Solar Energy Potential and Feasibility Study of a 10MW Grid-connected Solar Plant in Libya

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Abstract—**Libya is currently interested in utilizing renewable energy technologies to reduce the energy dependence on oil reserves and Greenhouse Gas (GHG) emissions. The objective of this study is to investigate the feasibility of a 10MW grid-connected PV power plant in Libya. NASA data are used to analyze the global horizontal irradiation, direct normal irradiation, and air temperature of 22 selected locations in Libya and to evaluate the potential of solar energy. RETScreen software is used to estimate the energy production, GHG emissions, and financial parameters for the 22 locations. Based on the solar atlas map, it is noticed that the highest global horizontal irradiation is in the southern part of Libya, which ranged from 2100 to 2500kWh/m^2. These results indicate that Libya has a huge solar energy potential that can be used to generate electricity. Moreover, based on techno-economic results, it is observed that the highest electricity generation of 22067.13MWh is recorded at Al Kufrah and the lowest at Al Jabal al Akhdar with a value of 17891.38MWh. Furthermore, Al Kufrah and Murzuq are the best locations for the future installation of PV power plants from annual energy and the economic parameters point of view. The maximum value of power that can be generated by the plant was estimated to be 22.06GW.**

Keywords-Libya; NASA data; solar energy potential; RETScreen; techno-economic analysis

I. INTRODUCTION

Energy is an indispensable need, which was met with the consumption of conventional fossil fuels until quite recently. However, the use of fossil fuels has polluted the environment and contributed to the climate change due to Greenhouse Gas (GHG) emissions [1]. The environmental problems resulting from the increasing fossil fuel consumption encouraged researchers to investigate alternative sources of energy that would be able to generate energy while protecting the environment [2-4]. Solar energy has become an important alternative source of energy because it is clean, cost-effective, and readily available. Solar energy can be converted to electricity by Photo Voltaic (PV) modules. The utilizing of PV systems has met the electricity demand in many countries. Many studies investigated the potential for solar energy to generate power in various countries. For example, authors in [5] assessed the feasibility analysis of a 6MW grid-connected PV power plant in six states in Nigeria. Authors in [6] evaluated the technical viability of 1MW grid-connected at the Pekan Campus and Gambang of UMP in Peninsular Malaysia by using PVGIS and PVWatt software. The author in [7] analyzed the feasibility of 1MW grid-connected PV power plant in Cyprus. The results indicated that the capital expenditure of the PV Park is a critical parameter for the viability of the project, in the case where no feed-in tariff is available. Authors in [8] evaluated the potential of developing 5MW gird-connected PV power plants in eight selected cities in the southern coast of Iran using RETScreen software. The results showed that the southern coast of Iran has a huge potential and presents actual market opportunities for investors to develop grid-connected PV projects. Authors in [9] assessed the performance of a 6.4kW grid-connected PV system for household buildings in three regions in Northern Cyprus using simulation software (PVGIS, PV*SOL, and PVWatts). The results showed that solar PV power was a feasible solution for supplying power and reducing the volume of CO_2 emissions. Authors in [10] presented the feasibility of 10MW grid-connected PV plants at 44 sites in Saudi Arabia. The author in [11] studied the feasibility of a PV grid-tied energy system in Jos, Nigeria by using HOMER. The results showed that the system could produce energy of 331.536GWh/year with a capacity factor of 40.4% from solar energy.

A. Renewable Energy Potential in Libya

Libya is now experiencing an energy crisis because of the power cuts that persist for seven years without proven solutions. The electricity service is worsening in Libya. Because of Libya's ongoing civil war, the country has faced a chronic power shortage, and various power plants have been damaged, which has caused a reduction in generation capacity in most populated areas. The Libyan electricity sector depends on a public network linking each power station to provide energy demand to all regions of Libya. The total produced electrical energy in generation stations during 2012 reached 33,980GWh. In 2017, the General Electricity Company of Libya (GECOL) stated that the available products for the network were 4,900MW, while the demand reached 6,500 MW, with a deficit of 130MW in the east and 1,470MW in the west. As a result, the power outage crisis has increased in most

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of the regions in Libya, i.e. the western region has five to eight hours of blackouts per day whereas the eastern region has 1 to 4 hours of blackouts per day. According to the GECOL statistics, the peak load was 7000MW in 2016. The electricity of Libya is nationalized under the control of the Ministry of Energy. The power plants in Libya are thermal power plants. There are several power plants in Libya, the most important of which are West of Tripoli (600MW), East of Tripoli (1400MW), Misrata (600MW) and Tobruk (740MW). Also, GECOL stated that it is expected that the maximum load will increase to 10,795MW by 2020, then to 14,834MW by 2030 and 21,669MW by 2050. These estimates are based on an optimistic assumption of the recovery of the Libyan economy, and the increase in demand from the industry and energy sector in particular. Therefore, it can be concluded that the amount of CO_2 and greenhouse gas emissions released will rise as a result of increasing energy consumption. Additionally, the electricity consumption demand in Libya will increase in the long term [12], which indicates that the amount of fossil fuels used for electricity production will increase in the future. Therefore, alternative energy sources, such as wind or solar energy could be the best solution to reduce fossil fuel demand and CO_2 emissions in the country.

