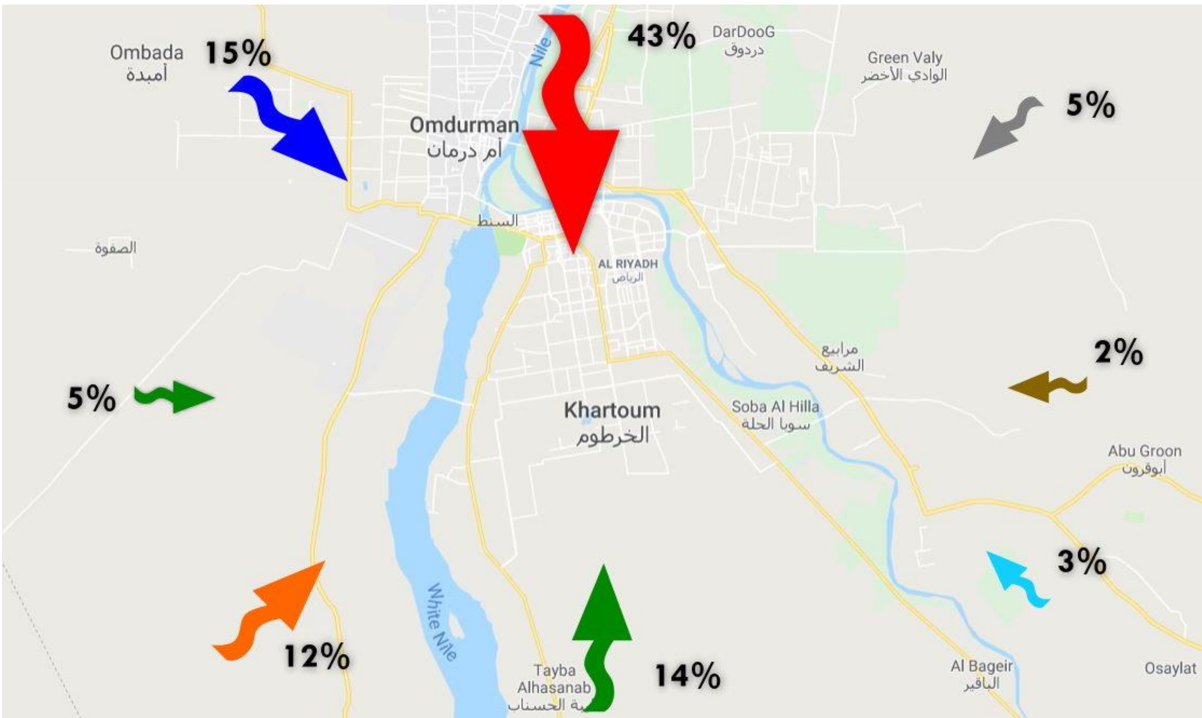


Figure 36: Wind direction percentages in Khartoum, Sudan

The optimal size of the wind turbine as has been discussed in both the United States and Germany, found that large turbines fitted in well with the ingrained habits of the power generation industry accustomed to the advantages of the economy scale.

The amount of energy that can be harnessed from the wind is proportional to the swept area of the turbine. For instance, the area swept out by a rotor with 100 metres diameter turbine is the same as that of 100 turbines in 10 metres turbine diameter. (Da Rosa, A.V., 2012). Furthermore, the mass of the plant varies with the cube of the diameter.

