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A Comprehensive Review of Possibility using Solar Energy for Electricity Generation in Libya

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ABSTRACT

Libya suffers from electricity shortages, and many challenges will have to be overcome to meet future increases in electrical demands. The deficiency of electricity generation in Libya is clearly manifested in the fact that demand on electricity still exceeds its supply as blackouts become more frequent. In peak demand time, blackouts and outages are the major phenomena in almost all the Libyan regions. Due to technical issues, illegal connections and throughout the lengthy civil war, the generation and transmission in addition to distribution functions suffered partial destruction and consequent outages. For all the mentioned problems, Renewable energy sources and technologies have potential to provide solutions to the long-standing energy problems being faced by the Libyan electricity. Alternative renewable energy sources like solar energy technology can be an important part of Libya's plan not only to add new capacity but also to increase energy security, address environmental concerns, as well as to overcome energy shortage. Libya is very rich in solar energy resources and possesses large wasteland areas in the Sahara that represent 88% of the total area and much of this is relatively flat. Libya is one of the countries with the abundance of this type of energy, with a daily average of the sunshine reached to 8.1 kWh/m2 /day, and where annual solar activity more than 3500 kWh/m2/year on the horizontal surface. Losses in the transmission and distribution system will be reduced since power is generated near loads. The grid availability and stability will increase and individuals can save money in their electricity bill and finally the generated power is clean and nonpolluting. This paper presents the main sources of alternative renewable energy in Libya and its potential besides the main reasons Libya is turning to alternative energy solutions; to fully utilize its renewable energy resources, fulfill the energy demand in the future and to reduce the outages of electricity and carbon emissions. The study also found that, there is need to investigate more the potential of offshore-wind, biomass, and hydro (tide and wave thermal energy).The paper finishes with some conclusions and recommendations.

KEYWORDS: *Libya; Energy; Electricity; Renewable Energy; Solar Energy; Solar thermal electricity; PV-Photovoltaic*

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1. INTRODUCTION

An energy crisis is one of the most casual problems of the 21st century. Consequently, the demand for energy is increasing rapidly to meet the requirements of the world's growing population. Therefore, it is important to find a reliable and cost-effective renewable energy source and to demonstrate emerging energy demand in the future. The most challenging faces the world is how to fulfilling the requirement of energy. Due to the limitation of the conventional resources, the world must find another alternative source of energy (Yadav et al., 2015). In many countries today, have implemented several initiatives to emphasize the development of renewable energy resources and stabilise carbon dioxide emissions to a sustainable level, and therefore, to reduce these emissions, various policies have been introduced in the electricity sector worldwide. The use of renewable energy as an electric power source is one of the most effective policies adopted by the energy sectors in all regions of the world. Solar energy, among other renewables, is a promising free energy available to manage long-term problems in the energy crisis, in addition to its abundance, and provides a solution for fossil fuel emissions and global climate change (Dawn et al., 2016).

Renewable energy sources and technologies can provide solutions to the long-term energy problems faced by developing countries like Libya (Khalil & Asheibi, 2015). Renewable energy is energy that is collected from renewable resources, which is naturally replenished on a human time scale such as sunlight and wind, and can be used to overcome the energy shortage in Libya Saleh, (2006), rain, tides, waves and geothermal heat however, all these sources have less potential in Libya (Asheibi & Khalil, 2013). Solar and wind power is the cleanest source of energy with the lowest carbon emissions or pollution. This helps decrease dependence on coal and other fossil fuels. To meet energy necessities as a result of rapid economic development, Libya require further guaranteed energy supplies than the total energy consumed today, thus, will have to build a new infrastructure in Libya after the massive destruction that occurred in consequence of the civil war over the past nine years.

Libya forms the middle of North Africa and is located between latitudes 20° and 34° N and longitudes 9° and 26° E, with an area of almost 1,759,540 square Kilometers which considered is one of the largest countries in Africa. Up to 88% of the country area, the south is located in the Sahara desert where there is high potential of solar radiation which can be used for electricity generation (Ekhlat et al., 2007). The geographic location of Libya situated in the solar belt region with an ideal direct solar radiation level indicates that Libya is promising country for the implementation of the Concentration Solar Power (CSP) for electricity generation. According to it is coast line it has about 1900 Kilometer coast on the Mediterranean Sea with a population of 6 million, mostly located along a thin strip along the coastline. The annual growth is 2.5%. Population intensity is high in the northern coastal area with average of 50 capita/km^2 when in the south is 1 capita/km^2 (Belgasim & Elmnefi, 2014).

Solar power generation demand increases worldwide as countries strive to reach goals for emission reduction and renewable power generations. Solar energy is deemed as one of the cleanest types of energy, which can be used as a substitute to fossil fuel energy resources and can slow down global warming (Najafi et al., 2015). Solar energy is one of the best renewable energy sources, for this reason different countries have formulated solar energy policies to reducing dependence on fossil fuel. The measurement of solar energy data in all Libya areas is essential for evaluating the advantages of using solar energy. The viability of solar radiation data is vital for the economical use of solar energy. The Libyan government concerned with the necessary and appropriate studies of development alternative energy for crude oil and which of these energies is the most appropriate use and economic cost as well as of course the most environmentally friendly, the solar energy is the favorite among these alternative solutions and for several reasons, namely:

- Libya atmosphere is characterised by high number of sunny hours during the year (12 months).
- High percentage of sunny days to rainy and cloudy days, even in winter.
- Easy installation of solar systems.

All these factors lead to the result to make solar energy the first choice for alternative energy source after the crude oil in Libya. The present paper outlines and describes the potential of solar energy within Libya. The work begins with the description of the current energy situation, with load profile oil and gas position. Subsequently, a literature review of the published studies in Libya is presented.

The study aims is to promote public awareness and to highlight the research hot points in the field to encourage and guide future research in order to deploy this technology in the country and inspire local governments to dedicate additional efforts and funds as well as have to be more aggressive targets to promotion of renewable energy to achieve environmental sustainability in Libya. Finally, the conclusions drawn from this study and the recommendations are presented for further consideration.

2. The Current State of Energy in Libya

The General Electric Company of Libya (GECOL) is totally government owned and is responsible for the operation of the entire power sector in the country. All power plants in Libya have been installed by GECOL since it was established in 1984. Gas and oil play a key role in ensuring a sustainable future for Libya as this energy source is used for electricity, therefore any strategy to reduce CO_2 emission levels must address the efficiency of power stations based electricity in the main cities and the province centers (Ahwide & Aldali, 2013).

2.1. Oil Situation

Libya's economy is heavily dependent on hydrocarbon production. The state is one of the top oil and gas producing countries in Africa and in the world. According to proven oil reserve Libya is the first African holder with about 48.363 billion barrels. In addition to proven gas reserve Libya is the fourth African country which is roughly 53.1 trillion Cubic feet. However, Libya has the same challenge which is related to ascent consumption of energy in the near future (Albarghathi et al., 2018). While the production and consumption of energy are increasing significantly, the country is still mainly dependent on oil and gas to provide the required energy. By burning more oil and gas internally reduces the countries revenue and increases the CO_2 emissions (Shoroug et al., 2019). Notably, oil exports revenues are significant to the country's economic development since they account for 90% of the total revenue (Grein et al., 2007). Before the 2011 the country was producing 1.68 million barrels per day (bpd), of high-quality oil. Almost, 70% to 85% of Libya's crude oil is exported to Europe, by statistics it clears that, Europe gets over 85% of Libya's crude exports, such as Italy 376,000 bpd (22%), France 205,000 bpd (16%), United Kingdom 95,000 bpd (9%), Greece 63,000 bpd (15%), Germany 144,000 bpd (8%), Spain 136,000 bpd (12%) and others (14.5%). While, the rest goes to China import (3%) in roughly 150,000 bpd of crude oil from Libya, as well as the United States in 2011 with an average 95,000 bpd. Although in 2013, the exportation were drop it to about 75% of Libya's crude oil Europe (El-Osta & Elghawi, 2020). The National Oil Corporation (NOC), a state-owned company was planning to reach 2.5 million bpd by 2015. However, this target was not reached because the lack of security. Therefore, the production decreased to 1.4 million bpd after 2011, leaving the total crude oil reserves about 47.1 billion barrels. As for the plants fueled by oil, whether heavy or light, have suffered from the fuel supply being cut off sometimes, and GECOL regularly loses at least 600 MW of the installed capacity due to the restraints forced by fuel supply (Asheibi & Khalil, 2013; Saleh, 2006). In Figure 1, it is clear that the oil situation in general and the most remarkable trend of the consumption is increasing sharply whereas, the production remains constant to the year of 2062 (Shoroug et al., 2019).