Libya is a country rich in renewable energy sources, particularly solar energy, as the annual average solar radiation of the horizontal surface ranges from 5.5kWh/m^2 in the coastal strip regions to 7.0kWh/m^2 in the southern regions [13]. Numerous studies have investigated the potential of renewable energy, especially solar energy, in Libya. Authors in [14] investigated the current utilization and the future of renewable energy in Libya by conducting interviews with managers, consultants, and decision-makers from different government organizations. The results demonstrated that renewable energy could be the solution to cover some of the energy demand in the country. Authors in [15] examined the potential use of renewable energy sources for improving the current and future energy situation in Libya. The results indicated that renewable energy systems could produce energy and achieve cost-saving and reduce CO_2 emissions. Authors in [16] investigated the feasibility of replacing the grid-connected HPS-lamp street lighting system with a solar-powered LED street lighting system for a 4km road in Libya. The results indicated that the stand-alone solar-powered LED lighting system reduces CO_2 emissions, saves fuel, and is economically feasible. Authors in [17] proposed photovoltaic-solar water heating and photovoltaic-photovoltaic/thermal systems for replacing the electrical heater and reducing the peak load demand in Libyan electric grid for households. Authors in [18] evaluated the feasibility of a 14MW PV plant in Houn city, Libya. The results showed that it is economically feasible and sustainable. Authors in [19] assessed the mean monthly solar radiation and sunlight duration to analyze the characteristics of radiation and duration sun rays over Tripoli in Libya. They concluded that solar energy can be considered as a major source of renewable energy in Libya and there is a need to attract investors to renewable energy technology by strengthening the existing infrastructure and laws. Moreover, according to [20], solar power will definitely help to solve the electricity supply problem. Authors in [21] provided an overview of the future of renewable energy in terms of solar and wind energy utilization in Libya. The results showed that Libya has a huge renewable energy potential especially solar and wind, which could be used for various purposes such as electricity generation, communication systems, and mechanical activities. Authors in [22] developed a 50MW PVsolar plant in Al-Kufra, Libya. The results indicated that the energy output was found to be 114GWh/year with a payback time of 2.7 years. In addition, Libyan Minister of Electricity stated that Libya intends to build a solar power station to reduce by one-fifth its electricity needs from fossil fuels [23]. Besides, according to a Member of the Board of Directors of the General Electricity Company in southern Libya, the Libyan government aims to construct a 100MW PV system to solve the electricity problem in Southern Libyan cities [24]. Moreover, according to the Vision of the Renewable Energies and Environment (REEO), the desert renewable energy project is one of the most promising projects in the world, which aims to supply Europe with energy extracted from the solar irradiation in North Africa, mainly Libya, and Middle East. The project can produce 250GW per year, thus preventing the emission of 150,000 tons of carbon dioxide.

In summary, most of the researchers investigated the potential of solar in different parts of Libya. They found that Libya has a great potential for harnessing solar energy, which could be used to generate electricity. Besides, the studies indicated that electricity generated from solar energy could help reducing the electricity sector's emissions and fossil fuel consumption. However, none of these studies analyzed the solar energy potential to examine the best location for the future installation of a PV system in Libya. In addition, none of these papers assessed the sustainability of a 10MW grid-connected PV plant in a suitable location in Libya using RETScreen software, which is a vital tool in project decision making where the uncertainty of any project is analyzed by predicting the future return of the renewable energy project for sustainability.

B. Scope of the Study

The literature review reveals a clear lack of evaluation of solar potential in different locations in Libya in order to examine the best location for the future installation of a PV system. Furthermore, there is a clear lack of exploring the potential of a 10MW grid-connected solar PV system generation. As mentioned above, according to GECOL, it is expected for the maximum load to increase to 10,795, 14,834, and 21,669MW by 2020, 2030, and 2050 respectively. Therefore, the primary goal of this study is to draw a solar energy roadmap that aims to decrease the electricity consumption generated by diesel fuel between 30% and 50% by 2030 when the excepted load will reach 14,834MW. Besides, this paper aims to greatly reduce the GHG emissions of the country. Therefore, the potential of exploiting solar energy in 22 regions in Libya is evaluated. Moreover, this study provides technical, environmental, and economic aspects of the 10MW grid-connected PV system for the regions in order to provide solutions to accommodate the increasing energy demand and to improve living quality in urban areas due to the rapid urbanization of the region. In addition, the production of electricity using solar systems can protect the environment. For this purpose, RETScreen Expert software was utilized to validate the techno-economic 10MW grid-connected solar PV system in the regions.

II. Materials and Methods

A. Locations

In this study, 22 regions located in different parts of Libya were chosen as case studies. Information for the geographical locations of the selected cities is listed in Table I.