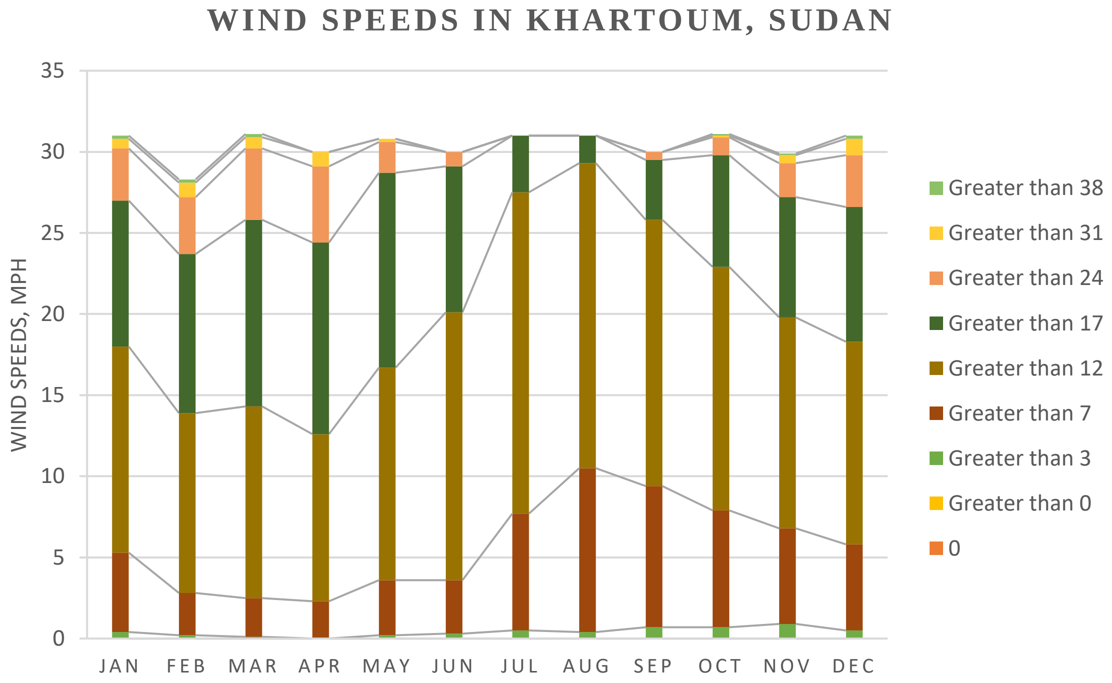


Figure 37: Wind speed distribution in days throughout the year in Khartoum, Sudan

8.2 Solar energy analysis

Solar energy is a very large inexhaustible source of energy. The power from the sun intercepted by the earth is approximately 1.8 x1014KW. (BADRI, A.S., 2005)

The total solar radiation in Khartoum can reach up to 2400 watt per square metre per annum which gives the photovoltaic panels a high potential in there.

According to NASA, the global horizontal irradiance (GHI) data base the solar GHI in Sudan can reach up to 1400 watt per square metre.

The solar energy utilization can be achieved through direct and indirect methods. Figure (38) shows the harnessing methods from solar radiation.

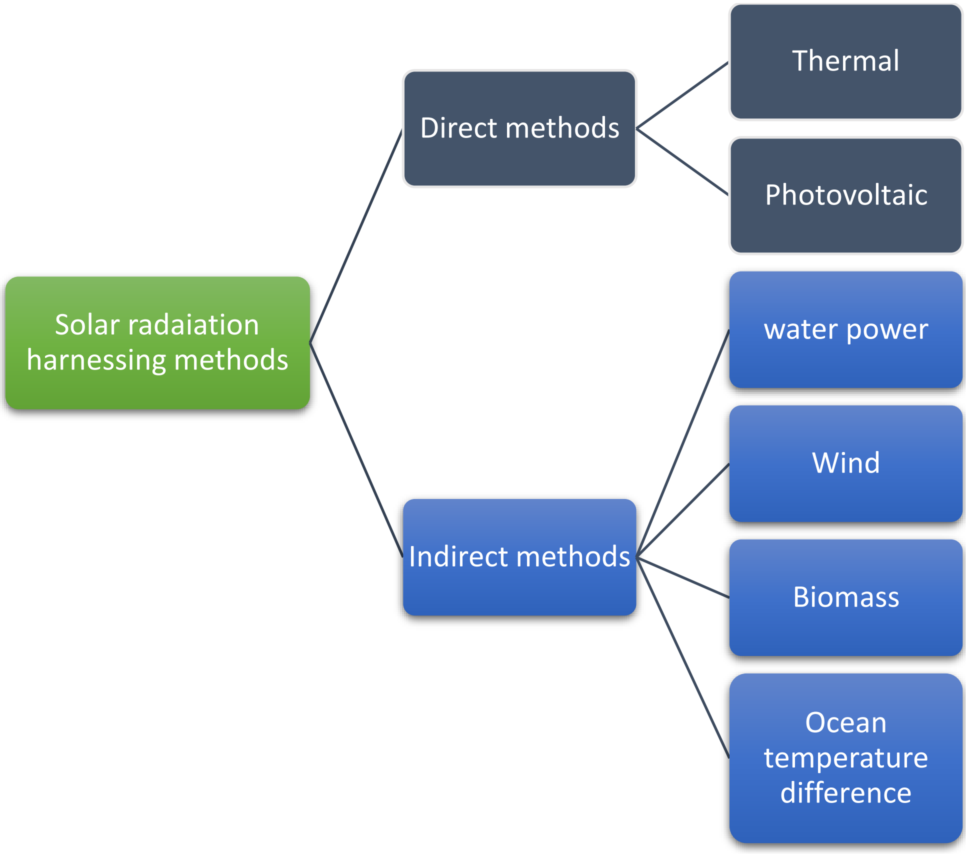


Figure 38: Direct and indirect energy harnessing methods from the solar radiation

Due to the high GHI rates in Khartoum, Sudan and due to the availability of the area in which solar systems can be installed in El-Munawara town which this study is supposed to be applied, solar PV panels were considered as a renewable supply source to be researched.

(Experimental programme, data analysis and interpretation)

8.3 Carbon Auditing:

Sudan power is generated mainly from fossil fuels which makes it a dirty source of power. An annual consumption of 1 Giga watt hour will result in significant amounts of carbon emissions due to the generation and the transmission as well.

