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Towards an extensive exploitation of solar PV technology in Libya: Legislative, economic and environmental considerations

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ABSTRACT

This paper investigates the issue of investment in renewable energy (RE) particularly solar photovoltaic (PV) as an electricity supplier and discusses the most important factors which affect the promotion and expansion of PV systems. The paper firstly provides a general overview of Libyan conventional fuel resources, its electrical energy status, and solar energy potential in the country. In addition, most important international experiences on Feed-in Tariff (FiT) policy are reviewed. The Libyan electricity tariff compared to the international electricity tariffs is also discussed. Furthermore, economic and environmental results of a small PV system installed in Benghazi is analyzed using the Hybrid Optimization Model of Energy Resources (HOMER) software. The simulation study considers different scenarios and rates of FiT, interest rate, and electricity tariffs. Results show that the FiT can play a vital role in developing a knowledge-based economy and encouraging the public to use such a clean energy source thus increasing the share of renewable energies in the total national energy mix. The findings of the paper are very important for all key players including the Libyan government, decision-makers, the national grid utility operator, industries, the PV system investor, and the environment.

1. Introduction

Libya is a Mediterranean country, located in the middle of North Africa, between 20 and 32 degrees north and between 10 and 25 degrees east. In the north of the country, the summer average temperatures range from 27 to 32°C and between 40 to 46°C in the south (desert), while in winter the temperature ranges from –1 to 12°C (WA, 2017). The annual population growth rate is 1.4%, with a reported population of 6.3 million for the year 2015 (WB, 2017).

Libya has indigenous oil supplies, currently the largest in Africa and ninth-largest globally with 48 billion barrels of proved crude oil reserves (BP, 2016). The proved natural gas reserves in Libya is 158 billion cubic feet (EIA, 2017a). Fig. 1 shows the infrastructure of oil and natural gas in Libya.

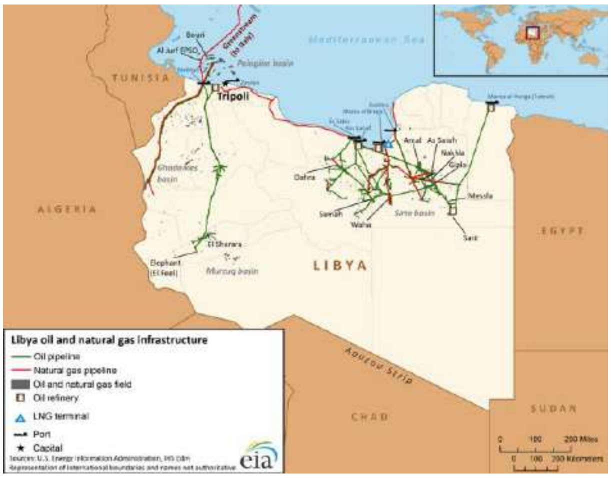


Fig. 1. Oil and Natural Gas Infrastructure in Libya (EIA, 2016)

The Libyan economy and energy sector is still heavily dependent on fossil fuels. Hydrocarbons account for over 65% of Gross Domestic Product (GDP) and 96% of revenue (IMF, 2013). However, oil prices are fluctuating resulting in an annual budget deficit and hence an inflation. The oil prices were below \$20 per barrel prior to the year 2000, then saw an upward trend to nearly \$75 per barrel in the third quarter of 2006, and reached \$147 by mid-2008. The price again rose to \$112 in 2011, and thereafter fell gradually to reach its lowest level at \$22.48/barrel during the 1st quarter of 2016 then settling above \$40/b in the third quarter of the same year (OPEC, 2016). While average oil price exceeds \$70/b during 2018, keeping a forecast by U.S. Energy Information Administration (EIA) for a High Oil Price case around \$230/b by 2050 (EIA, 2018).

2. Current status of electrical energy in Libya

Presently, Libya generates almost all of its electrical energy using fossil-fueled generation plant to satisfy its growing demand for electricity (Khalfallah *et al.*, 2016). The capacity of the existing power plants is about 8 GW whereas the available full capacity could reach 6.3 GW, of which around 60% is generated by oil and 40% is generated by natural gas (Zaroug, 2013). Fig. 2 describes the location and the capacity of power plants in Libya where most of them are located along the coastal line. The General Electricity Company of Libya (GECOL), the state-owned utility, is responsible for a generation, transmission, distribution, operation, and control of electricity as well as water desalination plants. Based on technology, gas turbine contributes with 53% of electricity production, combined cycle with 37%, and 10% from steam turbine (GECOL, 2013).

Fig. 2. Electrical Power Plants in Libya

The electricity sector is a key area that needs to be addressed since the country has been regularly hit by widespread blackouts, as power plants could not keep up with the electricity demand (Manfred & El Andaloussi, 2012). That is, power generation is below peak electricity demand which is close to 6,000MW, resulting in shortfalls. That is due to the age and conditions of the plants besides the damage of three power plants during the 2011 war (Ahmad *et al*., 2016). Specifically, the network in the eastern part of Libya has suffered from massive destruction, mainly in the major power substations. In addition, losing the interconnection between the North Benghazi power generation plant and other major power plants such as Zwitena, Sarir, and Western units has affected the stability and reliability in the entire network particularly in the Eastern Libyan electric network. The electricity shortage was reduced by importing electricity from neighbouring countries and renting MW scale diesel generators, which are considered uneconomic solutions.

The historical load profile data show that the maximum power occurs during the summer season and that the residential sector represents the highest share in electrical energy demand in Libya with 36% followed by the commercial with 14%, as shown in Fig. 3. (Dagroum *et al*., 2014). According to the Renewable Energy Authority of Libya (REAoL), the electricity demand in the country is estimated to be growing at around 7% per year and forecasted at around 8 GW by 2020 (Alsuessi, 2015). This makes the investment in new power plants crucial. However, the five power plants, which were under construction prior to the war, remain suspended as companies assess the risks of re-entering the war-torn country (Saleh *et al*., 2014).