TABLE I. LOCATIONS OF THE STUDIED REGIONS

Region	Latitude (°N)	Longitude (°E)
Al Butnan	30.178	24.053
Al Jabal al Akhdar	32.48	21.70
Al Jabal al Gharbi	30.705	13.223
Al Jifarah	32.786	13.163
Al Jufrah	28.006	16.743
Al Kufrah	23.33	22.084
Al Marj	31.911	21.14
Al Marqab	32.407	13.86
Al Wahat	29.157	21.750
An Nuqat al Khams	32.718	11.990
Az Zawiyah	32.763	12.726
Benghazi	32.129	20.082
Darnah	32.759	22.638
Ghat	26.020	10.434
Misratah	32.375	15.090
Murzuq	24.535	15.25
Nalut	30.613	10.67
Sabha	27.033	14.43
Surt	31.206	16.584
Tripoli	32.897	13.17
Wadi al Hayat	26.423	12.718
Wadi ash Shati'	27.602	12.864

B. Design of the PV Power System

According to [25], the parameters that are considered of most importance in designing a PV solar plant are:

- Power generating factor (PGE):

$$PGE = \frac{Solar\ irradiance \times Sunshine\ hours}{Standard\ test\ condition\ irradiance} \quad (1)$$

- Energy demand (ED):

$$ED = Energy\ consumption\ of\ all\ loads \quad (2)$$

- Solar PV energy required (SPVER):

$$SPVER = PER \times ELS \quad (3)$$

- PV module sizing:

$$Total\ Watt\ peak\ rating = \frac{Solar\ PV\ energy\ required}{panel\ generation\ factor} \quad (4)$$

$$PV\ module\ size = \frac{Total\ Watt\ peak\ rating}{PV\ output\ power\ rating} \quad (5)$$

- Inverter sizing:

$$Inverter\ size = PER \times Factor\ of\ safety \quad (6)$$

where PER is Peak Energy Requirement, ELS is energy lost in the system and the factor safety is 1.3 [25].

C. PV Plant Layout

Fifty hectares of land are usually needed in order to install a 10MW solar PV plant. For the proposed PV system, Canadian Solar mono-Si - CS6X-300M with an output power rating of 300W has been considered due to its high efficiency. To build the 10MW grid-connected PV plant in the chosen location, 33500 of the selected modules are required, as calculated with (5). Furthermore, the inverter size is estimated as 13MW. Fourteen units of central inverters of Sunny Central 850CP XT were utilized. Each selected inverter has a capacity of 954kW. The total capacity of 13.356MW was used for the proposed PV system to convert DC into AC power. The grid-connected PV system configuration is shown in Figure 1.

Fig. 1. Components of the grid-connected solar plant.

D. PV Solar Panels

The solar panels, composed of a number of solar cells, are used to change the sunlight into direct current using semiconducting materials. In general, when the solar radiation falls on the solar cell, the anti-reflective layer effectively traps the incident light by enhancing its transition to the next layers. On the other hand, the positive gaps move to the conduction area of the positive strip, resulting in a potential difference between the surfaces of the two-link. The two surfaces can be connected by an electrical conductor to obtain an electric current in an electrical circuit, where electrons pass through the negative to the positive link, and thus light energy is converted into electrical energy. In this study, monocrystalline PV panels are used. Table II tabulates the characteristics of the used PV panels.

TABLE II. CHARACTERISTICS OF USED PV PANELS

Electrical characteristics at (STC)	Value
Watts (STC)	300W
Watts (PTC)	217W
Max Power Voltage (VMPP)	36.5V
Max Power Current (IMPP)	8.22A
Open circuit voltage	45.0V
Short circuit current	8.74A
Max System Voltage (UL)	DC 600V
Efficiency	15.63%

E. Power Conditioning Units

Generally, PV panels convert solar radiation energy to electrical energy and the electricity is produced in the form of direct current (DC). Therefore, the DC current must be converted to alternating current (AC). For this purpose, inverters are used. The specifications of the applied inverter used in this study are presented in Table III.

TABLE III. ELECTRICAL PROPERTIES OF THE SELECTED INVERTERS

Type	Modular power switch
Max. DC power	954kW
Max. input voltage	1000V
MPP voltage range	681e850V/625e850V
Rated input voltage	681V
Max. input current	1400A
Max. DC short-circuit current	2500A
Rated power (@ 25°C)	935kVA
Nominal AC voltage/nominal AC voltage range	386V/348V-443V
Max. Output current/max. total harmonic distortion	1411A/0.03
Max. efficiency/European efficiency/CEC efficiency	98.6%/98.4%/98.5%

F. Power Evacuation

For the proposed 10MW grid-connected solar plant, transformers with a rated power of 1.5MVA were utilized. The PV system is integrated into the grid by a DC/AC inverter, a step-up transformer, and an evacuating line of 33kV. The evacuation of power demands the reliability of the distribution system to be 99.5%. The efficiency of the transformer is almost 97%

G. Simulation Software Used

PVGIS (Photovoltaic Geographic Information System) is widely used for evaluating the performance of solar PV power plants. The European Commission has developed a web application with a geographical location interface for analyzing "Solar Resource Geographical Evaluation and Performance of Photovoltaic Technology". This tool contains a package, which includes solar radiation databases, performance evaluation methods, and estimates of economic parameters including electricity cost. PVGIS allows the user to choose the PV technology to be used in the system, enter system capacity requirement for installation and enter the permissible total system losses. It also allows the user to choose the slope or tilt angle and azimuth angle of the PV module. In order to assess the technical, economic, and environmental impact of renewable energy projects, RETScreen program was used. RETScreen is a clean energy management program to ensure energy efficiency, renewable energy, co-generation analysis, and continuous energy performance analysis. RETScreen is a useful tool for analyzing and assessing the viability of a grid-connected renewable energy system. In this study, important economic measures are the net present value (NPV), the internal rate of return (IRR), the flat energy cost (LCOE), the payback period (PB), the annual life cycle savings (ALCS), and the benefit-cost ratio (B-C) which are calculated using the RETScreen. Figure 2 presents the outline of the methodology used by the RETScreen Expert software.