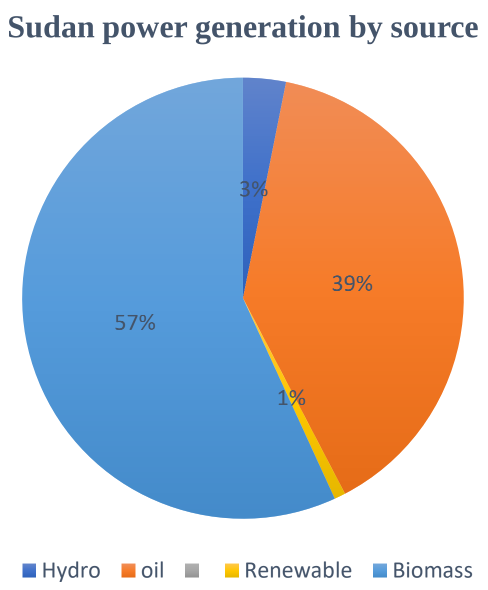


Figure 39: the total power consumption in Sudan, the maps shows that biomass is the main fuel in Sudan which us used in rural areas and by some bakeries in the main cities. More than 50% of the 24% of power consumption is used to generate electricity.

The availability and relative affordability of oil as an energy source has made electricity generation heavily dependent on oil by 35%; 28% of electricity is generated through burning natural gas, 6% through nuclear power and 2.3% is generated by hydroelectric stations and pumped storage stations assist with load management.

There are no statistics from the Ministry of Electricity and Water Resources about the carbon emissions from due to the electricity generation. The available benchmarks and the international agencies estimations tell that the CO_2 per capita is 0.38 tonnes. From the achieved renewable energy penetration which can be up to 89% as discussed in the results section, Carbon emissions would be reduced by the same percentage.

9 Simulation results:

Using the demand that was estimated in the previous sections and the renewable supply means as well, HOMER software modeller was used to simulate the supply-demand process in El-Munawara town in Khartoum, Sudan.

The first renewable supply facility that was examined by modelling software is 8 MW wind turbine. A renewable energy penetration value of 54% was achieved by this wind turbine and net present cost of $11.2 million.

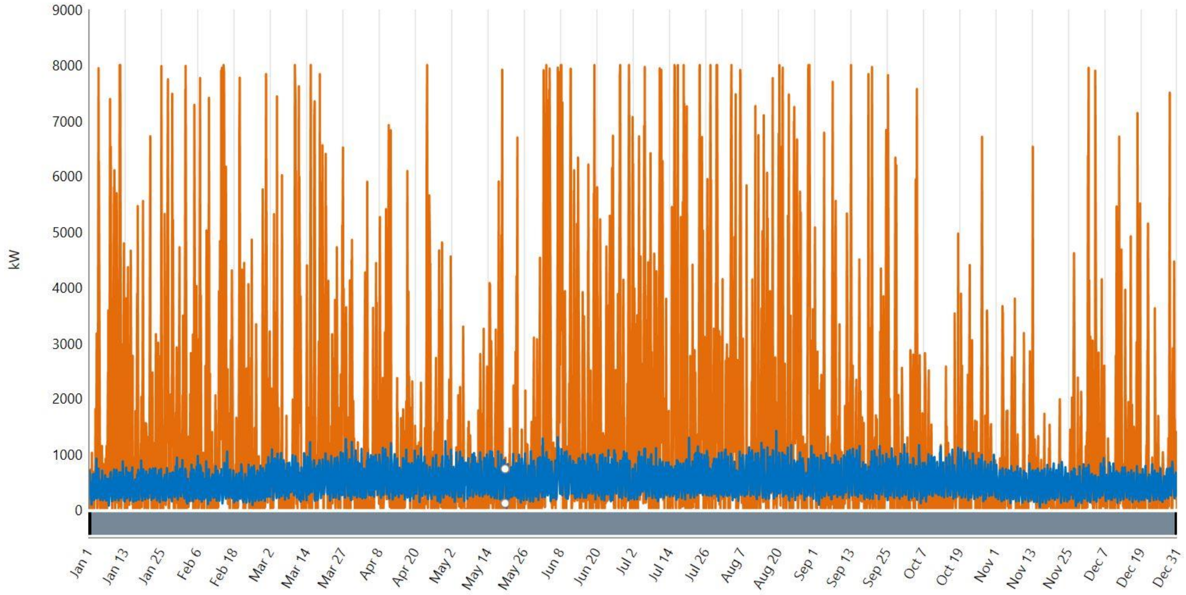


Figure 40: 8 MW wind turbine output (Orange) vs main primary load in El-Munawara town, from the figure, there is a high energy surplus that can be stored through increasing the system storage capacity

9.1 The effect of batteries on wind turbines power output

Due to the high energy surplus from the 8 MW wind turbine that is shown in figure 37, high amounts of electricity are wasted. A storage capacity was added to check the effect of the storage on increasing the renewable energy penetration.