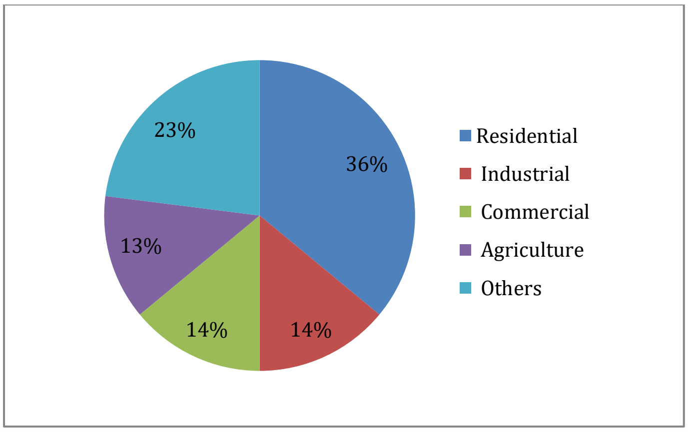


Fig. 3. Electricity consumption per sector (GECOL, 2013)

Similarly, most of the Libyan electric network is concentrated on the coast, where most of the inhabitants live. The Transmission system is completely interconnected nationally and regionally to ensure both reliability and security. The Libyan electric transmission system consists of 13706 km of 220 kV besides around 2422 km have been upgraded to 440kV to cope with the increasing load-growth (Sahati, 2014). Fig. 4 depicts the high voltage transmission network. In fact, Libya's national electricity grid was one of the primary infrastructures, which witnessed a tremendous damage during the civil war in 2011. The network incurred an estimated damage worth of US$1 billion in over 300 substations and 2,000km of power lines, and around 6,000km of distribution lines had been destroyed (BMI, 2013). Whilst repairs have been taking place on the electricity infrastructure since 2011, a number of power generation units are still out of service (Rajab *et al*., 2017a).

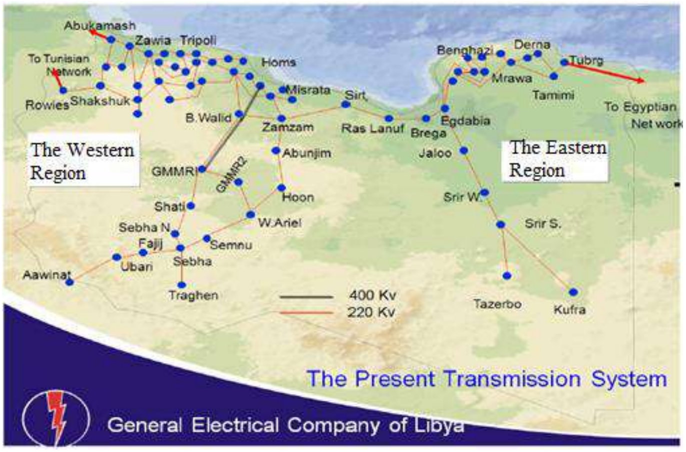


Fig. 4. Libyan national grid (220 kV & 400 kV)

At the same time, the main emitters of CO_2 are fuel combustion in the power generation sector, which contributes 60 million tonnes of the greenhouse gas emissions (Ekhlat et al., 2007). However, in order to maintain meeting the growing electrical energy demand and achieve a sustainable economic growth, the Libyan government established the REAoL in 2007 to promote RE use as well as to integrate those technologies in energy supply mix.

3. Solar energy potential in Libya

Industrialization and population rise have increased the demand for electrical energy drastically (Chmiel and Bhattacharyya, 2015). On the supply side, there is no clear trend in the fossil fuel prices, their ultimate depletion, and their associated problems with global warming (Otsuki 2017). These factors have prompted the research and implementations of RE resources to become more urgent (Akella *et al*., 2009; Brito *et al*., 2017).

On a global basis, 147 gigawatts (GW) of renewable power capacity was added in 2015 supplied about 23.7% of global electricity (GSR, 2016). Renewable electricity share in Germany achieved 24% in 2012 on the way to meet its national targets of 39% in 2020 (216 TWh), 50% in 2030, and 80% in 2050 (Rekinger & Thies, 2015; Cherp *et al*., 2017). The cumulative installed solar PV capacity in Germany reached 25,000 MW in 2011 and 40 GW by the end of 2016 (Fraunhofer, 2017). Projections of German National Renewable Energy and Action Plan (NREAP) that the PV generation would be 41.4 TWh in 2020 (Fulton, 2012). The American net generation from RE sources (excluding hydro) reached 43 TWh throughout 2016 of which 2.27 TWh was generated from solar energy systems. The generation from solar PV systems increases by 54% in 2017 (EIA, 2017b). China achieved 100% electrification from off-grid and on-grid PV systems installed since 2012. About 18 GW of solar installations is expected to be added in China during 2017 and planned to be increased to 110 GW of new installations in 2020 (CSI, 2017). The global solar PV sector reached a cumulative capacity of 245 GW in 2015 and increased to 291 GW by the end of 2016 (IRENA, 2017a). The 540 GW mark of PV capacity globally could be reached in 2019 (Schmela, 2016).

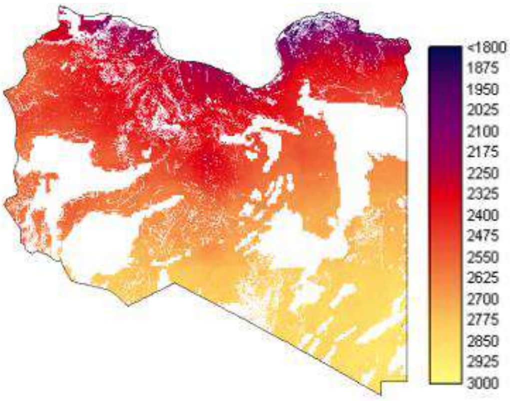


Fig. 5. Global Horizontal Solar Irradiation in Libya (kWh/m²/year)

Libya is a rich country in RE resources, it has the potential to produce the equivalent of almost seven million barrels of crude oil per day in energy (Belgasim *et al.*, 2018) i.e., seven times the current oil production level (EIA, 2017c). Specifically, PV technology in Libya has immense potential since it has one of the highest solar irradiation in the world, refer to Fig. 5.

The average annual solar irradiation is 2470 kWh/m²/year while the potential of solar energy resource is estimated at 140,000 TWh/year (RCREEE, 2010). Fig. 6 illustrates the monthly averaged insolation incident on a horizontal surface in some selected Libyan cities (NASA, 2017a).