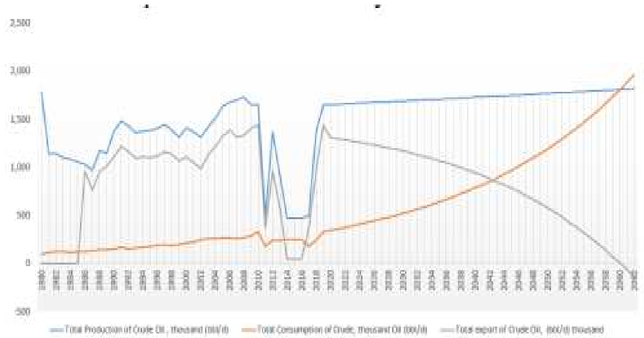

Fig. 1: Oil Situation (Exporting, Production, and Consumption)

According to the International Monetary Fund (IMF), oil and natural gas accounted for nearly 96% of total government revenue and 98% of export revenue in 2012. In 2013 and 2014, Libya experienced major swings in its oil production, falling to 0.2 million bpd at the end of 2013. Oil production had improved at the end 2016, where it had reached 0.7 million bpd and by the middle of 2017 it reached 1 million bpd and in 2019 arrive at 1.3 million bpd (El-Osta & Elghawi, 2020). On the other hand the oil output in Libya has fallen sharply since begging 2020 because of a blockade of ports and fields, and the production had dropped to 262,000 bpd, and could fall as low as 72,000 bpd within days, where before the stoppage was 1.3 million bpd (NOC, 2020). In contrast, the cost of the barrel of oil is decreasing nowadays and this may lead to a sharp drop in the national revenue, as exporting oil represents the main share of national revenue.

2.2. Natural Gas Situation

The natural gas is considered the second precious resource for production the country depends on after the oil in generating electricity (Shoroug et al., 2019). The proven natural gas reserves reported in 2012 is 52.8 trillion cubic feet. Libyan natural gas production and consumption is shown in Figure 2 (Khalil & Asheibi, 2015). However, the reliance and dependency on gas increased recently both for electricity generation and for the reduction in CO2 emissions and for exportation particularly after Libya began to export to Italy where 50% of its production is exported to Italy (Asheibi & Khalil, 2013). The increase in the gas consumption is due to the reliance on the gas instead of the oil for electricity production. According to, Libya's natural gas industry recovered in 2012, but its production still below the level of 2011. (El-Osta & Elghawi, 2020) stated that, Libya's proved natural gas reserves were about 55 trillion cubic feet in 2014, which makes it the fifth-largest natural gas reserve holder in Africa.

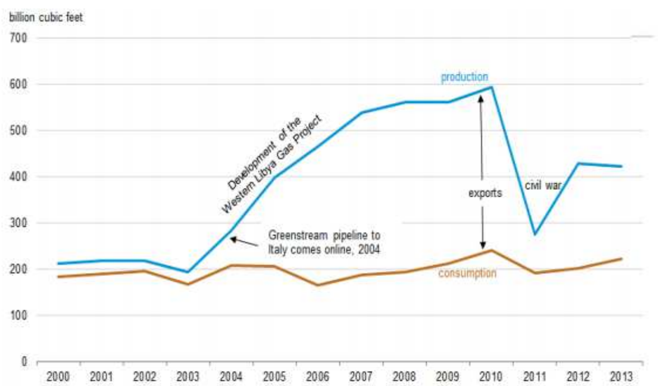

Fig. 2: The Natural Gas Production and Consumption from 2000 to 2013

However, natural gas reserves which stand at 1,300 billion m^3 is unlikely to be depleted in the next 50 years. A big proportion of Libya's energy resources are exported. Future prospects of the energy sector in Libya are not promising if the current trend is continued (Mohamed & Masood, 2017). Most of the GECOL generating units are gas turbine, which is considered an excellent option environmentally but not economically; since they need a higher maintenance requirement with a constant inspection than that of steam turbines. In recent report by GECOL, (2017b) indicated that the consumption of natural gas in Libya 157,147 million cubic feet (MMcf) per year and 23,880 cubic feet per capita every year, or 65 cubic feet per capita per day as of the year 2017.

Both kinds of energy have continued to play a major role in the country's economy since they are an important feed stock for many industries and more than half of the energy production of oil and natural gas are exported. For the sake of saving oil and reducing the CO2 emission, more gas fired power plants have been installed. In addition, according to the GECOL report the energy produced 37% and 54% from the oil and from the gas respectively (Shoroug et al., 2019; Albarghathi et al., 2018; Khalil et al., 2017). Oil will continue to be the dominant fuel, despite the share of gas which rose from 38% in 2010 to 41% of total energy demand by 2030. The main increase in gas demand will occur in the energy sector between 2003 and 2030, since 51% of total production will be gas-fired by the year 2030 (Mohamed et al., 2013b).

Generally, the Libyan energy market statistics provide an understanding on the dynamics and key issues that shape the energy market as well as the economy. In order to meet electricity demand in the future, the government of Libya needs to develop a strategic long term plan to ensure sustainability. Energy consumption planning is essential for the country's development. The roadmap includes increasing the use of natural gas, increasing the share of Renewable Energy sources and adopting energy efficiency programmes. A national renewable energy plan has been devised with a target of contributing 10% of the country's electricity demand by 2050. The population of Libya is likely to grow to 10 million by the year 2050.

3. Current Electricity Situation in Libya

All power plants in Libya have been installed by GECOL and are responsible for the operation of the entire power sector in the country. It is a state owned vertically structured power utility with a monopoly over generation, transmission and distribution. Fossil fuel-fired thermal power plants are used to meet all of the electrical energy demand. In Libya, all of the electrical energy demand comes from fossil-fuelled power plants, with a total number of 12 power plants in 2014 most of them are located along the coastal side of Libya, and were the 85% of population live (Khalil & Asheibi, 2015; El-Osta & Elghawi, 2020**)**. Because of population density, logistical *issues and other* technical and financial reasons, most of the power plants are located at the north on the coast. However, many villages or remote areas are wide spread over the large country's territory and located far away from the national electric grid. Many villages are not connected to the national grid. For these rural and remote areas, with small populations and small energy demands, it is an interesting option to rely on renewable energy for different applications (such as electricity, water pumping) and to replace traditional diesel generators.

Since 2011 the country has been neither politically nor economically stable and many sectors of the infrastructure were damaged including those of GECOL. In addition the lack of security and safety led to the suspension of most projects, a large increase in thefts, and a decrease in the GECOL ability to carry out maintenance. The result has been a decline in network performance and a severe shortage of power generation, causing long power outage in many parts of the country, especially during summer and winter peak periods (Elmanfi et al., 2019). Despite the difficulties and obstacles Libya had suffered since 2012, moreover, in order to solve this GECOL has commissioned new generation units with an addition of 2.295 GW to the installed capacity to cover the demand that has consistently grew at around 4% per year (Shoroug et al., 2019).

The power plants are capable of supplying 8.347 GW while the available capacity is 6.357GW in 2015. While in 2017, the power plant installed capacity is 10.238 GW but the available capacity around 5.345 GW which represents 52.2% of installed capacity GECOL, 2017a; Elmanfi et al., 2019). The peak load of electricity continues to increase in a growth rate from 7 to 10% per annul which constitutes a great challenge for Libya's power sector (Mohamed & Masood, 2017; El-Osta & Elghawi, 2020). Furthermore, the difference between the generation and the consumption forcing the GECOL to apply load shedding in order to secure the stability of the power system.

Indeed, GECOL has serious financing issues due to partially low electricity prices (around 0.02 LD/ kwh) and also to the fact that only 40 % of Libyans pay their energy bills. Included in 2013 public budget of the state which approved by parliament, 12 LD million for the implementation of projects related to renewable energy, but it did not accomplish any projects in this regard and the outcome of implementation of the plan is 'zero' until now (GECOL, 2017a). Therefore, within few years with the rate of production and consumption conventional sources it also consumes them internally to generate electricity will deplete causing an increase in their cost and maybe unable to cover for the future load demands.