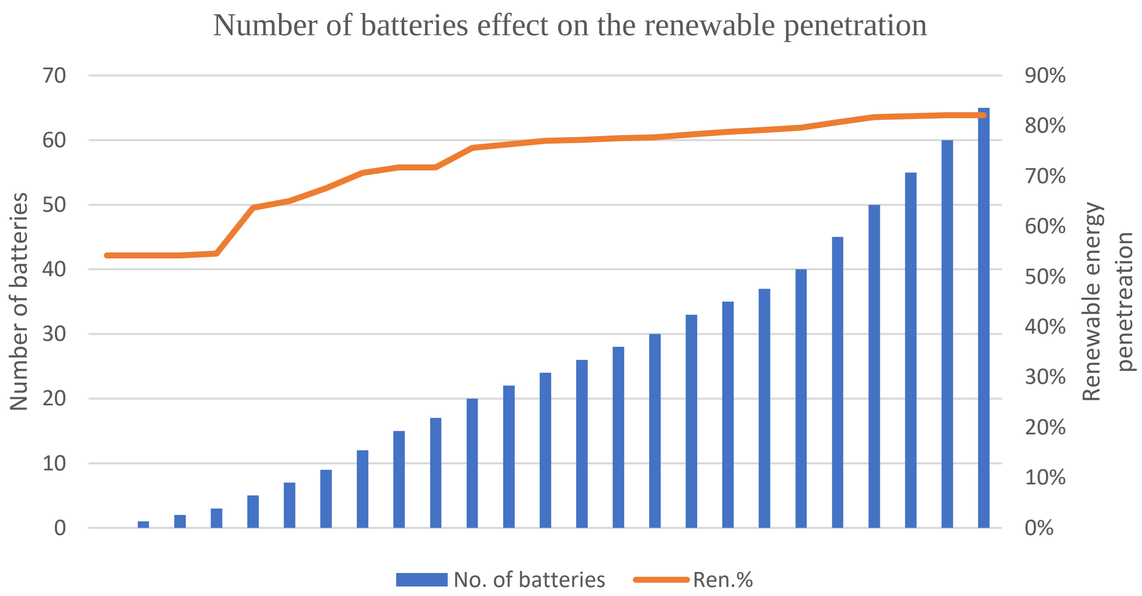


Figure 41: The effect of increasing the number of batteries on renewable energy penetration. 100KWh Li-ion battery was used as the storage capacity and then the number of the batteries were increased gradually until 65 batteries.

Increasing the storage capacity would result in decreasing the NPC cost due to the saving from the electricity purchases that can be achieved by the storing the surplus amounts of electricity.

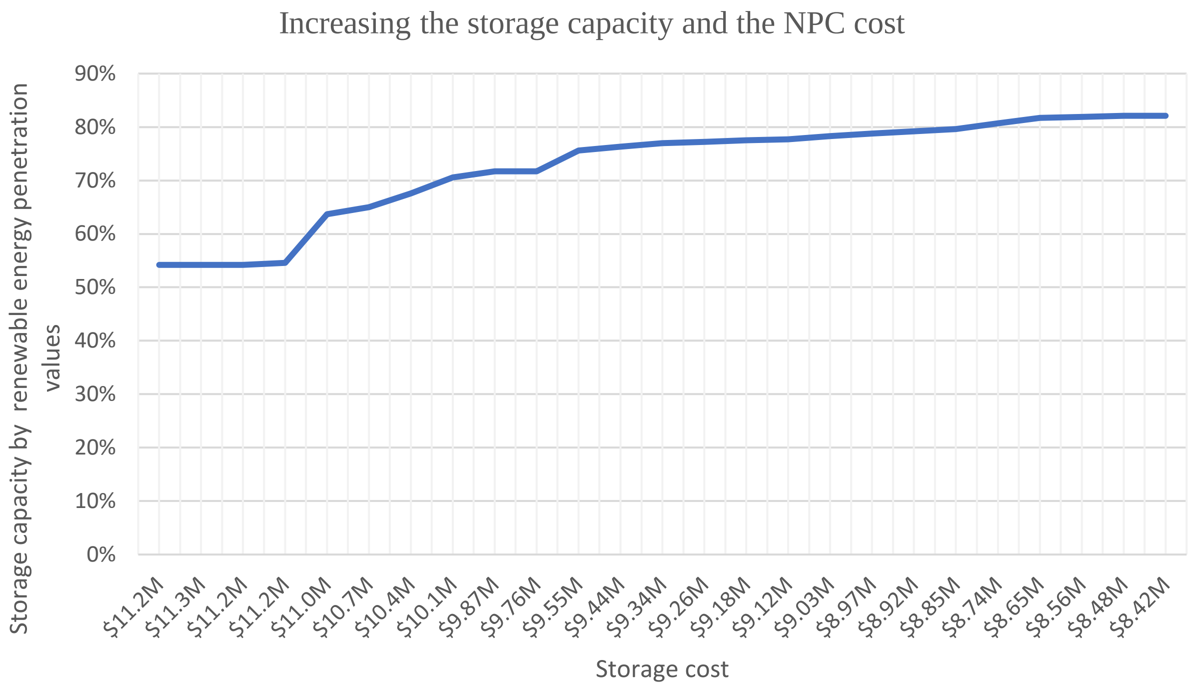


Figure 42: Increasing the storage capacity effect on the NPC cost. Savings from the purchased energy from the grid would result in the semi-fixed CAPEX cost for the batteries when the renewable penetration exceeds 75%.