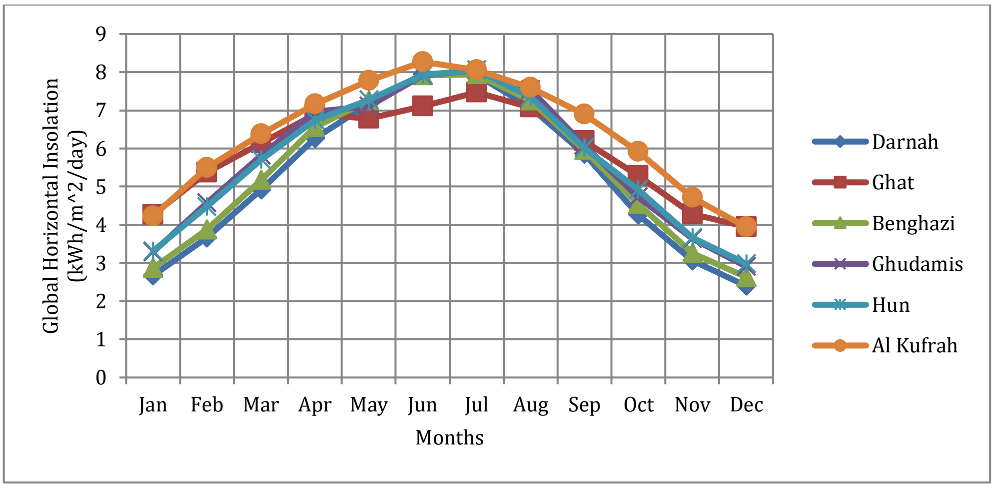


Fig. 6. Global Horizontal Irradiation (kWh/m²/day)

On research aspect, a potential of installing a 50 MW PV power plant in the southern region of Libya at Al-Kufra was evaluated (Aldali *et al.*, 2011). The study concluded that the proposed plant can generate 114 GWh per annum with a payback time of 2.7 years and a reduction of CO_2 pollution by 76 thousand tons per year (Aldali, 2012). Performance of an experimental PV water pumping system of 1200 Wp installed in Marada, located in the Libyan desert, was evaluated. The results demonstrated the technical and economic feasibility of using the PV systems for water pumping especially in remote areas of the high potential of solar insolation (Sbeta and Sasi, 2012). A study conducted by GECOL revealed that around 9.3% of the national electricity consumption in the country is consumed by water heating for domestic purposes (Ekhlat, 2009). Another study conducted by Center for Solar Energy Research and Studies (CSERS) concluded that replacing electric water heaters with solar water heaters in the Libyan residential sector will alleviate the electricity peak by 3% and the annual energy savings could reach to 2.55 TWh (Abdunnabi *et al.*, 2016).

Historically, the use of PV technology in Libya started back in the mid-seventies, and since then several systems have been established for different sizes and applications such as cathodic protection, rural electrification, water pumping, and communications (Rajab *et al.*, 2017b). The total installed PV capacity in Libya so far is nearly 5000 kWp (Zaroug, 2013). The first project put into work was a PV system to supply a cathodic protection for the oil pipeline connecting Dahra oil field with Sedra Port in 1976. The accumulated total power of PV systems in the field of cathodic protection was 650 kWp from 320 systems installed. A PV system to supply energy to a microwave repeater station was built near Zella in 1980, while projects in the field of water pumping were started in 1983 (Sayah, 2017). The accumulated estimated peak power for PV water pumping is 120 kWp from 40 PV systems. Fig. 7 depicts one of PV water pumping installed at Beer Tssawa.

Fig. 7. PV Water Pumping Beer Tssawa

It was a successful experience technically and economically to exchange all diesel stations with PV stations in the Libyan communication networks. The total number of PV powered stations in the field of telecommunications exceeding 120 stations with approximately 3 MWp total installed capacity (RCREEE, 2013). The successful experience was based on the following criteria: no failure has been registered for the systems installed, no running cost, the average energy output for systems of 1.2 kWp was 6 kWh/day (Saleh, 2006). More than 400 systems have been installed for rural electrifications with total peak power of 725 kWp. The majority of standalone PV systems were installed by GECOL and CSERS (CSERS, 2017). Fig. 8 shows samples of PV systems installed in remote areas.

Fig. 8. PV rural electrification sites in Libya

The REAoL proposed a mid-term goal to reach 10% of the energy supply from RE resources by the year 2025, which would account for a total capacity of 2,219 MW (Bindra *et al.*, 2015). The plan included; 844 MW capacity of PV projects, 375 MW of concentrated solar power, 300 MW of solar water heating and 1000 MW of wind farms (RCREEE, 2013). Examples of suspended projects are 14 MW PV power plant in Hun deep in the desert, 60 MW wind farm in Dernah and another one with the same capacity in Mesallata (IEA, 2013a). Other projects have been studied and proposed which include; 50 MW PV power plant in Shahat, 40 MW PV power plant in Sebha, 15 MW PV power plant in Ghat, 3 MW PV rooftop systems, 2×120 MW wind farms in Al-Magroun (MESIA, 2015).
Although there is an organization in Libya responsible for the promotion of renewable energies, namely REAOL, yet the development of tools and mechanisms to promote renewable energies are still very weak. Indeed, there is no clear legislation to regulate renewable energies, nor even its funding. In the meantime, chances for the possible involvement of private investors are very slim. Therefore, the objective of this work is to investigate the role of FiT to boost and expand the application of PV systems in Libya and to formulate recommendations for the regulatory steps required in the years to come.