3.1. Electricity Network

Based on the fact of big area and distributing populations in different and far area, the power plants in different areas and the centers of the loads are connected by each other through means of transmission lines networks system at different levels of voltage (Al-Hashmi et al., 2017). The voltage levels which is used in Libyan grid as main power transmission between the generating power plants and the load centers in different regions are 220 and 400 KV (Ahwide & Aldali, 2013), while the power is transmitted in each local regions through 66, 30, 11 KV lines. The transmission lines is facing many problems related to the operating and maintenance issues, as well as the problems which connected to the environmental effects, such as salt sediments, wind containing large volume of very soft sand…etc. these problems are causing numerous faults or even local blackouts. However, the wide area and fragmenting loads force GECOL to provide yearly continues investment to deal with the load growth and to save continues flow of the power for all the customers (Al-Hashmi et al., 2017). According to the World Bank Libya enjoys a well-developed national electric network have access to electricity that is accessible to 99.8% of the Libyan population and has connections with eastern and western neighboring countries, which is the highest rate among African countries (El-Osta & Elghawi, 2020; World Bank, 2020).

As another step toward reducing the gas emission beside the increasing reliance on the natural gas, the GECOL has built and improved its transmission line infrastructure, in order to minimize losses in the network and to improve its efficiency and reliability. The national electrical grid consists of a very high voltage of 400 kV with a total circuit length of 2,290 km of lines, divided across 14 substations with a capacity of 9,600 MVA. As for the high-voltage transmission level of 220 kV, the total length of the circuit is about 13,706 km of lines distributed on 81 substations with a capacity of 15.458 MVA. The sub transmission voltage level is 66 kV and 30 KV, with a total circuit length of 14,311 Km and 11,142 Km respectively (World Bank, 2017). The distribution network's voltage level of the transmutation lines is very long with a total length 41,449 km but not very powerful as in Figure 3, which illustrates the high and medium voltage networks within Libya (Ahwide & Aldali, 2013). There is an operating grid interconnection at 220 kV voltage level to Egypt with a capacity of 240 MW which is 180 km long and the interconnection between Libya and Tunisia was completed in 2009, also at the 220 kV level (RCREEE, 2016).

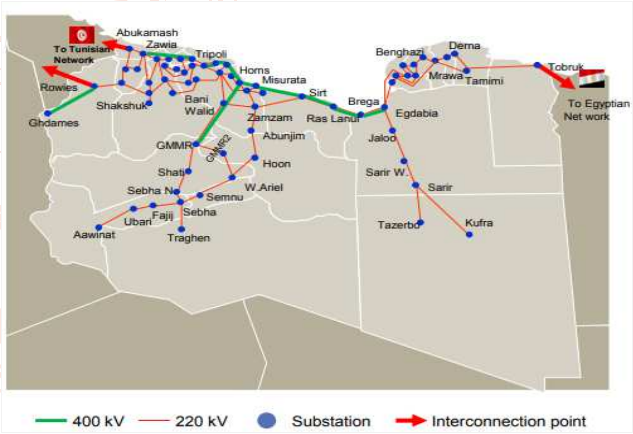

Fig. 3: Libyan National Grid (220 & 400 kV)
Source: World Bank, 2017

Libyan Electrical Network as any other electrical system suffering many problems and should be modernised to meet the smart grid requirements or at least to be ready for interfacing with the modernised electrical networks.

3.2. Electricity Demand

The high economic growth and greater investment in the oil and natural gas sectors, energy demand has risen rapidly in Libya over the last decade and high peak demand has led to many blackouts, because of unforeseen national events, GECOL faced a shortage in the energy production process, which led to load shedding 1200 MW of total peak load. The peak load growth rate of about 10 % per year in electricity, a fair amount of additional capacity will be needed in the near future which constitutes a great challenge for Libya's power sector (El-Osta1 & Elghawi, 2020). Considerations have to be given not only to the commissioning dates of future capacity additions, but also to the type of generating equipment that best fit the Libyan environment.

The peak load increased from 5.8 GW in 2010 and due to the excessive uses of the air conditioners to 5,981 MW in summer 2012 Guwaeder & Ramakumar, 2017), and reached in 2015 to around 8.347 GW as shown in (Figure 4) (Hana et al., 2017). Demand previsions are estimated around 10 GW in 2020 and could reach 16 GW in 2030 by electricity users in Libya (Ministry of Planning, 2019). These forecasts can be explained by the urbanisation process, population growth and industrialisation. Despite growth in electricity generation and a high electrification rate, the country suffers from regular outages and the oil sector is also affected by power supply issues. It is anticipated that Libyan electricity demand will increase more than two and half folds by the end of 2020 (Mohamed et al., 2015). The growth in electricity power demand will out-strip production capacity; therefore GECOL plans to build new combined cycle and steam cycle power plants. In addition to increasing generation capacity, GECOL also plans to upgrade and expand the country's power transmission grid (El-Arroudi et al., 2009). From an energy perspective, further expansion of the electricity grid and its integration in the region seems to be the country's major challenge.

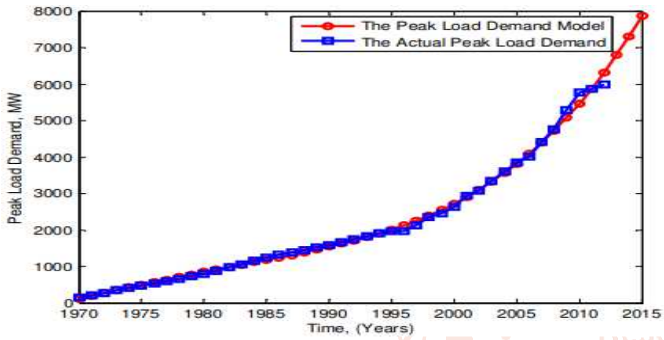

Fig. 4: The Peak Demand from 1970 To 2015

Due to the increased energy demands, the GECOL forced to apply load shedding and the major cities remain without electricity for days. As most of the loads are domestic there is a strong correlation between the load demands and the weather. The maximum load increases greatly in the hottest months in summer (June, July, Aug, Sept and Oct), is a result of the excessive irrational use of air conditioners while the peak load demand increases in the coldest months (winter) in the year (Jan, Fab and Dec), is correlated with the excessive use of heaters as illustrated in (Figure 5). The behavior of the electrical loads in Libya and the sun radiation in the region has been studied to show that an efficient peak load shaving can be achieved using solar energy (Khalil & Asheibi, 2015). The Figure shows the load profile based on maximum load throughout one year and the measured temperature at the region. The correlation of the temperature and the load demands is clear in the figure.

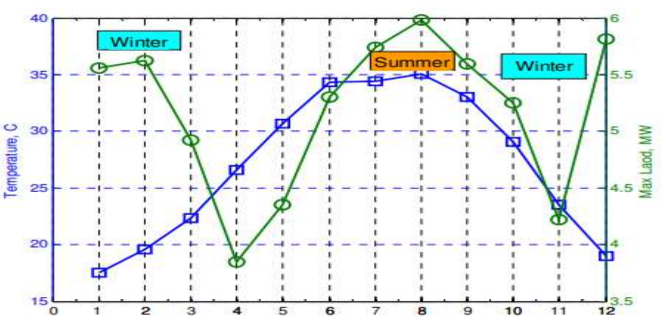

Fig. 5: The Load Profile and the Average Temperature throughout the Year

Libya is facing rising energy demands, which are expected to double within the next decade and the demand for electricity will triple (Jouini, 2019), and it is difficult to build new centralised power plants due to the weak economics and civil war in the country. One issue leading to rapid energy demand growth is the fact that electricity is heavily subsidized, at perhaps one-third of the cost per kilowatt-hour. Renewable energy could be the solution to cover some of this demand. Moreover, there is a need to attract investors in renewable technologies by enhancing the infrastructure and the existing investment regulations. Additionally the growth in population is causing significant increase in electricity demand all over Libya which is creating a considerable need for further investment in the infrastructure including power lines and additional power stations.

3.3. Distribution of Electricity Consumption

Overall consumption of the electrical energy in Libya is projected to increase by (21%, 16%, 19%, 8%, 6%) foreseen respectively, from 2010 to 2014, with use rises from 6706 MW in 2010 to 11298 MW in 2014, while from 2015 to 2020 increase by 3% yearly, to arrive 13714 MW in 2020 (Ahwide & Aldali, 2013). On the other hand the total energy consumed in 1990 was 10 TWh, and in 2012 reached to around 33.98 TWh as depicted in (Figure 6) which was based on the normal growth, and projected to reach 90 TWh in 2030 (Shoroug et al., 2019; GECOL, 2017a; Hana et al., 2017). Study by Hana et al., (2017) referred that, the rooftop grid-connected PV in Benghazi can generate 3.63 TWh which is around 10% of the Libyan electricity demands. Furthermore considering per capita electricity consumption, Libya still remains in first place with 3431 kWh/inhabitant in 2011. This is due to wide dispersion of the country, the lack of efficiency in electricity transport and infrastructure distribution and the high demand on electricity as a source of energy because of the ease access to this form of energy, particularly at a low tariff level (Jouini, 2019).