Solar power has a strong potential in Khartoum Sudan due to the high GHI solar rates. Adding 1.1 MW photovoltaic system was the second choice to be examined by the software simulator. The output without batteries was plotted to check the ability of the PV panels to cover the demand in the town and the renewable penetration was 28%. *(See figure 40)*

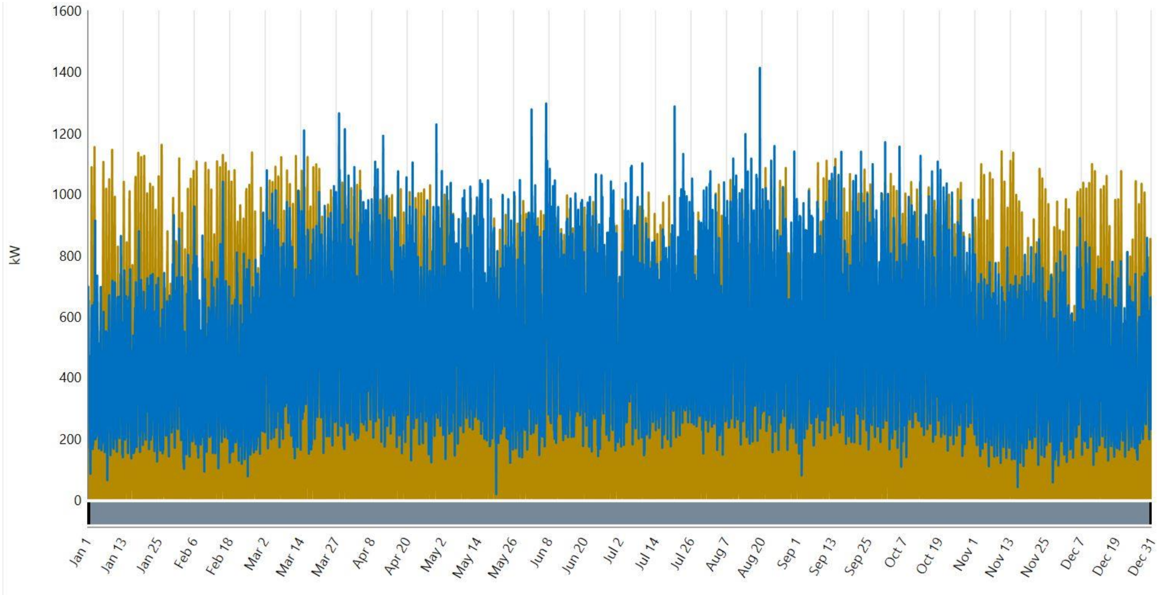


Figure 43: The 1.1 MW PV unit power output VS the primary load in El-Munawara town

The effect of the number of batteries on the PV panels systems has a significant effect because the PV systems produce electricity during the day hours and the surplus of the energy output needs a storage facility to be stored in. The effect of increasing the number of batteries on the renewable energy penetration was tested by increasing the number of the batteries from 1 to 20 gradually. *(see figure 44)*

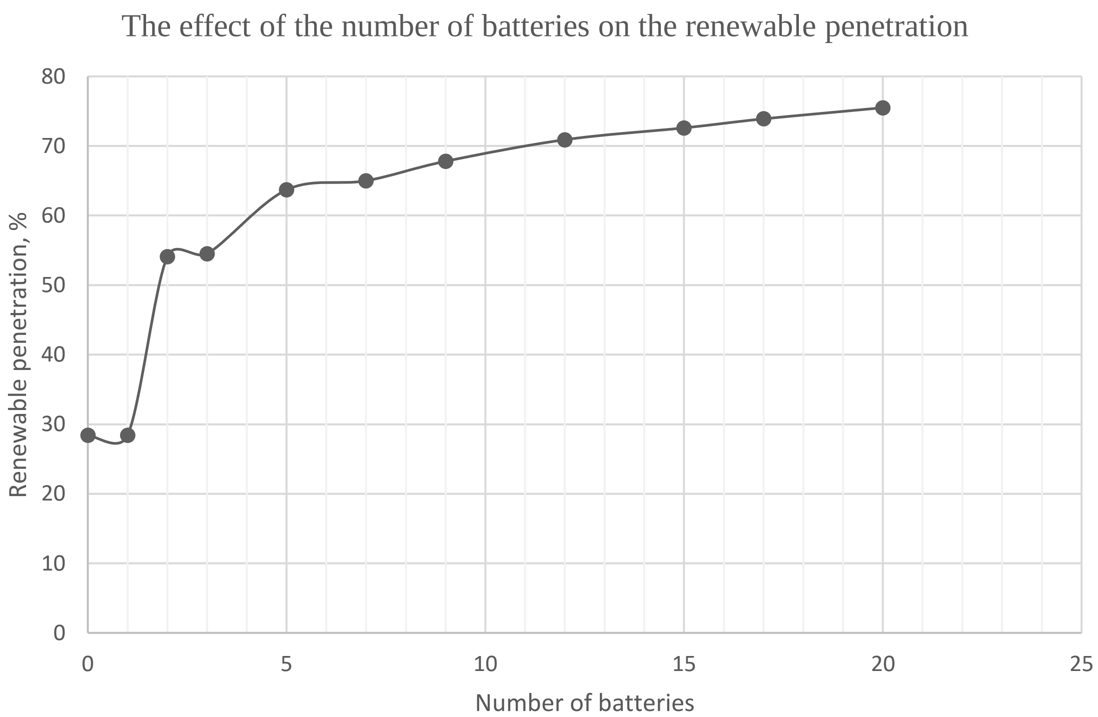


Figure 44: The effect of the number of the batteries on the 1.1 MW PV solar system