- Net present value (NPV):

$$NPV = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n} \quad (7)$$

- Levelized cost of energy (LCOE):

$$LCOE = \frac{sum\ of\ cost\ over\ lifetime}{s\ of\ electricity\ generated\ over\ the\ lifetime} \quad (8)$$

- The internal rate of return (IRR):

$$O = \sum_{n=0}^{N} \frac{C_n}{(1+IRR)^n} \quad (9)$$

- Simple payback (SP):

$$SP = \frac{C-IG}{(C_{ener}+C_{capa}+C_{RE}+C_{GHG})-(C_{o\&M}+C_{fuel})} \quad (10)$$

- Equity payback (EP):

$$EP = \sum_{n=0}^{N} C_n \quad (11)$$

- Annual life cycle savings (ALCS):

$$ALCS = \frac{NPV}{\frac{1}{r}\left(1-\frac{1}{(1+r)^N}\right)} \quad (12)$$

- GHG emission reduction cost (GRC):

$$GRC = \frac{ALCS}{\Delta_{GHG}} \quad (13)$$

- Benefit-Cost ratio (B-C):

$$B-C = \frac{NPV+(1-f_d)C}{(1-f_d)C} \quad (14)$$

- Capacity factor (CF)):

$$CF = \frac{P_{out}}{P \times 8760} \quad (15)$$

where P_{out} is the energy generated per year, P is the installed capacity, N is the project life in years, C_n is the after-tax cash flow in year n, r is the discount rate, C is the total initial cost of the project, f_d is the debt ratio, B is the total benefit of the project, IG is the incentives and grants, C_{ener} is the annual energy savings or income, C_{capa} is the annual capacity savings or income, C_{RE} is the annual Renewable Energy (RE) production credit income, C_{GHG} is the GHG reduction income, $C_{o\&M}$ is the yearly operation and maintenance costs incurred by the clean energy project, C_{fuel} is the annual cost of fuel, which is zero for renewable projects, and Δ_{GHG} is the annual GHG emission reduction.

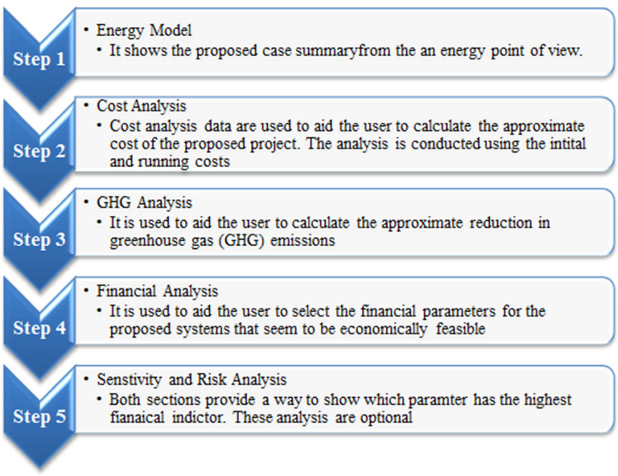

Fig. 2. Standard analysis in RETScreen software.

III. Results and Discussion

A. Global Solar Resources

Two parameters, namely Global Horizontal Irradiation (GHI) and Direct Normal Irradiation (DNI) are used to analyze the solar resource in Libya. The annual averaged GHI, DNI, and TEMP values for all the locations are provided in Table IV. The values of GHI were found to vary from 2020.807kWh/m^2 to 2308.587kWh/m^2. The maximum and minimum annual values of GHI are recorded in Al Kufrah and Tripoli, with a value of 2308.587kWh/m^2 and 2020.807kWh/m^2 respectively. Furthermore, it is found that the highest annual value of DNI of 2429.203kWh/m^2 occurs in Misratah and the lowest value (2267.607kWh/m^2) is recorded in Darnah. Additionally, it is noticed that the maximum and minimum value of air temperature is recorded in Ghat and Al Jabal al Akhdar with a value of 25.047^{o}C and 17.298 ^{o}C respectively.

TABLE IV. ANNUAL GHI, DNI AND TEMP FOR ALL SELECTED REGIONS

Regions	GHI [kWh/m^2]	DNI [kWh/m^2]	TEMP [°C]
Al Butnan	2110.6	2294.8	22.8
Al Jabal al Akhdar	2035.3	2309.2	17.3
Al Jabal al Gharbi	2101.8	2323.5	21.5
Al Jifarah	2187.2	2350.2	22.6
Al Jufrah	2187.2	2350.2	22.6
Al Kufrah	2308.6	2394.4	23.4
Al Marj	2068.9	2314.1	21.6
Al Marqab	2069.9	2375.7	20.6
Al Wahat	2131.4	2309.3	23.8
An Nuqat al Khams	2049.0	2373.6	22.9
Az Zawiyah	2060.5	2420.7	23.2
Benghazi	2065.6	2400.5	21.4
Darnah	2058.9	2267.6	20.3
Ghat	2206.3	2311.8	25.0
Misratah	2061.5	2429.2	22.1
Murzuq	2248.5	2318.7	24.3
Nalut	2080.5	2274.0	22.7
Sabha	2145.1	2271.8	24.8
Surt	2117.7	2416.1	22.4
Tripoli	2020.8	2397.3	22.3
Wadi al Hayat	2211.1	2330.9	23.4
Wadi ash Shati'	2166.1	2295.9	24.6