4. Feed-in tariff

Different countries have implemented RE policies particularly solar PV to increase domestic energy production and reach the grid parity. The renewable portfolio standard (RPS) and the FiT are the most popular incentives to promote the use of RE (Solangi *et al.*, 2011). According to forecasting study conducted by European Photovoltaic Industry Association (EPIA), the development of PV technology is based, to a large extent, on the assumption of follow-up and an introduction of support mechanisms (EPIA, 2014). Both domestic and industrial users are able to generate electricity through solar PV, or any other RE sources, and sell it back to the national power grid at a premium rate. On the other hand, FiT must be fixed for a long enough period such that it gives certainty of the market and provide businesses with the security for RE market development (Almaktar *et al.*, 2015a). For example, Germany's system of FiT was initiated in 2000 and amended in 2004, 2009, 2011 and, most recently, in 2012. From 0.58 €/kWh in 2004 with 5% annual degression rate until 2009 (Fulton and Mellquist, 2011). Since 2008, costs of PV components have declined sharply, with PV module prices falling nearly 40% in 2008 alone resulting in a revision of FiT to be set at 0.43 €/kWh in 2009, and finally below 0.2443 €/kWh since 2012 onwards as a result of the market massive development (Solangi *et al.*, 2011; IEA, 2013b). Fig. 9 depicts the history of the FiT in Germany. It is obvious that the PV electricity has achieved the grid parity for small rooftop PV systems in 2012. For rooftop systems put into operation by Dec. 2016, the FiT is up to 12.31 € cents/kWh guaranteed over the next twenty years, independent of size (Fraunhofer, 2017).

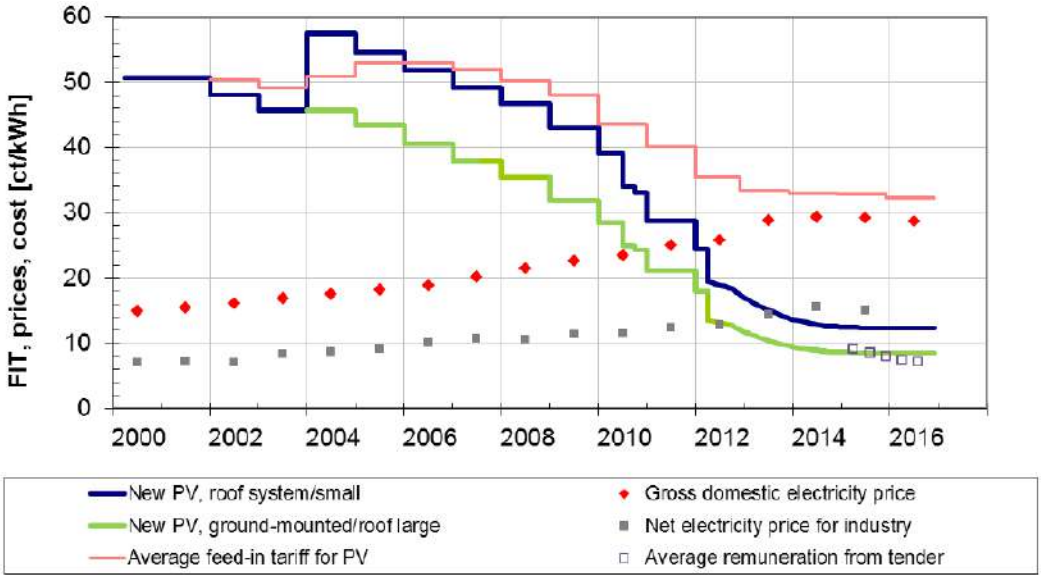


Fig. 9. FiT for PV power and electricity prices in Germany (Fraunhofer, 2017)

In 2009, the Ontario Power Authority (OPA) launched the FiT program for small-scale solar PVs to receive the highest tariff rate of 80.2 ¢/kWh. In this Canadian province, the PV system installer is paid a fixed price over a 20-year term (IESO, 2017a). The 2008 Spanish FiT for installations ≤ 100 kW was set at 595% of the Reference Average Tariff (RAT) and the annual degression rate is capped at 10% (Dusonchet and Telaretti, 2010). The Victorian government introduced a premium FiTs in 2009 that paid AU$0.60 per kWh for PV systems ≤ 2 kW. A new current Victorian minimum FiT rate of 11.3 cents to be implemented from 1 July 2017 (VSG, 2017). By the end of 2008, the Australian Capital Territory implemented FiTs which pays 3.88 times the domestic electricity price for PV systems that are equal to or less than 10 kVA (Solangi *et al.*, 2011). The FiT in Japan has been reexamined every year. The last amendment was on 2016 where for systems less than 10 kWp it was set at 31 JPY/kWh for a purchase period of 10 years, decreased from 42 to 31 JPY/kWh over the period from 2012-2016 (IEA, 2016).
The FiT in Malaysia is rather a recent experience in the country. Prior to the establishment of the FiT policies in 2010, the incentives in the PV projects were in the form of capital grants (Chua *et al.*,

2011). Table 1 summarizes the FiT since 2012, the year in which the first FiT was implemented, valid for 21 years (SEDA, 2017). It is clear that the FiT decreases by 8% which reflects the PV market development, was set initially at 1.23 RM/kWh for systems less than 4 kW installed capacity compared to 0.21 RM/kWh (more than 5 times) for base electricity tariff (KeTTHA, 2011; TNB, 2017).

Table 1

History of FiT in Malaysia in Malaysian Ringgit (RM)

Year	FiT (RM)		Bonus (RM) (one or more)	
	Capacity ≤ 4kW	4kW≤Capacity≤24kW	Use as an installation in a building structure	Use of locally manufactured or assembled solar PV modules
2012	1.23	1.20	+0.2600	+0.0500
2013	1.1316	1.104	+0.2392	+0.0500
2014	1.0411	1.0157	+0.2201	+0.0500
2015	0.9166	0.8942	+0.1938	+0.0500
2016	0.8249	0.8048	+0.1550	+0.0500
2017	0.7424	0.7243	+0.1395	+0.0500

The African governments also intend to increase the share of renewable energies in the power mix through FiT policy. Algeria was the first African country that had introduced a FiT-scheme in 2004. Solar-based electricity receives a premium rate of 300% of the electricity retail market price, guaranteed for the full lifetime of a project (AMEM, 2017; Meyer-Renschhausen, 2013). South Africa's Renewable Energy Independent Power Producer Procurement Program (REIPPPP) has run four competitive tenders/auctions since 2011, which has been successful to reduce electricity prices of solar PV by 71%, reaching the grid parity. Over the four bidding rounds, US$19 billion has been invested in 92 RE projects totaling 6327 MW. REIPPPP has been introduced after the REFiT approved in 2009 by the national energy regulator of South Africa, NERSA (Eberhard and Kaberger, 2016).