The effect of increasing the number of batteries in the NPC cost is surprisingly interesting. The NCP cost would decrease by increase the number of batteries and that is due to the increments in the renewable energy penetration which will decrease the energy purchases from the grid. Another investigated effect was the effect of the storage capacity on the net present cost (NPC). Figure (45) shows the effect of increasing the batteries number on the NPC cost.

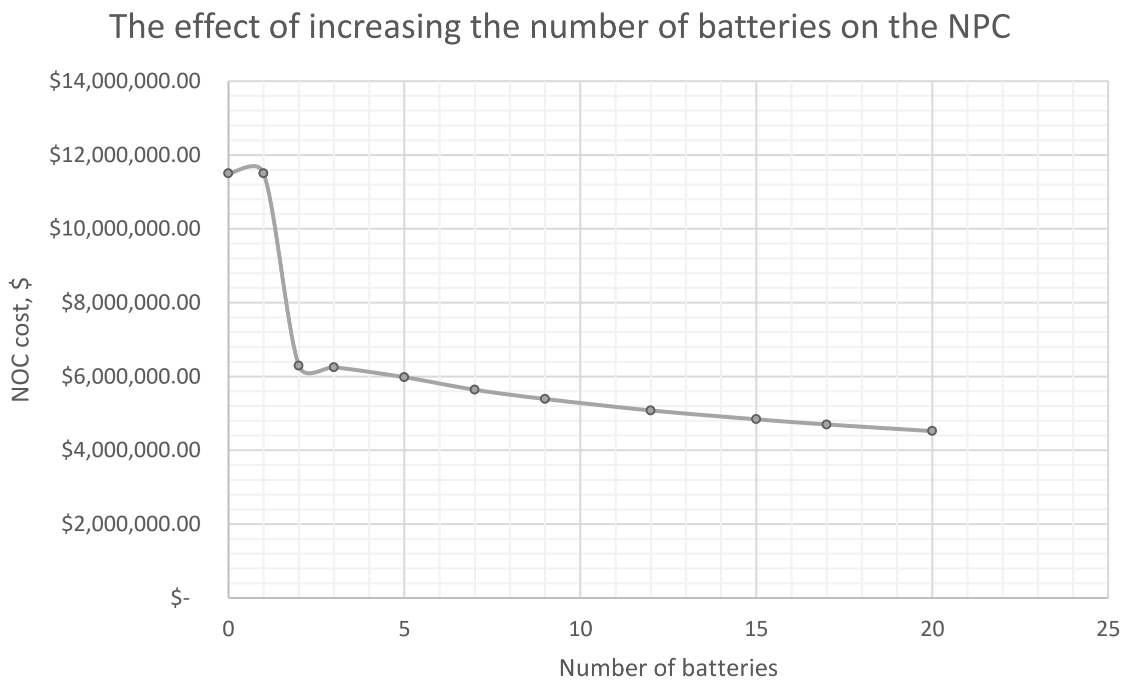


Figure 45: The effect of increasing the number of batteries on the PV panels system of 1.1 MW, increasing the number of batteries would result in increasing the renewable penetration which would decrease the energy purchases from the grid

Combinations between different cases were examined in the software simulator to find the optimum solution for the renewable energy supply. The different facilities examined included:

- 1165 KW PV panels system that manufactured by Ingeteam Company
- 330 KW PV panels system that manufactured by Schneider Company
- 630 KW PV panels system that manufactured by Schneider Company
- 1650 KW wind turbine that manufactured by Vestas Company
- 2000 Kw wind turbine that is manufactured by Enercon Company
- 30 Kw PV panels system that is manufactured by Huawei Company
- 8000 Mw wind turbine that is manufactured by Vestas Company
- 100 kw Li-Ion battery