B. SimulationRresults of Energy Generation and Capacity Factor

In this study, PVGIS software is used to find the optimum slope angle and azimuth angle for all selected locations in Libya. Table V lists the optimum angle for the future installation of a PV system for all chosen locations. RETScreen is utilized to investigate the feasibility of a grid-connected 10MW PV system in the selected locations. The mean monthly electricity generation from the proposed system is shown in Table VI. Figure 3 illustrates the annual electricity exported to the grid from the proposed PV system. It is observed that the highest annual electricity generation of 22067.128MWh is recorded at Al Kufrah and the lowest one of 17680.901MWh is obtained at Al Marqab. Moreover, based on the results of electricity generation for Al Kufrah and Al Marqab (see Table VI), it is noticed that the maximum monthly electricity generation is achieved in July with a value of 1986.72MWh for Al Kufrah and 1847.528MWh for Al Marqab. The minimum monthly electricity generation is recorded in December for Al Marqab and Al Kufrah. The Capacity Factor (CF) for the proposed PV project for all chosen locations is presented in Figure 4.

TABLE V. OPTIMUM ANGLES FOR PV SYSTEMS

Location	Slope angle [°]	Azimuth angle [°]
Al Butnan	29	-6
Al Jabal al Akhdar	28	-7
Al Jabal al Gharbi	30	-7
Al Jifarah	30	-3
Al Jufrah	27	-6
Al Kufrah	22	-5
Al Marj	29	-8
Al Marqab	30	0
Al Wahat	28	-5
An Nuqat al Khams	31	-4
Az Zawiyah	30	-3
Benghazi	29	-2
Darnah	28	-4
Ghat	26	-6
Misratah	30	-4
Murzuq	24	-7
Nalut	30	-6
Sabha	26	-7
Surt	29	3
Tripoli	30	4
Wadi al Hayat	27	0
Wadi ash Shati'	28	-2

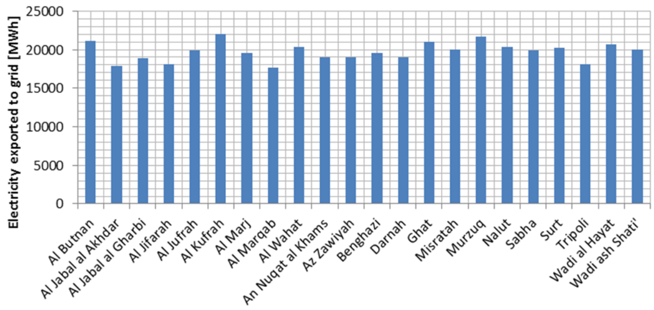

Fig. 3. Annual electricity exported to the grid for all selected locations.

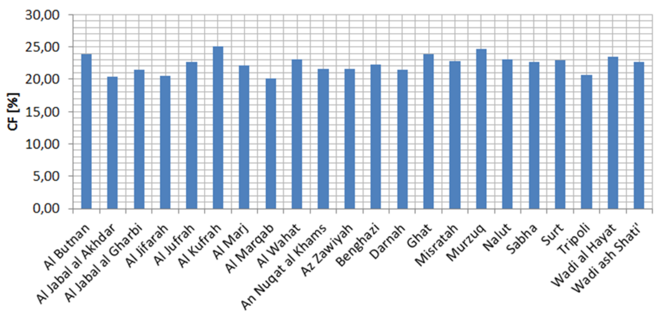

Fig. 4. CF for all locations.

The maximum capacity factor is observed for the climatic conditions of Al Kufrah with a value of 25.07%. The values of CF are within the range 20.08%-25.07%. These values indicate that the selected regions are suitable for developing PV projects. The results of the annual energy exported to the grid and their CF in each city in Libya are compatible with the acceptable values [10, 26] and hence, it is technically sustainable to build and operate solar PV plants in the selected regions based on the technical viability of the solar system.

C. Simulation Results of Financial and Emission Reduction Analysis

Economic analysis is essential in order to know if the project is economically viable and sustainable. Studying the economic viability of PV power plant benefits and informs both investors and policymakers. The financial analysis worksheet of RETScreen software includes some financial parameters like inflation rate, discount rate, reinvestment rate, debt ratio, debt interest rate as input variables. Based on the input variables, Simple payback, Equity payback, Net Present Value (NPV), Annual Life Cycle Savings (ALCS), and Levelized Cost of Electricity were determined. Table VII shows the financial parameters including inflation rate, discount rate, debt ratio, debt interest rate, and project life which are used as input variables for assembly to be economically feasible.