The Government of Egypt (GoE) represented by the Ministry of Electricity and Renewable Energy (MoERE) has adopted a FiT scheme since November 2014. The scheme aims to support investment in RE by setting a target of 4300 MW in the first regulatory period. This includes 300 MW of PV projects below 500 kW and 2000 MW for projects starting from 500 kW up to 50 MW (MoERE *et al*., 2014). The purchase price for residential solar generation is 0.848 EGP/KWh while for non-residential installations of less than 200 kilowatts of installed generation capacity, the price rises to 0.901 EGP/KWh. Between 200 and 500 kW installed capacity, the investor will be paid 0.973 EGP/KWh. Installations ranging from 500 kW to 20 MW would be paid 0.136 USD/KWh while projects stretch between 20-50MW, will be paid 0.1434 USD/KWh. The lifespan of the solar projects has been set at 25 years (EEUCPRA, 2014).

As addressed earlier, the FiT has been lowered over time because of the technology maturity. The continuous development of PV technology has, in turn, led to a reduction in the PV module cost (Brown *et al*., 2018). According to Hanwha Q Cells the average selling price, excluding the processing services, decreased from 1.24 $/W in 2011 to $0.67 per watt in 2012 (Hanwha, 2017). The cost of PV modules has fallen by 80% between 2009-2017 and 50% over the last four years (Labordena *et al*., 2017). Due to economies of scale and technology improvements, with every doubling of cumulative installed capacity solar PV module prices drop by 20%. Presently, 24.2 $/MWh have been granted in 350 MW solar PV park auction in Abu Dhabi which is considered a record-breaking cost (IRENA, 2017b). Typical Levelized Cost of Energy (LCOE) by PV technology is predicted to be in the range 0.06-0.15 $/kWh by 2025 (Blaabjerg and Ionel, 2015).

Energy prices are highly subsidized in Libya, with fuel prices among the lowest in the world leading to expenditures on fuel and electricity subsidies that are equivalent to more than 11 percent of GDP (Richard *et al*., 2014), see Fig. 10 (Ataieb, 2014). On the other hand, the inflation in Libya had a serious hike with 28% during 2017 compared to 11% in 2015. Fig. 11 depicts the fluctuation of inflation since 2008 as provided by the Central Bank of Libya (CBL, 2017).

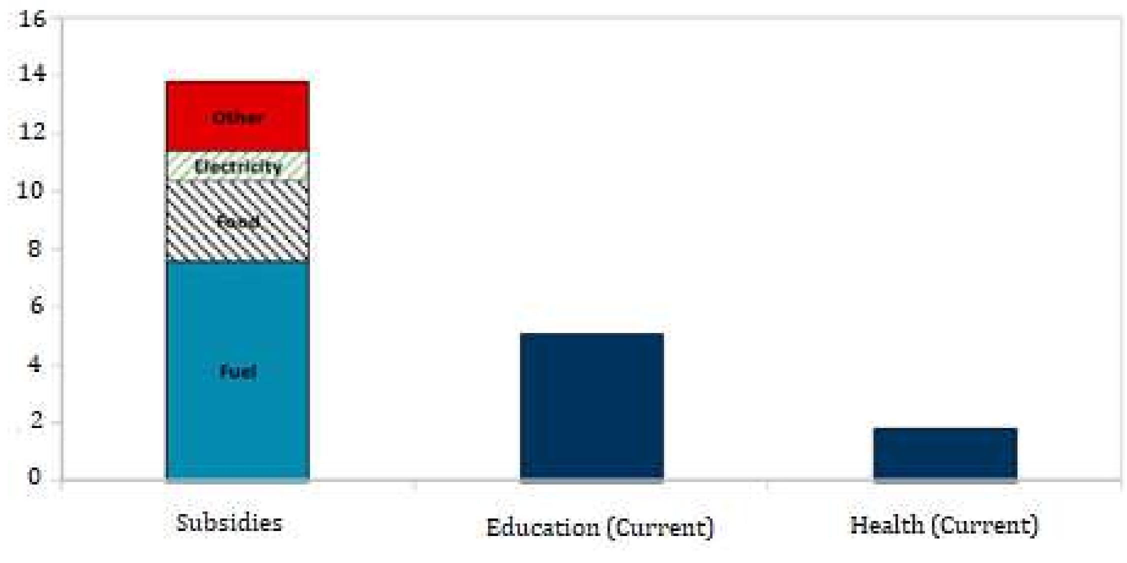


Fig. 10. Libya Budget Items, Share of GDP (%)

The inflation rate has affected by a drastic drop in oil revenues, the main national income source, from 67 billion dinars and 52 billion dinars in 2012 and 2013 in comparison to just 20 billion dinars and 10.5 billion dinars in 2014 and 2015 respectively (NOC, 2017). In 2016, the oil revenue has fallen dramatically further to only 2.8 billion dinars in the first half of the year (MOF, 2017). This is due mainly to the political crisis in the country besides the absence of security in most of large oil fields and ports.

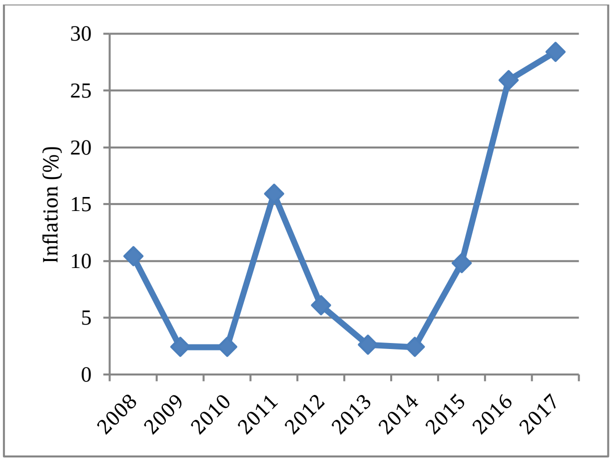


Fig. 11. The inflation rate in Libya during 2008-2017 (CBL, 2017)