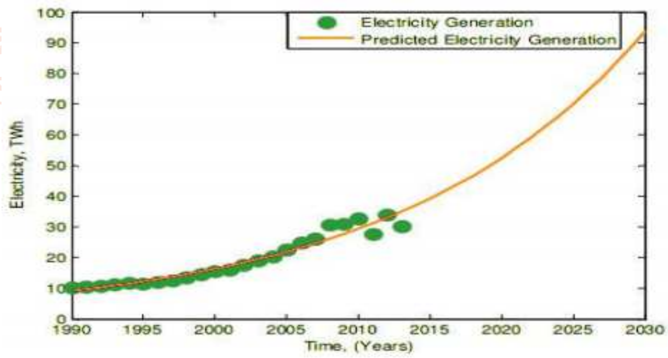

Fig. 6: Electricity Generation Through 1990 to 2030

The electric energy generated in 2012 classified sector wise is shown in (Figure7). It could be noticed that the domestic consumption is the highest. However, the share and the types of the loads in Libya indicate that residential represented more than one third (32%) of total electric energy consumption and street lightning (19%) are both the highest consumption load with the Libyan electricity demand by 2012 (GECOL, 2012; Jouini, 2019).

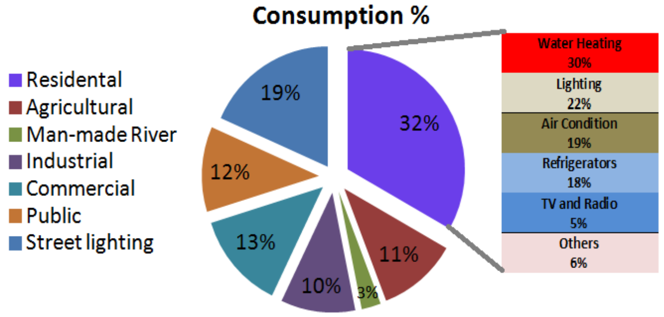

Fig. 7: Types and Shares of Customers of Libyan Electricity Generation in 2012

It could be noticed that more than a fifth of the electricity power consumption in Libya is from the street lighting and is above international standards. Where the country struggles to cover for the increasing load demands for numerous roads which are far from the grid requiring extra distribution, transmission, and generation costs, therefore, and appropriate measures should be taken towards this sector to save energy with the use of new technologies which can save up 80% (El-Osta & Elghawi, 2020). The roadmap includes increasing the use of natural gas, increasing the share of Renewable Energy sources such as solar energy and adopting energy efficiency programs.

These findings didn't really change nowadays if compare them to the findings found by GECOL in a recent study performed in 2017 as shown in Figurer 8, 9 at winter and summer season respectively.

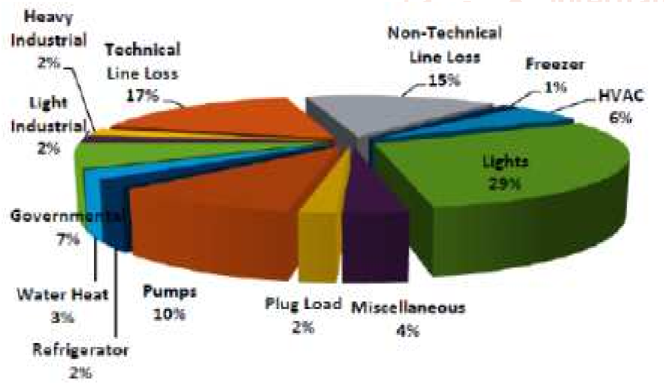

Fig. 8: Winter Peak Demand by Libyan End Use, 2017

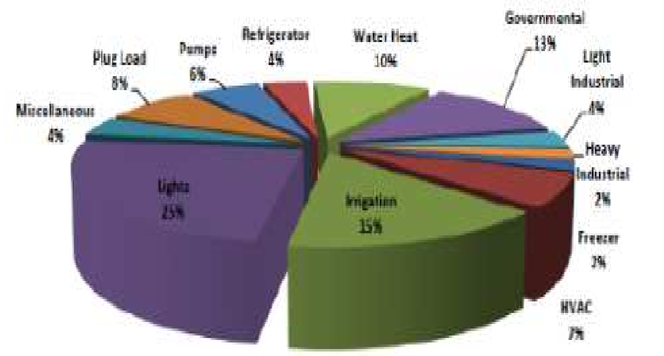

Fig. 9: Summer Peak Demand by Libyan End Use, 2017

From the figures can see that there is considerable potential to reduce peak loads through promoting the use of more energy efficient equipment such air conditioners, water heaters and lighting. Encouraging the shift to solar water heating is also an option. Large irrigation demand could also be replaced with solar powered water pumping and irrigation systems (Jouini, 2019).

As far as energy pricing is concerned, Libya as major energy producing country has heavily subsidized local price of energy. That's why it has one of the lowest values of share of energy expenditure in the household budget in 2003 and 2009 (Jouini, 2019). Furthermore, electricity consumption in Libya is generally high and the growth rate increased annually. This because of several factors, such as cultural norms and social life practices, but the most significant reason is the subsidised electricity tariff, the energy sector is subsidised, where the electricity tariff is considered to be the second least expensive in the world, where it ranges from 0.015 $/kWh for residential consumers to 0.052 $/kWh for public services and commercial consumers, while the generating cost is equal to 0.20 $/kWh (Sayah, 2017).

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

Libya needs an urgent national plan to improve its energy sector. The current energy system is inefficient and unsustainable. The electricity is heavily subsidized which is resulted in irrational use of electricity. The GECOL should initiate policies to give more room for the renewable energy and one of the steps to increase the renewable energy penetration is to develop feed-in tariff. This will allow the costumers and the private sector to participate in developing the renewable energy sector. Additionally, the new technologies such as the smart meters should be adopted to reduce the irrational use of electricity (Khalil & Rajab, 2017).

4. Renewable Energy Reviews

It is good to start this section by the following question: Why renewable energy for Libya? The answer not only because of the shortage in electricity but also because of: rising prices of oil and gas, ample resources and sites available, ecological hazards, government incentive, abundant sunshine, and increased financing options. Renewable energy is the energy produced by a natural energy resource such as hydro, solar, wind, biomass, geothermal, tides, waves and ocean energy are environmentally clean and non problematic sources of energy and due to their technical simplicity are certainly an interesting option in addition, have attracted increasing attention from all over the world due to their almost inexhaustible and non-polluting characteristics. These natural resources are free and continuously replenished. However, renewable energy generation systems are still more expensive than conventional ones and choosing to invest in these systems is a matter of resource availability and cost optimisation. Renewable energy resources are rapidly being recognized as clean sources of energy to withstand damages to environment and to avoid future crisis. Renewable energy could play an important role in the energy balance of Libya.

The conventional energy systems are ecologically problematic and it is estimated that, the life of oil reserves are limited and will not last very much longer; thus, a switch to alternative energy systems solutions is crucial. Furthermore the policy to burn them for their heat should be replaced by programs to save/utilize them towards achieving a sustainable development (Mohamed & Masood, 2017).

Libya as a major oil producing country has increasingly paid attention to the non-fossil energy resources, in particular to renewable energy sources for its longer term energy plans. In order to reduce its dependence on fossil fuels and to promote renewables, the Renewable Energy Authority of Libya (REAOL) was founded in, which are supposed to be in order to implement the National Renewable Energy Plan and to promote and supporting as well as responsible for the development of the renewable energy sector also established that assists different industries and companies, which produce renewable energy in Libya where has established targets up to 2030. Intermediate targets are 6% through 2015 and by 2020 rising to 10% as shown in Figure 10. Long-term plans are to meet 25% of Libya's energy supply via renewable energies by the year 2025 and by 2030 the renewable energies are projected to contribute 30% of power generation, which mainly includes wind energy, CSP, Photovoltaic (PV) and Solar Water Heating System (SWHS) (REAL, 2016). While attainable, this objective requires strong political and financial supports as well as immediate action by the government. Off course, 30 percent renewable energy contribution in only 10 years needs determination, data acquisition, technology achievements and planning. For this purpose crucial elements of a national programme should be defined. Due to the instable situation in Libya this plans is suspended.