TABLE VI. MEAN MONTHLY ELECTRICITY EXPORTED TO THE GRID IN MWH FROM THE PROPOSED PV SYSTEM FOR ALL SELECTED REGIONS

Month	Al Butnan	Al Jabal al Akhdar	Al Jabal al Gharbi	Al Jifarah	Al Jufrah	Al Kufrah	Al Marj	Al Marqab
Jan.	1482.45	1019.00	1137.54	1234.86	1305.08	1587.19	1190.31	1161.49
Feb.	1532.75	1122.34	1323.06	1362.68	1454.17	1727.04	1294.09	1221.70
Mar.	1808.01	1543.41	1733.07	1660.70	1823.52	1977.31	1715.83	1565.76
Apr.	1858.58	1717.82	1786.08	1695.56	1840.12	1917.34	1847.94	1649.98
May.	1925.64	1840.15	1828.81	1717.70	1862.01	1977.39	1907.59	1730.37
Jun.	1941.69	1851.44	1828.21	1692.20	1852.40	1942.22	1898.76	1733.37
Jul.	1990.48	1912.75	1977.69	1783.46	1965.28	1986.72	1990.33	1847.53
Aug.	1973.41	1825.05	1903.45	1749.74	1931.31	1986.00	1959.44	1757.98
Sep.	1875.02	1617.19	1667.62	1605.74	1694.00	1908.28	1744.61	1509.14
Oct.	1787.17	1401.08	1471.30	1384.86	1645.74	1909.36	1588.51	1368.89
Nov.	1492.16	1084.45	1140.12	1209.22	1332.55	1644.73	1258.60	1098.46
Dec.	1395.02	956.69	1036.59	972.08	1189.02	1503.55	1118.96	1036.23
Month	**Al Wahat**	**An Nuqat al Khams**	**Az Zawiyah**	**Benghazi**	**Darnah**	**Ghat**	**Misratah**	**Murzuq**
Jan.	1344.84	1131.85	1121.16	1199.03	1095.93	1708.74	1308.39	1575.42
Feb.	1495.15	1308.28	1300.75	1300.83	1217.36	1756.72	1386.79	1710.57
Mar.	1793.38	1709.27	1705.56	1722.05	1639.14	1936.71	1784.12	1969.93
Apr.	1814.05	1813.11	1816.07	1852.16	1787.48	1855.74	1859.89	1899.62
May.	1878.66	1883.10	1891.56	1910.15	1915.47	1729.51	1911.88	1897.24
Jun.	1896.32	1892.96	1904.02	1900.78	1939.33	1669.57	1899.34	1891.20
Jul.	1978.18	2006.89	2017.62	1992.77	2015.16	1827.65	2011.52	1977.58
Aug.	1962.10	1946.14	1951.76	1963.15	1933.42	1848.92	1982.71	1983.57
Sep.	1778.01	1679.92	1678.75	1750.10	1730.47	1730.30	1745.93	1848.98
Oct.	1718.07	1457.72	1450.79	1596.42	1490.30	1747.30	1615.68	1839.03
Nov.	1418.04	1162.27	1152.28	1267.29	1173.66	1556.77	1295.03	1604.16
Dec.	1209.80	1021.90	1011.22	1127.98	1006.26	1612.43	1212.14	1484.67
Month	**Nalut**	**Sabha**	**Surt**	**Tripoli**	**Wadi al Hayat**	**Wadi ash Shati'**		
Jan.	1387.45	1398.51	1371.93	1245.03	1517.70	1428.35		
Feb.	1544.91	1517.54	1486.18	1370.03	1634.83	1539.58		
Mar.	1909.76	1859.00	1858.57	1666.24	1918.52	1869.55		
Apr.	1915.71	1806.54	1852.67	1699.41	1859.38	1801.19		
May.	1813.48	1742.48	1860.13	1720.87	1773.15	1726.66		
Jun.	1823.95	1781.60	1846.30	1695.48	1757.20	1759.97		
Jul.	1927.75	1898.81	1961.08	1786.96	1882.92	1877.79		
Aug.	1957.52	1861.55	1938.07	1753.29	1861.94	1851.15		
Sep.	1739.24	1710.85	1716.92	1610.29	1786.41	1714.41		
Oct.	1632.32	1724.00	1695.64	1391.14	1787.48	1744.61		
Nov.	1408.61	1377.89	1395.14	1218.08	1453.56	1404.58		
Dec.	1249.98	1261.15	1256.48	980.89	1406.55	1290.30		

TABLE VII. FINANCIAL PARAMETERS

Factor	Unit	Value
Inflation rate	%	8
Discount rate	%	6
Reinvestment rate	%	9
Project life	year	25
Debt ratio	%	70
Debt interest rate	%	0
Debt term	year	25
Electricity export escalation rate	%	5

Based on the input variables the NPV, ALCS, and other financial parameters were calculated by the RETScreen software. According to [27], NPV and the payback period are the main economic viability factors in order to measure a PV project. According to our analysis, the NPV values for all regions are positive (see Figure 5), which indicates that the proposed project is estimated to be financially and economically feasible [10, 27]. The simple payback period which is the length of time that will take to recoup the project's initial investment is shown in Figure 6. The proposed PV project in Al Marqab region has the longest payback period of

15.91 years followed by the one in Al Jabal al Akhdar region with 15.72 years, while Al Kufrah region has the shortest payback period of 12.75 years. In addition, Al Marqab has the highest equity payback of 6.31 years, while the one in Al Kufrah has the least with 4.79 years. Furthermore, it is found that Al Kufrah region has the lowest cost of electricity of 0.06564$/kWh followed by Murzuq region with a value of 0.0668$/kWh, while Al Marqab has the highest electricity cost of 0.0819$/kWh as shown in Figure 7. Further analysis of the project was carried out by estimating the value of the ALCS of the developed PV plants. Figure 8 presents the results of this analysis for all selected regions. The proposed PV project in Al Kufrah region has the highest ALCS of 2375881.48 $/year followed by the one in Murzuq region with 2309133.84$/year, while Al Marqab region has the lowest ALCS of 1615756.51$/year.