5. Results and discussion

HOMER software (HOMER, 2017) determines the economic feasibility of a hybrid energy system, for either grid-tied or off-grid environments, optimizes the system design and allows users to really understand how hybrid renewable systems work. Many feasibility studies have been conducted using HOMER software. For example, the techno-economic feasibility of utilizing hybrid PV/wind/diesel with battery storage systems to meet the load of typical rural healthcare facilities at six selected sites of Nigeria was assessed (Olatomiwa *et al.*, 2016). Based on previous site surveys and data collections from two sites located in Sabah, Malaysia, the optimum design of all possible standalone diesel generators, hybrid PV/diesel/battery, and 100% PV/battery scenarios was obtained. In addition, the operational behaviors of different PV penetration levels were analyzed to accurately quantify the impact of PV integration (Halabi *et al.*, 2017). Using HOMER software, an economical and optimized design for electricity generation using PV/Biomass for an agricultural farm and a residential community centered in a small village in Pakistan was obtained (Shahzad *et al.*, 2017). Fig. 12 provides a general picture of the user-friendly interface of HOMER software. As illustrated in Fig. 13, the hybrid system simulated in HOMER can have one or more of generators and storage devices such as PV system, wind generator, diesel engine, gas turbine, hydro turbine, fuel cell, battery, and flywheel.

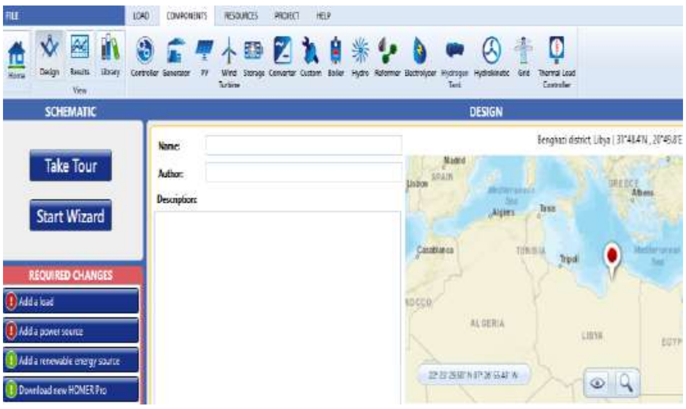


Fig. 12. HOMER Software

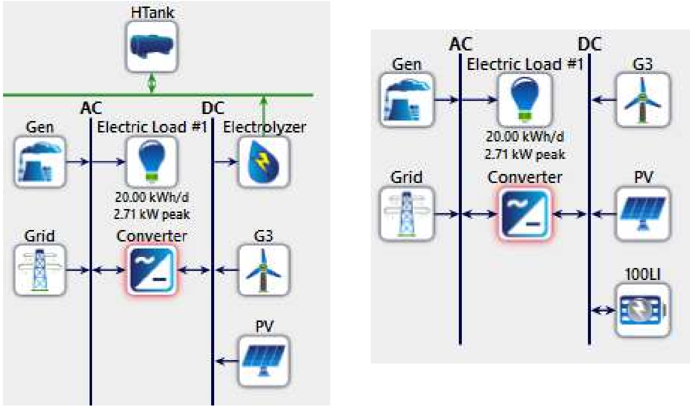
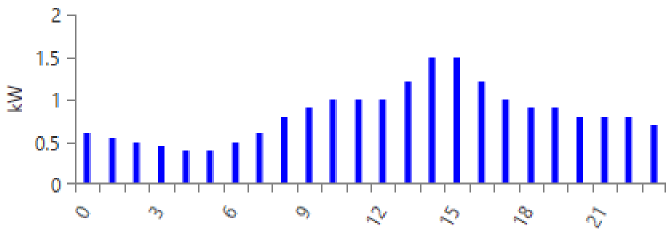


Fig. 13. Microgrid hybrid renewable energy system

This paper conducts an economic and environmental study on a grid-connected PV (GCPV) system for a residential house located in Benghazi. HOMER simulation software is used to simulate a small 5 kW PV system connected to the grid which was designed to fulfill 20 kWh average daily energy demand of the house. Fig. 14 shows the daily load profile of the house as obtained by GECOL. Five kW inverter was used to convert DC power output to AC and then transmitted to the house while any excess power can be sold to the grid under FiT rate. Fig. 15 presents an illustrative configuration of the analyzed GCPV system. The PV system including the panels and the inverter cost around 9000 Libyan Dinars (LD) according to the current prices in the international market.



Metric	Baseline	Scaled
Average (kWh/d)	20	20
Average (kW)	.83	.83
Peak (kW)	2.71	2.71
Load Factor	.31	.31

Load Type: AC DC

Fig. 14. Load Profile of the house over 24 hours

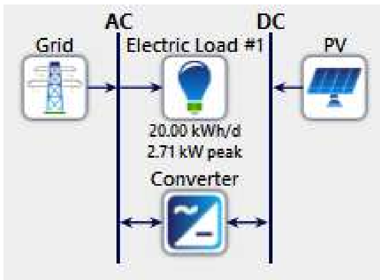


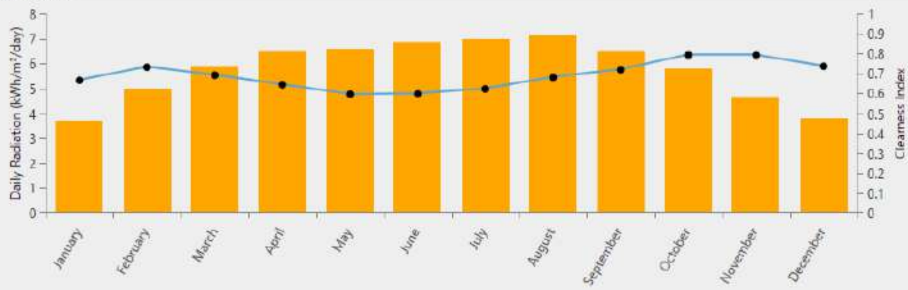
Fig. 15. The 5kW GCPV simulated in HOMER