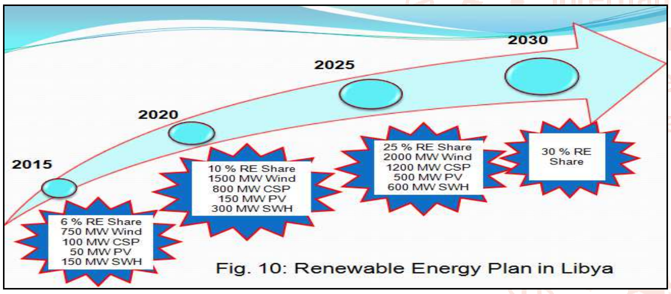

Fig. 10: Renewable Energy Plan in Libya

The advantage of utilizing both renewable and traditional energy sources is that the deficiency in one source can be filled by the other one in a normal or controlled mode. Now, Libya in especial case, planned to make the share of the renewable energy to be 20% in 2020 of the generated power. The projects planned are mainly solar and wind energy systems. By the year 2020 Libya will generate around 20% of its power from solar energy. This will be around 3 GW (20% of around 15 GW) (Khalil & Asheibi, 2015). Nevertheless the current renewable energy share in Libya is negligible and is not yet a priority of the Libyan economy, the share in the energy mix is underutilized and form 1% of the energy used in the country. The target has not been achieved because of the instability. Additionally there is no true will to launch these projects (Khalil & Asheibi, 2015); Mohamed et al., 2013a). The government therefore plans to utilize the renewable energy sources to their full potentiality by the year 2050 in order to satisfy the energy requirements of the country and still export the excess energy. This means that by 2050, Libya will be using the renewable energy more that the fossil energy a reverse of the situation as it is now (Mohamed & Masood, 2017).

From the author perspective, Libyan decision-maker should admit that it's important to support the economy with renewable resources to maintain the standard of living and facing the country's growing demands for energy not only for energy supply but also for financial revenues, sustaining the public budget as well as providing good service to the people in scattered villages and countryside areas.

A number of instruments to improve the investment climate have emerged at global, regional, national and subnational levels. Various factors, including poor governance, institutional failures, macroeconomic policy imperfections and inadequate infrastructure, as well as weak legal systems and a lack of transparency in government departments, all lead to an unfavorable investment climate.

The strategy has been revised because nothing has been achieved up to 2019 and to introduce the Renewable Energy Programme as an integral part of the national energy strategy (Figure 10). The Libyan authority expects then the renewable energy to reach 10% of energy demand by 2025 and 22% by 2030 as explained in Table 1 (Jouini, 2019).

TABLE 1 New Strategic Plan for Developing the Renewable Energy in Libya (2019-2030)

	Phase 1	Phase 2	Phase 3	Phase 4	Cumulated Production (MW)
Year	2019-2021	2022-2024	2025-2027	2028-2030	
Wind Power	300	200	200	150	850
Solar Concentrates	-	-	100	300	400
Solar Cell Technology	850	900	1050	550	3350
Total Power MW	1150	1100	1350	1000	4600
% RE	5%	11%	10%	17%	22%
Total Required Investments (Million US$)	1380	1320	1620	1200	5520

Source: Based on Renewable Energy Authority of Libya (REAOL) and Ministry of Planification data

5. Solar Energy

Renewable energy technology and in particular solar energy is being considered worldwide due to the fluctuations in oil prices, global warming and the growing demand for energy supply (Solangi et al., 2011). Today, solar energy is being utilized vastly in many countries for power generation as well as heat production. Based on published statistics by International Energy Agency (IEA) in 2010, found it in Hosseini et al., (2013) the growth trend of solar energy is higher than other RSE during these years. Table 2 depicts the trend of different Renewable and Sustainable Energy (RSE) growth in the world.

TABLE 2 the Trend of Different RSE Growth in the World

RSE	The rate of growth (%)
Solar energy	42.3
Wind energy	25.1
Biogas	15.4
Liquid biomass	12.1
Solar thermal	10.1
Geothermal	3.1
Hydro	2.3
Solid biomass	1.3
Total	1.9

Source: (IEA) 2010

Libya is well-known for long hours of sunshine during the day and due to the location of Libya on the cancer orbit line with exposure to the sun's rays throughout the year considered to be one of the highest solar densities in the world. The viability of solar radiation data is vital for the economical use of solar energy. Solar energy has the potential to provide sufficient electricity to meet all of Libya's domestic electricity requirements and provide some electricity for export. The measurement of solar energy data in all Libya areas is essential for evaluating the advantages of using solar energy. Areas of highest solar density are the desert areas in the southern; the coastal areas in the north part of a country have the lowest solar density.

Libya has an area of almost 1.75 million square kilometers and approximately 88% of this area can be considered as hot sunny desert. The Libyan Desert covers the entire range of Libyan longitude 11° 44' to 23° 58' E and a latitude range of 24° 17' through to 30° to 3' N (Ahwide & Aldali, 2013). Due to various topologies, the climate of Libya is great extremes and mostly semi-arid to arid which is considered to be one of the world's most arid countries with only 2% of its surface receiving rain that allow to practice agricultural activities and less than 10% of the territory receives an average annual rainfall of almost 100 - 150 mm as well as most rainfall falls in the winter and with average temperature of almost 28–45 °C in summer and 10–27 °C in winter. According to climate scenarios, average annual temperature is expected to increase by 2 °C by 2050, with more frequent heat waves. Average annual precipitation is also expected to decrease by 7% through 2050, with an increase in rainfall intensity and extreme events (Jouini, 2019).

Seventy nine percent of energy production in Libya comes from oil and gas (RCREEE, 2012), which put extra pressure on its natural resources and renewable energy resources share under 1%. Since Libya has very rich fossil energy resources, little attention has been paid so far to explore alternative energy production (Mohamed & Masood, 2017). Continuing the existing trend may lead to a path away from the goals of sustainable development set for the country. Due to the distinctive location Libya occupies within the high solar belt and the most favorable sunny zone (Khalil & Asheibi, 2015), the country is considered an excellent candidate to be one of the major countries that generate energy by renewable techniques for itself and also to be able to export power to other countries simultaneously. Furthermore, the small population of the country makes it feasible and economically viable for the use of renewable energy applications (Hewedy et al., 2017). The Solar Energy Research Center and Studies (SERCS) was founded in 1978 to research potential and development renewable energy applications in Libya such solar water heating technologies. Some appreciable initiatives like solar system projects and programmes have been taken by SERCS that helped to aware the people about use of this renewable resource (Almukhtar, 2015). This technology can be assumed a reliable source for rural electrification in Libya.

Estimates in the coastal regions show that the daily average of solar radiation on a horizontal plane accounts to 7.1 kWh/m² per day, and the greatest solar potential is located in the Sahara Desert in the south region with a solar radiation of 8.1 kWh/m² per day. The average sun duration of more than 3,500 hours per year means it is equivalent to a layer of 25 cm of crude oil per year on the land surface (Saleh, 2006). Libya has the second highest solar potential (53 000 GW) in the Maghreb, following Algeria (63 000 GW) (Jouini, 2019). Based on data acquired from The Centre for Solar Energy Research and Studies, the average annual solar radiation in some cities in Libya is summarised in Figure 11 (Mohamed et al., 2013a). Therefore, the solar energy could provide a good complement to meet peak loads. And this in turn can be a good reason for encouraging solar energy projects in Libya.

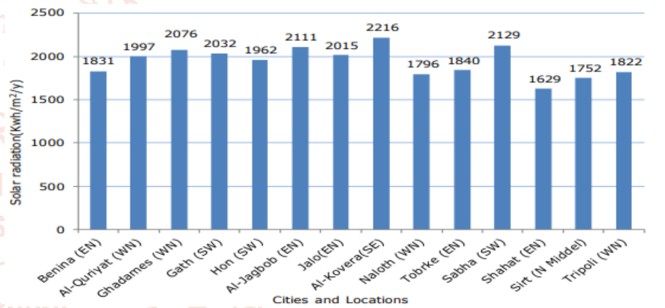

Fig. 11: Average Annual Solar Radiation in Some Areas in Libya

The solar radiation in different areas in Libya is shown in Figure 12 (Khalil & Asheibi, 2015). Solar energy can be exploited through the solar thermal and solar photovoltaic (PV) routes for various applications.