Table 30: Different solutions obtained from the software simulator

SOLUTION	TOTAL RATED CAPACITY, KWH	NCP	REN. %
1. INGETEAM 1165 KW +SCHNEIDER 680 + XANT 330 KW	2175	7,310,000	73.10%
2. INGETEAM 1165 KW +SCHNEIDER 680	1845	7700000	66.80%
3. INGETEAM1165 PV PANELS (1165)	1165	6320000	52.90%
4. INGETEAM1165 PV PANELS (1165) + 100 KWH BATTERIES	1165	6430000	52.90%
5. VESTAS V82 WIND TURBINE (1650KW) + ENERCON E82 WIND TURBINE (2000KW)	3650	2270000	80%
6. VESTAS V82 WIND TURBINE (1650KW) + ENERCON E82 WIND TURBINE (2000KW) + HUAWEI SUN PV PANELS (2000KW)	5650	2310000	80.50%
7. VESTAS V82 WIND TURBINE (1650KW) + ENERCON E82 WIND TURBINE (2000KW) + SCHNEIDER PV PANELS (630KW)	4280	2340000	87.70%
8. VESTAS V82 WIND TURBINE(1650KW) + ENECON E82 (2000KW) SCHNEIDER PV PANELS (630KW) + INGETEAM PV PANLELS (1165KW)	5445	6270000	92.70%
9. 2 ENECON E82 (2000KW) SCHNEIDER PV PANELS (630KW) + INGETEAM PV PANLELS (1165KW)	5795	6940000	93.80%
10. VESTAS 164 WIND TURBINE (8 MW)	8000	3040000	79.40%
11. VESTAS 164 WIND TURBINE (8 MW) + ENERCON E115 WIND TURBINE (3 MW)	11000	2370000	92.20%

12. VESTAS VES8000 WIND TURBINE (8MW) + ENERCON E115 WIND TURBINE (3MW) + 5 100KWH BATTERIES	11000	5150000	89.90%

For the solutions that were obtained by software simulation modeller, the renewable fraction and the Net Present Cost (NPC) were plotted. Figure (46) shows the solutions that were obtained by the software simulator and the NPC of them.

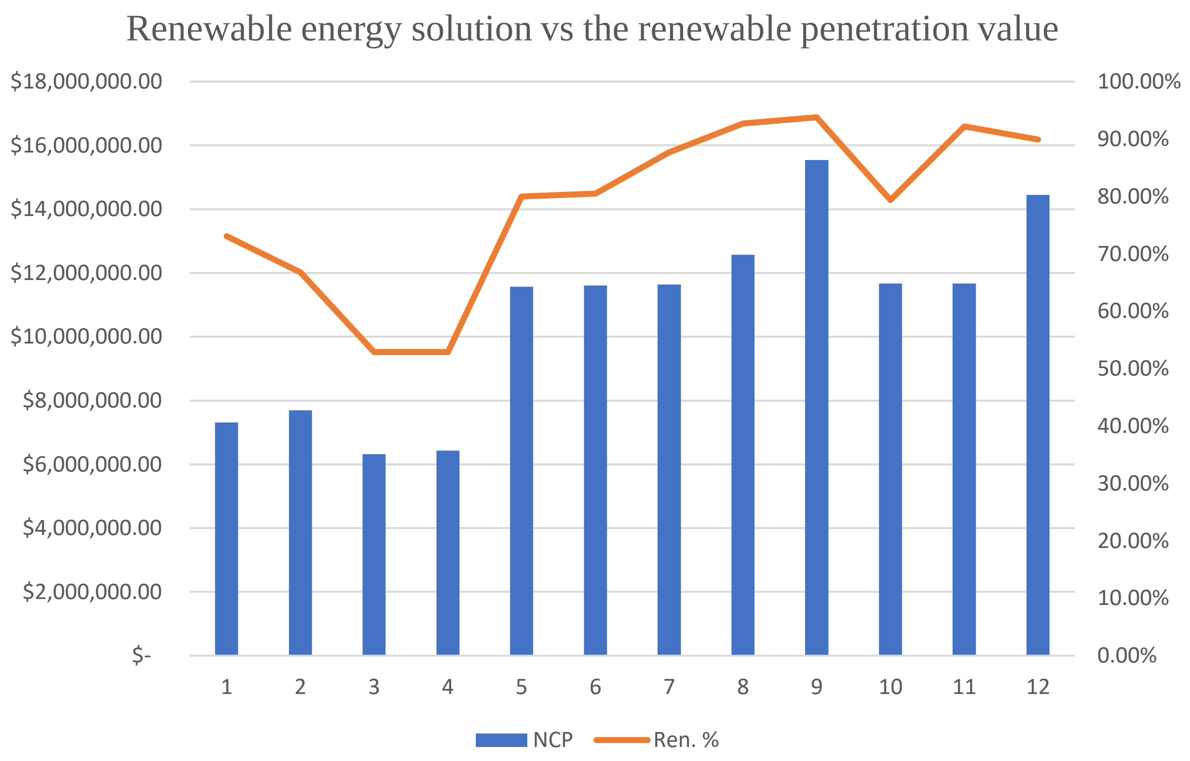


Figure 46: Different solution were obtained from the software simulation modeller (HOMER); the figure shows the renewable penetration and the Net Present Cost (NPC) of each solution. The number of every solution can be found in details in table (30)

The power output from the 2 Mega Watt wind turbine was plotted against the primary load to check the coverage of the supply source to the load and to find the power surplus that would happen in case of supplying the town by renewable energy from wind.