The solar irradiation data and the clearness index employed in HOMER for Benghazi are obtained easily by inserting the location's latitude and longitude. Fig. 16 depicts the monthly averaged solar irradiation and the clearness index in Benghazi where the average daily irradiation is 5.78 kWh/m^2/day, which is the averaged peak sun hours used in PV system design and its energy output calculation. Meanwhile, sensitivity analysis for the designed 5 kW PV system installed in Benghazi is performed. Fig. 17 presents the results acquired which are the cost of energy (COE), net present cost (NPC), renewable fraction, energy purchased by the house and energy sold from the PV system to the grid. The analysis results were obtained at different rates of energy price, FiT (sell back price), and nominal discount rate (interest rate). Worth mentioning that positive NPC means the PV system installer (investor) would lose at the end of the project lifetime, which is considered in this study as 21 years. For instance, when the base electricity price is 0.02 LD/kWh, which is the tariff approved by GECOL for domestic buildings, the FiT is 0.11 LD/kWh, the nominal interest rate is 2%, then NPC is LD 6778 which means that the project is not feasible. From the results, it is clear that the most favourable scenario for the PV investor is when the base electricity price is 0.02 LD/kWh, the FiT is 1 LD/kWh, the nominal interest rate is 2%, which leads to LD 57872 as a profit.

Now, the electricity tariff is assumed to be unsubsidized by the government. International experience in electricity tariff shows that the electricity price ranges between 10–20 cents per kWh (IEA, 2012; EIA, 2017d). Fig. 18 exhibits the electricity rate in some selected countries where Korea and Canada have the lowest rate with 0.1 $/kWh to as high as 0.35 $/kWh in Denmark and Germany. In fact, it is worth to emulate the successful experience of the developed countries in terms of electricity price and the FiT policy. In this respect, the electricity rate in Libya is assumed to be increased to 0.14 LD/kWh instead of 0.02 LD/kWh. This was adopted by the American and the Canadian electricity tariff which is the lowest rate among the IEA countries (IESO, 2017b).

Monthly Average Solar Global Horizontal Irradiance (GHI) Data

Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.665	3.700
February	0.731	5.000
March	0.691	5.900
April	0.642	6.500
May	0.594	6.600
June	0.597	6.850
July	0.621	7.000
August	0.679	7.100
September	0.718	6.500
October	0.792	5.800
November	0.791	4.620
December	0.736	3.800



Annual Average (kWh/m²/day): 5.78

Fig. 16. Monthly day-average solar irradiation in Benghazi

Sensitivity			Architecture			Cost		System	PV	Grid	
Power Price (ل.د/kWh)	Sellback Rate (ل.د/kWh)	NominalDiscountRate (%)	PV (kW)	Grid (kW)	Converter (kW)	COE (ل.د)	NPC (ل.د)	Ren Frac (%)	Production (kWh)	Energy Purchased (kWh)	Energy Sold (kWh)
0.0200	0.110	2.00	5.00	5.00	5.00	$0.0344	$6,778	66.8	8,616	3,846	4,270
0.0200	0.110	4.00	5.00	5.00	5.00	$0.0441	$7,156	66.8	8,616	3,846	4,270
0.0200	0.200	2.00	5.00	5.00	5.00	$0.00122	$240.72	66.8	8,616	3,846	4,270
0.0200	0.200	4.00	5.00	5.00	5.00	$0.0109	$1,764	66.8	8,616	3,846	4,270
0.0200	0.500	2.00	5.00	5.00	5.00	-$0.109	-$21,552	66.8	8,616	3,846	4,270
0.0200	0.500	4.00	5.00	5.00	5.00	-$0.0999	-$16,208	66.8	8,616	3,846	4,270
0.0200	1.00	2.00	5.00	5.00	5.00	-$0.294	-$57,872	66.8	8,616	3,846	4,270
0.0200	1.00	4.00	5.00	5.00	5.00	-$0.284	-$46,162	66.8	8,616	3,846	4,270
0.140	0.110	2.00	5.00	5.00	5.00	$0.0743	$14,630	66.8	8,616	3,846	4,270
0.140	0.110	4.00	5.00	5.00	5.00	$0.0840	$13,631	66.8	8,616	3,846	4,270
0.140	0.200	2.00	5.00	5.00	5.00	$0.0411	$8,093	66.8	8,616	3,846	4,270
0.140	0.200	4.00	5.00	5.00	5.00	$0.0508	$8,240	66.8	8,616	3,846	4,270
0.140	0.500	2.00	5.00	5.00	5.00	-$0.0696	-$13,700	66.8	8,616	3,846	4,270
0.140	0.500	4.00	5.00	5.00	5.00	-$0.0600	-$9,732	66.8	8,616	3,846	4,270
0.140	1.00	2.00	5.00	5.00	5.00	-$0.254	-$50,020	66.8	8,616	3,846	4,270
0.140	1.00	4.00	5.00	5.00	5.00	-$0.244	-$39,686	66.8	8,616	3,846	4,270

Fig. 17 Sensitivity analysis for the 5 kW GCPV system

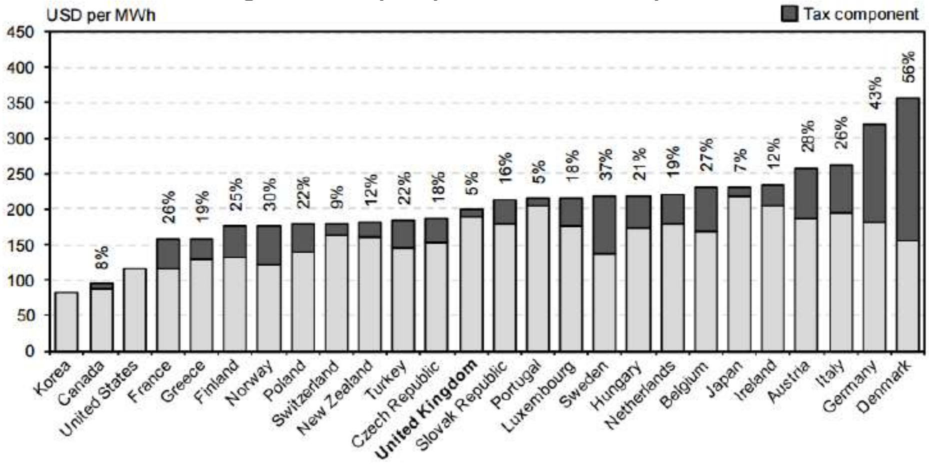


Fig. 18. Household's electricity prices in IEA member countries

As can be seen, at a base electricity price 0.14 LD/kWh, the FiT is one LD/kWh, 2% nominal interest the investment would earn about LD 50000 at the end of the contract lifetime. The cash flow of the best scenario, which is the one highlighted in Fig. 17, is presented in Fig. 19, whereas Fig. 20 summarizes the monthly average electrical production for both the PV system and the grid.