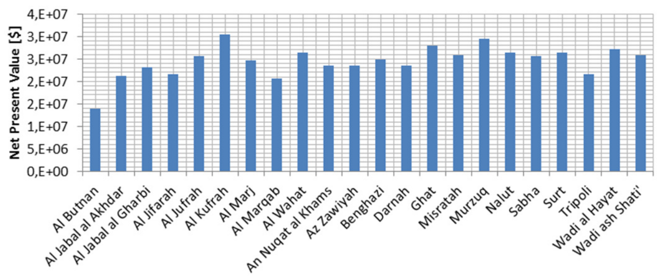

Fig. 5. Net present value in $ for all locations.

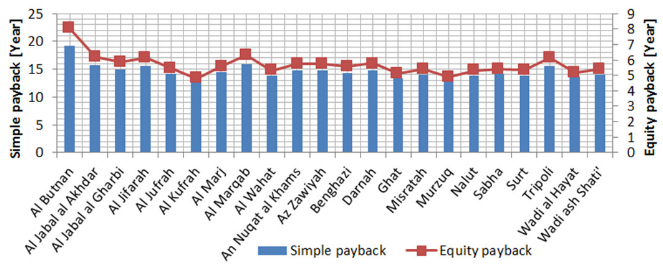

Fig. 6. Simple payback and equity payback in years.

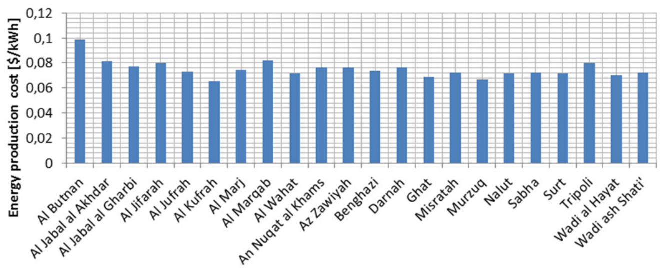

Fig. 7. Energy production cost in $/kWh for all locations.

The emission analysis worksheet was used to calculate the GHG emission reduction resulting from carrying out the solar PV installation. The software calculates the gross annual GHG emission reduction for each of the 22 regions as shown in Figure 9. The project in Al Kufrah region has a maximum GHG emission reduction of 14025.28t CO_2. It is followed by the project in Murzuq region whereas the least emission reduction is obtained from the project in Al Butnan region.

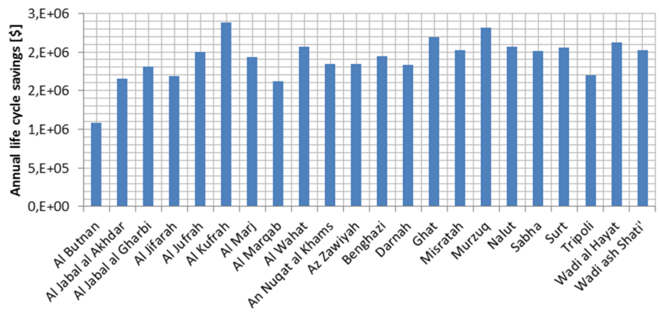

Fig. 8. Annual life cycle saving in $/year for all locations.

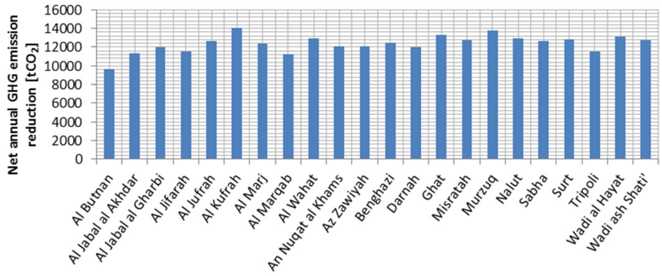

Fig. 9. Emission reduction results.

IV. SUCCESSFUL POLICIES FOR SUPPORTING SOLAR PV POWER SYSTEMS

Renewable energy policies depend on a country's geography, population density, technical and financial capacity, and sovereignty obligations that govern deployment and development of its renewable energy sources [28]. In order to develop and promote renewable technologies and especially solar PV technology in a country, different policy suggestions and interventions are required. Generally, the successful renewable policy or market needs five steps that make up the policy design cycle, which are [28, 29]:

- Defining renewable energy sources targets
- Identifying an appropriate strategy to reach the targets
- Implementing the strategy
- Enforcement and monitoring
- Evaluation of compliance