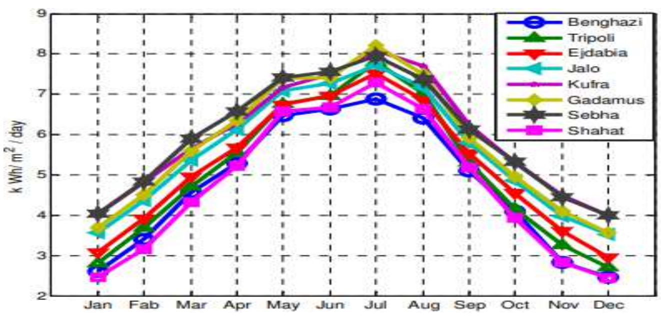

Fig. 12: Monthly Solar Radiation in Different Cities in Libya

5.1. Photovoltaic (PV) Systems

The Photovoltaic conversion systems utilisation, which is the direct conversion of solar energy to electricity may be the most reliable source and considered as a new technology for rural electrification for the developing countries like Libya. The objective of this technology in terrestrial applications is to obtain electricity from the sun that is cost competitive and has advantages on other energy sources. However, adopting this technology faces several barriers. For instance, high initial cost, low efficiency per unit area, lack of PV market and immaturity of technology. In contrast, and in general the experienced advantages of using PV solar generators can be summarised as low running cost, high reliability, fewer services visits,, low maintenance cost, less number of thefts, and more economical in comparison with stations running by diesel generators (Al-Jadi et al., 2005). Thus, the photovoltaic solution is recommended to wait for further technical and economic development. However, at the present time, it could be a good solution for isolated areas that suffer from frequent or emergent electrical outages (Ibrahim et al., 2013).

Solar photovoltaic is used to generate electrical energy by converting solar radiation into electrical current. Solar irradiation is readily available in Libya and it was proved that PV generators are reliable and cost effective in comparison with diesel generators. The PV system assumed to have a life time of 25 years, and the batteries of 8 years, no electronic parts expected to be replaced. Photovoltaic systems have been used to electrify rural villages in Libya. The villages are located in the south shore of the Mediterranean where the solar radiation level is more than that of the north part of the Mediterranean (Saleh & Kreama, 2007).

PV can be categorised into two groups based on the connectivity (remote and grid-connected) and the size (such as small, and large scales) to provide clean and reliable energy sources which can be used in many applications and most of them in Libya are standalone and the role of PV application is growing in size and type of application (Shoroug et al., 2019; Saleh, 2006). The use of PV energy sources both large and small-scale will help to reduce harmful gas emissions. More research is being conducted to establish the economic feasibility in many of these applications within Libya (Shoroug et al., 2019). PV energy technologies are suitable for the following statues:

- Due to uniform distribution of solar radiation throughout Libya, solar PV technology is suitable for producing electricity throughout Libya.
- Solar PV technology is also suitable for off-grid electricity generation in power plants in rural desert areas where the solar energy can reduce diesel fuel use.
- The efficiency of PV cells is influenced by high air temperature and dust contamination. Due to the dusty weather in Libya, in particular in autumn season it is important to investigate the type of dust, density of dust, rate of accumulation of dust, and the effect of dust on the PV performance.

Libya started using clean energy techniques in some applications in the 1976, and since then many projects have been erected with different sizes and type of applications where it was utilized to supply power for communication field to provide energy to microwave stations, and for the cathodic protection systems, water pumping for irrigation in some villages, for lighting and electrification in rural areas Mousa et al., (1998), and finally was used recently at the rooftop PV generation (Shoroug et al., 2019; Hana et al., 2017; Elabdli, 2015) and street lighting system was established and a very high reliability was recorded (Shoroug et al., 2019; Elmanfi et al., 2019; Rajab et al., 2017a; Khalil et al., 2017). However further studies in recent years by Rajab et al., (2017b) and Mohamed et al., (2013a) confirms that the PV technology is economically feasible in many applications in Libya.

5.1.1. PV in Cathodic Protection (CP)

Solar systems were first project put into work was in 1976 to protect the oil pipe line connecting Dahra oil field with Sedra Port. The total PV system in this field is around 320 systems, with a total installed PV system of 650 KWp (Elabdli, 2015; Saleh & Behamed, 2003). The cost of supplying CP stations which are normally far away from the grid can be expensive using conventional types of generators, due to the problems with the maintenance, fuel supply and the running cost. As the generators must be near the CP stations, the remote location is not considered an issue in case of using PV systems as long as the size of the PV is suitable for the load. Figure 13, shows PV system installed for CP. Depending on some studies, indicate that it is not feasible to use this type of source for this kind of applications when a CP (15 KWh/day) station located more than 2 Km from 11 KV transmission line (Saleh, 2006; Mousa et al., 1998; Al-Jadi et al., 2005;).

Fig. 13: Solar Array for Cathodic Protection

5.1.2. PV for Water Pumping

In 1984 the projects in the field of water pumping were started. The system was considered as one of the best PV applications to pump water for human and live stoke in rural places. PV systems were first applied to power water pumps for the purpose of irrigation in El-Agailat village, and the water pumping project consists of installing of 10 PV systems with a total estimated peak power for this application is 40 KWp. Then the project consists of installing of 35 PV systems with a total peak power of 96 KWp. The total estimated peak power for this application is 110 KWp. After that, around 40 PV systems were installed with total estimated peak power of 120 KWp (Bindra & Salih, 2014; Al-Jadi et al., 2005). Residents of areas of small population and remote location are limited to four options to receive the supply of water:

- The electricity supply network which is not a valid option in developing countries since they in the main only providing electricity for cities.
- Wind energy driven turbine that is considered to be a non-reliable or constant source for supplying loads.
- Diesel generators which could be used under the condition of having constant maintenance and the attendance of skilled persons that sometimes is not available in rural areas.
- Solar powered pumping system where this is considered the most appropriate approach to acquire water which has proved to be efficient in this kind of application especially in rural areas (Shoroug et al., 2019; Saleh, 2009; Saleh, 2006). Figure 14, demonstrates PV system for irrigation.

Fig. 14: PV panels installed for irrigation

5.1.3. PV in Electrification and Lighting Rural Regions

To extend high voltage lines in order to provide the electrification for the rural areas, it can be expensive and financially uneconomical it is a problem faced all countries like Libya in small regions with low population, and being away from the electric networks. However, could be benefit to use of solar energy systems to fulfill the daily requirements of electricity for districts where some hundreds or so of residents. The Libyan national plane to electrify rural areas consists of electrifying scattered houses, villages, and using PV for water pumping in rural areas (Shoroug et al., 2019; Saleh, 2009; Saleh & Behamed, 2003). The use of PV systems for rural electrification and lighting in Libya was started in 2003 and 318 PV systems were installed to supply small remote area with a total power 236 KWp as shown in Figure 15, below Elabdli, (2015), like Mrair Gabis, Swaihat, Intlat and Beer al-Merhan villages where such systems were used to supply for a number of scattered houses as well as Wadi Marsit village as an example of a village having diesel generator (Shoroug et al., 2019; Saleh 2009; Saleh & Kreama, 2007).

Fig. 15: Different Sites PV Panels Installed In Rural Electrification and Hybrid PV and Diesel System To Supply Villages Such as (Wadi Marsit)

By 2006, the total number of remote systems installed by GECOL was 340 with total capacity of 220 kWp Bindra and Salih (2014), while 150 systems where one of the systems is a hybrid of central solar arrays and diesel generator for supplying a 200 resident village with a total power of 125 KWp that installed by (SERCS) and Saharian Center, the applications are as, 380, 30 and 100, systems for isolated house, systems for police station and systems for street lighting respectively, where the total peak power of 345 KWp. The estimated number of solar systems that are installed for the rural electrification PV systems is about 800, with total peak power of 725 KWp (Saleh, 2009; Saleh et al., 1997). Currently, there are three PV projected in the pipeline: a 14-MW power station in Houn, a 40-MW project in Sabha, and a 15-MW power station in Ghat. Regarding to solar heaters, 10 systems were installed in 1983 in addition to 2000 had been deployed by 2006 (Bindra & Salih, 2014; Saleh & Kreama, 2007).

5.1.4. PV in Microwave Communication Networks

Later in 1979, first PV system was used in the communications sector to supply energy to the microwave repeater station near the village of Zella. The total installed photovoltaic peak power installed is around 3 MWp. An installed PV system to supply a tower is shown in Figure 16. It was the success of the PV systems technically and economically that pushes the changing of all possible diesel stations to PV stations in the Libyan communication networks. The Libyan Microwave communication networks consist of more than 500 repeater stations and only 9 remote stations were running by photovoltaic systems till the beginning of 1980 and four of them are still working Shoroug et al., (2019) and Saleh, (2009) with a total peak power of 10.5 KWp (Al-Jadi et al., 2005; Saleh & Kreama, 2007).

Fig. 16: PV Panels Installed To Supply Telecommunication Tower

In 1980's, remote stations were operating by diesel generators only, while the stations near the electric grid were supplied mainly from the grid itself and with diesel generators as backup, which suffered service failures. For instance, in the year 1997 one of the stations was out of service for 17 days. The success the PV systems which had accomplished in the communication field both economically and technically encouraged the changing of the rest of the stations into using solar systems as a direct replacement to diesel generators (Saleh, 2006; Al-Jadi et al., 2005).