Environmentally, Fig. 21 provides the type and amount of pollutions resultant from the electric system feeding the designed house. As the results provide, the combination of PV-grid sources results in 268 kg/year of CO_2 emissions and much less amount of sulfur dioxide and nitrogen oxides.

On the other hand, powering the electrical demand completely by the grid is also simulated. As shown in Fig. 22 the house owner would pay LD 2484 to the grid over 21 years, which is expressed as positive NPC in the figure. As a matter of fact, the grid contributes negatively to the environment. This is demonstrated in Fig. 23 where the CO_2 resultant from the grid is 17 times more than its counterpart when the PV system is involved. Similarly, the sulfur dioxide emitted when the grid works as the only supplier is 20 kg/year compared to only 1.16 kg/year when the PV technology is involved.

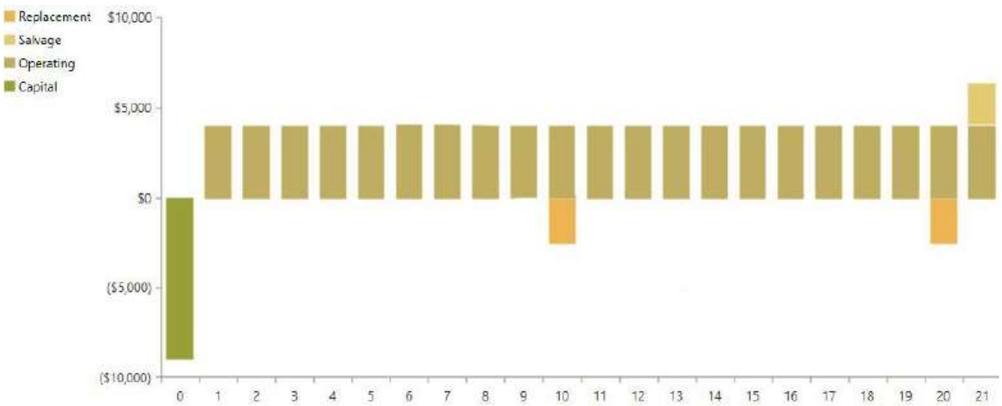


Fig. 19. Cash flow for the best scenario

Production	kWh/yr	%
Generic flat plate PV	8,616	69.1
Grid Purchases	3,846	30.9
Total	12,462	100

Consumption	kWh/yr	%
AC Primary Load	7,300	63.1
DC Primary Load	0	0
Grid Sales	4,270	36.9
Total	11,570	100

Quantity	kWh/yr	%
Excess Electricity	570	4.57
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	66.8
Max. Renew. Penetration	104

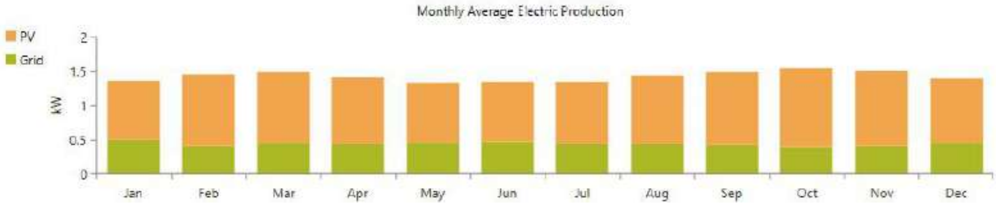


Fig. 20. Monthly average electrical production

Quantity	Value	Units
Carbon Dioxide	268	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	1.16	kg/yr
Nitrogen Oxides	0.568	kg/yr

Fig. 21. Major pollutants resultant from the PV-grid system

Fig. 22. NPC when only the grid supplies the house

Quantity	Value	Units
Carbon Dioxide	4,614	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	20.0	kg/yr
Nitrogen Oxides	9.78	kg/yr

Fig. 23. Major pollutants resultant from the grid as the only supplier

6. Conclusion

Renewable energy projects in Libya face a number of legal, bureaucratic, financial and even cultural issues that need to be considered. However, the solar energy particularly photovoltaic can be one of the most efficient solutions to the energy shortage in Libya. This RE resource has many technical advantages besides its beneficial impact on the national economy in terms of less reliance on fossil fuels and its contribution to the industry thus a creation of jobs.

Under the FiT policy, the PV house will be able to sell clean energy back to the grid. The literature and the acquired results showed that the feed-in tariff could play a key role towards a wider use of solar PV technology. This is one of the most important measures along with increasing the fuel-based electricity price to be considered by the Libyan government for a wider dispersion of PV technology and improving the economy.

To promote PV installations and RE resources in general, medium and long-term strategies and initiatives is crucial. For example, the governmental subsidy for conventional fuel source should be gradually eliminated and/or transferred to PV installation projects as a subsidy. However, the most challenging issue, which adversely affects the development of PV technology, is the inflation rate. Nonetheless, this can be seen as a temporary problem since it is mainly related to the current political instability of the country. The study is believed to encourage and initiate the public to build a successful investment and contribute to the development and deployment of new clean energy sources. Furthermore, the study offers a strategic plan for all key players in order to establish an economy that is based on the technology and knowledge. The advantages of the development of PV installations in Libya can be summarized in the following points:

- Promotion of GCPV helps in reducing the consumers' need of electricity to purchase from the utility, thus reducing their electricity bills.
- Deferment of investment on transmission network expansion by installing PV system at new load points.
- Intensifying the uptake of solar energy technology projects for electricity generation enables the utility to reduce the dependence on conventional fuels as energy generation source thus reduces the growth rate of greenhouse gas emissions.
- Diversification, reliability, and security of energy supply.
- Solar power industry can support the economy of the country and creates thousands of jobs.

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