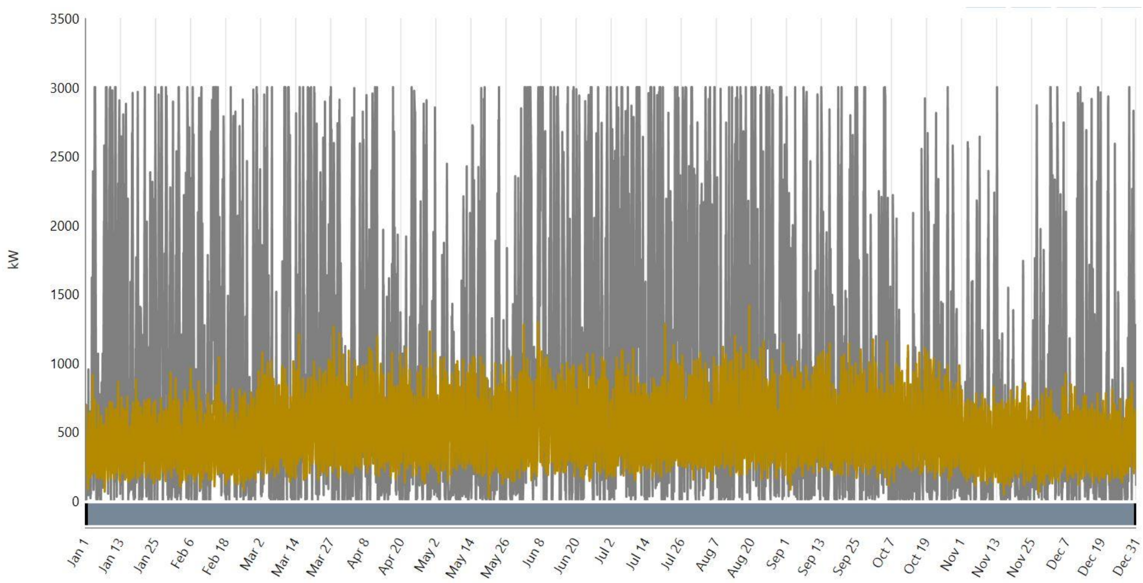


Figure 47: Primary power load in El-Munawara town (Brown colour) Vs the power output (Grey colour) from Enercon wind turbine of the 2 MW capacity. The figure shows that the power output is highly over the primary demand in the town. The power surplus cannot be sold to the grid but it can be returned voluntary.

9.2 Answering the research questions:

- *Can El-Munawara town be supplied totally or partially by renewable energy?*

The town can be supplied totally by renewable energy by a penetration up to 96% considering a reasonable cost. 8 MW wind turbine with a combination with another 3 MW wind turbine and 1.1 MW PV panels system and 50 batteries of 100 KW storage capacity battery can give up to 95 % renewable penetration; however, this solution is not practical and not economically sufficient because it costs more than $23 Million dollars.

The most practical solution that was found by the simulation process was a combination between the 8 MW wind turbine and 3 MW wind turbine and a storage capacity of 50 batteries of the 100 kw battery.

- *Can the intermittent renewable energy supply cover the town supply during the blackouts and the electricity cuts?*

The blackouts and electricity cuts shapes 30% in Khartoum, Sudan (H. Ibrahim, 2018), meanwhile the renewable supply can cover up to 89% of the supply, which means the blackouts and electricity cuts are going to reduce by 19% giving a possibility of occurrence of 11% to blackouts and electricity cuts in the worst cases. The apparent issue with the blackouts in Sudan is that they are not scheduled which makes it difficult to predict when they would happen.

- *Does it require storage facilities to facilitate the intermittent renewable energy supply?*

As has been previously reported in the literature, storage facilities have a great significance on the output of the renewable energy systems generally and in Khartoum, Sudan as has been proved in this study. An increment in the power output of more than 55% can be achieved by increasing the storage capacity in wind energy case. On the other side, an increment of up to 40% can be achieved by increasing the energy storage for the PV panels system. This value can vary and can be more than this in a number of other countries, but due to the high temperature degrees in Khartoum, the PV panels efficiency decreases.

- *By how much would the air pollution be reduced if the town is on renewable energy supply?*

As the renewable penetration that can be achieved can reach up to 89%, the carbon emissions per capita from the electricity consumption would decrease by same value. Furthermore, there would be no emissions from energy transmissions because the supply would be very close to the load.

10 Conclusion and Recommendations

The research concluded these points:

- Wind energy is the most suitable renewable energy source that can be used in Khartoum to provide renewable energy to the town of El-Munawara,
- Increasing the renewable energy system capacity would not increase the renewable energy total penetration and that is due to the sporadic manner of the wind and solar,
- Increasing the storage capacity would increase the renewable penetration for both the wind systems and the PV systems, and
- The NPC cost would decrease by increasing the storage capacity and that is due to the decrease in energy purchases from the grid

The research concludes that wind energy with the appropriate energy storage have a better potential than the PV panels systems to provide the town of El-Munawara by renewable energy.

11 Future work

A more systematic and theoretical analysis is required for the effect of the converter in the power output from the renewable facilities in Khartoum, Sudan as a future consideration. Furthermore, scaling up the study to involve the whole city of Khartoum would be an important pursuing to this study.

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