Consequently, where the total number of 80 stations running by PV in the field of communications have been established Al-Jadi et al., (2005) and in all till 2006 was reached 120 stations, the increase in the number of PV stations counter a decrease of the number of stations running on diesel (Guwaeder, 2018). The total installed photovoltaic peak power was around 420 KWp as per estimates in 2005 Saleh & Kreama, (2007) and, it exceeded to 950 kWp in 2012 Guwaeder, (2018). General Post and Telecommunication Company of Libya (GPTC) exceeding 100 stations with a total peak power of 450 KWp, Oil companies has also its own telecommunication network with a total peak power of 250 KWp. Mobile companies installed PV systems with a total peak power of about 150 KWp. The total photovoltaic peak power installed by the year 2008 is around 850 KWp (Saleh, 2009).

5.1.5. PV in Roof Top Systems

The use of PV grid connected roof top systems was started in 2010. Therefore, 10 PV grid connected roof top systems were installed with a capacity of 3 KWp each (Elabdli, 2015). Distributed grid-connected PV systems are a better option for covering the current load demand that will keep constantly increasing, without burning fuels or harming the environment. Rooftops grid connected solar systems in particular are considered the perfect choice in all ways; the invertors are synchronised with the grid without the need of batteries which are the most expensive component in the solar system due to the maintenance they require. The installation of the PV panels is shown in Figure 17 (Hana et al., 2017).

Fig. 17: Solar Panels on the Center's Roof

Many studies have shown that PV systems are cost effective and reliable (Abanda et al., 2016; Griffiths & Mills, 2016). However, all researchers met at the point that, the rooftop grid-connected PV systems are technically possible and economically feasible. Hana et al., (2017) performed that PV technology could play important role in the Libyan energy mix. Among the grid-connected PV systems, the rooftop grid-connected PV systems are the most attractive for many reasons such as:

- The PV generator will be on the site and therefore the energy transmission cost and the losses are omitted especially the losses in Libyan grid are high.
- Rooftops in Libya are flat and hence suitable for PV installation.
- The cost of the new infrastructure such as generation, distribution, and transmission is avoidable

Recently study conducted by Hana et al., (2017) investigates the viability of rooftop grid-connected PV systems in Benghazi. The study indicates that, the rooftop grid-connected PV in Benghazi can generate 3.63 TWh which is around 10% of the Libyan electricity demands. Finally, installing rooftops solar systems was a popular decision of the local residents due to the constant numerous blackouts being uncounted.

5.1.6. PV for Street Lighting

Libya is rich in terms of renewable energy sources and, therefore, renewable energy is one of the alternatives that could play a great role, especially in the street lighting system and home energy systems, is encouraging the use of sustainable clean lighting systems in road applications. High Pressure Sodium (HPS) lamp is the most widely used type in main roads, but other types of lamps such as mercury vapor lamps or metal halide lamps can be utilized for street lighting. Rajab et al., (2017a) reported that, the electricity consumed by residential loads and the street lighting forms around 50% of the total electricity consumption. Street lighting consumes more than 3.996 TW h, which is around one fifth of the energy demands in Libya. The country relies on very old and inefficient street lighting systems.

Since it enables energy and money saving, Light Emitting Diode (LED) light technology has replaced high pressure sodium lamps nowadays. Once solar power system PV is integrated with LED lamp for street lighting, the amount of saving and local impact might be enriched. LEDs used as light sources in road lighting luminaries with rising lumen values, decreasing junction temperature, higher color rendering efficiency, longer lifetime have become more efficient than many light sources with the latest developments. Lina et al., (2015) and Liu, (2014) informed that, the solar powered LED street lighting system proved to be economically feasible and saves fuel and money over its lifespan and prevents the emission of CO_2 and can save 50% of energy with comparison to HPS lamps. Street lights are one of the most crucial parts for public lighting systems which consume a major part of the generated electricity. Basically a smart street lighting system is a flexible street lighting system consists of various sensors and a controller which make it an intelligent street lighting system. Moving to LED solar street lighting can provide many advantages, especially for small villages, the best alternative for the traditional street lighting systems, they are efficient, cost-effective and environmental friendly. At day time the solar panel charges the battery, and at night or cloudy weather the battery powers the LED lamp (Khalil, 2016).

As a number of roads need to be electrified, Libyan government should build new power plants because the country is struggling to satisfy the current load demands. The traditional lighting system widely used in Libya has been found as the most expensive and inefficient option. Where the country struggles to cover for the increasing load demands for numerous roads which are far from the grid requiring extra distribution, transmission, and generation costs, the GECOL uses the HPS for the lighting purpose, with 250W for the streets and 400W for the highway roads inside cities Khalil et al., (2017), while in neighbor countries the 150W type is used (Mokhtar et al., 2011). If GECOL switches from 400W to 150W types, the street lighting consumption will decrease from 3.996 TWh to 1.4985 TWh, which is around 37.5%, therefore, to overcome this issue a solar powered street lighting system should be adopted because of the short installation time it takes and the lack of maintenance required (Shoroug et al., 2019).

Nevertheless, replacing the HPS lamps with LED lighting can save 75% of both, the consumed electricity and reducing the CO_2 emissions (Khalil et al., 2017). According to the results of the study conducted by a PV street lighting system was installed along the airport road in Benghazi as shown in Figure 18 (Shoroug et al., 2019). Additionally the installation cost is usually low for the following reasons: no need for long and heavy cables, and long life products (for LED approximately 60,000 hours maintenance free and the PV panel 25-30 year lifetime). The power consumption is 40-70 % lower than traditional lighting system, LED solar light (Khalil, 2016). One of the main barriers for solar energy installation is the high initial investment comparing with the conventional ones, however, for the street lighting systems in Libya the initial cost of the solar powered LED street lighting system is lower than the cost of the traditional street lighting system (Elmanfi et al., 2019). LED solar light is shown in Figure 19.

Solar powered LED lighting systems is a standalone PV system. The grid-connected fossil fuel LED lighting system has the lowest maintenance cost. Over 20 years the cost of the solar powered LED street lighting system is 1,250,000 LD while the cost of the HPS lamp street lighting system widely used in Libya is 2,117,255 LD, which is around 60% reductions in the cost if the GECOL changes to the LED lighting (Rajab et al., 2017a). On the other hand the current street lighting system in Libya is nonrenewable and unsustainable. The solar powered street lighting system is the optimum solution because Libya struggles to satisfy the energy demands and it is difficult in meantime to build new centralized power plants.

The applications of the PV technology were successful from technical and economical point of view; however, the PV applications are still limited to small scale systems (Rajab et al., 2016); Elmanfi et al., 2019).

Fig. 18: PV Panel Installed in the Airport Road

Fig. 19: LED Solar Street Light

In general, as shown in the Table 3 which presents a list of all the PV systems installed in Libya up to the year 2012 and their respective kWp, the installed power capacity for solar PV was 5MW in total (Mosbah, 2018).

TABLE 3 PV Systems and Kwp in Libya To 2012

PV	KWp
PV (rural power)	725
PV (water pumps)	120
GPTC	850
Almadar	1500
Libyana	330
Oil Comp.	120
Other	10
Total PV (communication systems)	2810
PV (street lights)	1125
Centralized PV system	110
PV (rooftop systems)	30

Source: Mosbah, (2018)

Some of the projects referenced in the table include the Wadi-Marsit project (centralised system) that features a peak capacity of more than 67 kWp, as well as communication repeater stations (with a peak capacity of 950 kWp) and small-scale grid-connected PV systems (with a 13 peak capacity of around 42 kWp) (Mosbah, 2018). Along with the country's enormous potential in relation to PV-based power production, Libya is also positioned to take advantage of PV infrastructure-related opportunities by becoming a regional leader in the manufacturing of PV components such as pods, panels, mounting systems and water tanks (Mosbah, 2018; Naseem et al., 2015).

In Libya, highly reliable stand-alone PV solar energy production has been provided for several decades for the purpose of water pumping, cathodic protection, communications and rural power supplies. The low cost has made this service even more attractive for users and producers alike, particularly in poor and remote regions of the country. Currently in Libya, solar PV's total installed peak power capacity has reached 1.5 MW while at the end of 2015 the installed PV capacity reached to 5 MWp Salma et al. (2015); Khalil et al. (2017), but this amount is likely to rise, given the excellent performance of the renewable resource and the willingness of the government to invest in solar PV technology, especially to supply electricity to remote areas. Furthermore, the adoption of the PV system in Libya reducing the CO2 emission Rajab et al. (2017b).

5.2. Solar Thermal Systems

It is well known that most Libyan households are equipped with electrical water heaters. It is clear that most residents rely on electric heaters for hot water production and this adds an unsustainable burden on the Libyan electricity sector. Despite this analysis, urban Libyan areas consist of houses and multi-floor apartments and thus, the free space is very unrestricted. This could be an important factor concerning solar water heating system installations in the country. Therefore, an important portion of the residential electrical consumption may be saved by the adoption of Solar Water Heating Systems (SWHS) as illustrated in Figure 20 especially if their use is extended to cover space heating. Economically, it is indicated that the average payback period of the installed solar hot water system is around 4–5 years, if it is supposed to replace an electric water heater.

Fig. 20: Solar water heating system

As well known, domestic solar water heaters can be found today in the market as active or passive systems. SWHS are appliances that utilize the sun's energy directly to heat water and provide it to households, hotels, factories and other recipients (Karagiorgas et al., 2003). SWHS systems are the most common systems used worldwide in domestic appliances, where the demand for the hot water is not too insistence (Abdunnabi et al., 2018). The use of domestic solar heaters started in 1983 with a pilot project which included 10 systems. Since then about 2000 additional solar heaters have been installed in Libya (Siala & Abdurhaman, 1995). Water heating in Libyan domestic sector represents over 29% Abdunnabi et al., (2018) and 12% of the total electrical consumption and of the national electricity production respectively (Almukhtar, 2015). However, despite the large potential that offered by these technologies, the country continues to rely heavily on conventional fuel as well as electricity for water heating. As such, there is considerable scope to increase the application of SWHS in the country (Abdunnabi et al., 2018). A study conducted by Ekhlat et al., (2005) has shown that about 30% of the electricity in Libyan houses is consumed in domestic water heating. This means that the installation of solar water heater would reduce the electricity bill by about 22.5%. Although, Libya is blessed with high solar potential that can play a vital role in providing hot water to the residential and industrial sectors there is no wide-spread application of SWHS technology across the country for many reasons can be listed through the following:

- The cheap price of both electricity and electric water heaters,
- Lack of clear and systematic policy, and
- Lack of environmental awareness.
- No national or personal industry has been established for local individuals.
- Lack of information for the people.
- Low electric energy tariff.

Overall SWHS not only help in bridging the gap between demand and supply of electricity during peak demand but also save money in the long run. However, solar water heaters have many benefits and advantages over the other technologies for providing hot water, these advantages such as:

- Can save as much energy as 4915 GWh over 10 years.
- Create new industry for manufacturing solar systems.
- Create new jobs (manufacturer, installer).
- Million tones of CO_2 can be avoided.
- Enhance the local industry through the use of local material and might lead to cost reduction.

Concerning the electricity generation using the solar thermal, CSP systems are usually utilized. These systems use mirrors to concentrate the direct solar radiation (beam) and produce steam which, in turn, is used to produce electrical energy through steam turbines. CSP systems need large free flat portions of land; however, this requirement is limited in a small size and mountainous country like Libya. CSP can be used for:

- CSP is expected to be very well suited to the long days of sunshine and the high temperatures found in Libya.
- Investigations are underway in Libya to improve the use of CSP during high temperature weather conditions.
- The use of solar water heater systems by domestic loads has increased.

According to the studies that reviews previously, the Libyan government, in its strategic plan for renewables for the period 2013-2025, had set targets for 300 MW of PV by 2020 and 450 MW by 2025.; while for CSP, these two targets are 150 MW and 800 MW, by 2020 and 2025 respectively. Solar-PV and solar-thermal for electricity generation are subjected to rapid technical evolution as well as their current levelised costs.

CSP plants require direct solar radiation in order to generate electricity, given that only strong direct sunlight can be concentrated to the temperatures required for electricity generation. This limits the use of CSP to hot, dry regions. The insulation time over the most of the national territory exceeds 2500 h annually and may reach 3900 h in high plains and Sahara.

PV and/or CSP system implementations have shown that their efficiency and reliability depend on many factors, including orientation (longitude and latitude), environment (solar intensity, temperature, humidity, wind, dust, rain, pollution, etc.) and the PV technology used. Thus, before committing to a large-scale (in megawatts) PV or CSP project, a thorough investigation of the above factors is essential.

6. Conclusion and Recommendations

Libya's electricity consumption is expected to increase significantly over the coming years, where the majority of generated electricity is produced from oil and gas, both of which are considered the primary revenue sources of the Libyan economy. Which, the currently produces energy of 33 TWH to meet the demand on the local electricity market. This growth will lead to considerable need to new power stations to cover the continuous growth in demand, and more consumption of oil and gas which causes a reduction in the national economical revenue and more CO_2 emissions. In spite of, the full potential and advantages of renewables are currently hindered in Libya due to the existence of many barriers like the institutional barriers and as far as energy pricing is concerned, has heavily subsidized local price of energy as well as low electricity prices associated with the use of such resources. Regarding to electric power efficiency in power stations in Libya is very low, except at North Benghazi station, which has a good efficiency of 47%. For these reasons, Libya can be considered as a place with high potentiality for renewable energy production. On the other hand, renewable energy sector could provide significant power generation levels and could also be the solution to cover some of its load requirements, if not all without the need to build new fossil fuel stations. Therefore, decision makers in Libya should create an urgent strategy to use its alternative energy supplies to cover some of its load demand. Solar energy resources in particular can be of great source of energy for Libya after oil and natural gas. There is a great potential for utilizing, home grid connected photovoltaic systems, large scale grid connected electricity generation, and CPS.

The use of a stand-alone PV power supply in the fields of communications, cathodic protection, rural electrification, water pumping, rooftop PV generation and street lighting system was established and a very high reliability was recorded. The strategies that should be adopted to involve renewable energy in order to save some of the oil and gas share. Starting from street lighting system which can save 20% of the total consumption, then, the SWHS saves 10% of the total consumption and Benghazi rooftops save 10% If the other cities were included in, it may cater for more than 30%, totaling, 60% of the generated power will be saved. There is a need to attract investors in renewable technologies by enhancing the infrastructure and the existing laws. Renewable energy technology is still within its early days in Libya. A clear strategy and time plan is still needed to take this sector forward particularly in relation to developing the skills and knowledge needed for installation and maintenance of such systems. Finally, with its huge solar potential, Libya has to gain by developing a local photovoltaic industry, and increasing efforts to spread this technology to all corners of the country to reduce its dependence on fossil fuels. However, the current political situation in Libya has put most renewable energy projects and strategies on hold, perhaps until the situation becomes more stable.

On the basis of the discussion and conclusions mentioned above, the author would like to suggest some recommendations that could play an important role in the development of the renewable energy sector in Libya, which can be summarised as follows:

- The availability of renewable energy could provide a good complement to meet peak loads and current energy demand, and this in turn can be a good reason for encouraging wind and solar energy projects in Libya.
- The solar energy density in Libya is among the highest in the world, and there is significant wind energy potential in several areas in Libya is need more investigation.
- Social awareness must be spread to educate people of the benefits of renewable energy, this can be done through the social media and TV channels, and taxes and regulations of the wasteful consumption must be applied.
- Legislations and laws for using low power electrical appliances. This can be achieved through encouraging people to use the energy efficiently.
- Create education and training programs to qualify more people in the field of renewable energy technology.
- With a high potential for renewable energy in the country, there is only one research center located in the western part of the country. Therefore, Libya must build a number of research centers in different parts of the country.
- To diversify the resources of energy production by utilising the available renewable energy particularly solar and wind energy.
- Enhance the educational and training system to enable the necessary development in the sector.
- Encourage local industries and investments related to the renewable energy sector to develop new employment opportunities, reduce pollution and provide energy savings for future generations.
- Enhance the current regulations in order to attract foreign investors in the renewable energy sector.
- Significant investments are required in the generation, transmission and distribution of energy. The public sector is unable to address the funding gap and attracting foreign and private sector participation is critical, especially in the area of generation.
- The potential of the other renewable energy options such as off-shore wind, tidal, biomass, hydroelectricity, and geothermal power in Libya is founded, but is limited in comparison with solar and wind energy, therefore more studies needed to be investigated.
- Government support is required for implementing small, renewable energy pilot projects, especially those that serve people in rural areas.
- Financial support for studies that investigate renewable energy in Libya and its applications is required.
- Introducing solar thermal collectors in public buildings to produce hot water can be considered a first step towards reducing dependence on fossil fuel resources.
- Encouraging and sponsoring projects in the field of renewable energy and focusing in particular, on research and postgraduate studies in renewable energy science programmes, that will serve as incentives for the workforce to promote the increasing use of renewable energies in Libya and encourage a gradual transition towards more informed and sustainable use of energy sources.

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