Additionally, a successful renewable policy or market depends on the technology-specific financial support [30]. However, there are some obstacles in using renewable energy in developing countries in general and Libya in particular, which are classified into financial, institutional, and technical constraints. Financial and economic constraints are considered the most important factors that affect utilizing renewable energy technologies as generation power in developing countries. These constraints are concentrated in the high capital cost of renewable energy projects with a lack (or absence) of financing mechanisms, in addition to the misconception that investing in such projects represents a financial risk. Also, some banks and financing sources may not encourage loans and investments in emerging fields compared to traditional energy projects, and this supports that investments in renewable energy fields may not be of clear in-kind value, and may not be economically attractive (cost-benefit analysis) when compared with other investment opportunities. Therefore, the government can encourage investment in new and renewable energy fields by:

- Setting environmentally oriented policies such as exempting or reducing taxes on energy production from renewable and environmentally friendly sources, and setting taxes and fines on more polluting sources.
- Providing financial assistance and support and ensuring project loans that drive towards the use of renewable resources.
- Setting and developing standards and legislation related to new and renewable sources within the concept of all concerned partners.
- Reconsidering petroleum products pricing systems and linking them to fuel quality.

These must be held in addition to taking into account detailed project proposals that include a description of procedures, mechanisms and the proposed implementation schedule for the project, determining technical needs, techniques, equipment, and expertise needed for implementation, estimating the total value of investments and their terms, and assessing the direct and indirect financial benefits of the project.

Moreover, public awareness is categorized as one of the constraints of utilizing renewable energy technology. The lack of interest in using renewable sources for energy production and a misunderstanding of the nature of the work and applications of renewable energy technologies by the parties concerned and society at large is a major impediment to relying on clean sources for energy production. This obstacle strengthens the general feeling among institutions and individuals that there is little benefit in endeavors related to the environment and the feasibility of using systems that depend on varying natural phenomena (such as the sun and wind). Here, the role of information and awareness emerges to push towards the rehabilitation of individual and public opinion towards a correct concept of energy production from clean and environmentally friendly sources, bearing in mind that awareness is not limited to the media campaigns of the public and its encouragement to switch to new and renewable energy technology only. Rather, it should extend to repeated training and technical education through training programs, scientific seminars, workshops, and conferences for engineers and technicians, and decision-makers in the field of energy and transportation, which help clarifying economic, environmental, and technical facts in these areas.

V. CONCLUSIONS

The problem of power outages continues to trouble the people of Libya since the civil war destroyed the substructure and transmission of the only source of electricity, while the quantities of fuel needed to operate the generation stations are reducing. This situation poses a challenge to the besieged Libyans and forced them to resort to many alternative options such as bringing small generators, storing electricity in car batteries, etc. However, the widening circle of generator users in Libya has left an atmosphere of noise and pollution not seen before, which prompted several researchers to investigate the potentiality of solar energy to generate electricity. Therefore, the investigation of the feasibility of a 10MW grid-connected PV system was made in this study. To achieve this, RETScreen software was utilized to determine the financial parameters and reduction of CO_2 emissions. The main findings of the current study are:

- The annual average global horizontal irradiation of Libya is within the range of 1900-2700kWh/m^2. The highest global horizontal irradiation is in the southern part of Libya, ranging from 2100 to 2500kWh/m^2. These results indicate that Libya receives a huge amount of solar energy that can be used to generate electricity.
- The values of GHI varied from 2020.807kWh/m^2 to 2308.587kWh/m^2. The maximum and minimum annual GHIs are recorded in Al Kufrah and Tripoli, with values of 2308.587kWh/m^2 and 2020.807kWh/m^2, respectively.
- It was found that the highest annual value of DNI of 2429.203kWh/m^2 occurs in Misratah and the lowest value, 2267.607kWh/m^2, in Darnah.
- Maximum and minimum value of air temperature is recorded in Ghat and Al Jabal al Akhdar.
- It is observed that the highest annual electricity generation of 22067.1284MWh is recorded at Al Kufrah and the lowest (17680.901MWh) is obtained at Al Marqab.
- The values of CF are within the range of 20.08%-25.07%. These values indicate that the selected regions are suitable for developing PV projects.
- Al Kufrah region has the lowest cost of electricity of 0.06564$/kWh and Al Marqab has the highest electricity cost of 0.0819$/kWh.

Based on the analysis, it can be concluded that Al Kufrah and Murzuq are the best locations for future installation of PV power plants from the annual energy and the economic parameters point of view.

REFERENCES

[1] L. D. V. Burton, *Agriscience: fundamentals and applications,* Australia: Cengage, 2019.

[2] Y. Zhou, W. X. Wu, and G. X. Liu, "Assessment of Onshore Wind Energy Resource and Wind-Generated Electricity Potential in Jiangsu, China," *Energy Procedia*, vol. 5, pp. 418–422, 2011, doi: 10.1016/j.egypro.2011.03.072.

[3] N. A. Arreyndip and E. Joseph, "Small 500 kW onshore wind farm project in Kribi, Cameroon: Sizing and checkers layout optimization model," *Energy Reports*, vol. 4, pp. 528–535, Nov. 2018, doi: 10.1016/j.egyr.2018.08.003.

[4] R. Goura, "Analyzing the on-field performance of a 1-megawatt-grid-tied PV system in South India," *International Journal of Sustainable Energy*, vol. 34, no. 1, pp. 1–9, Jan. 2015, doi: 10.1080/14786451.2013.824880.

[5] A. B. Owolabi, B. E. K. Nsafon, J. W. Roh, D. Suh, and J.-S. Huh, "Validating the techno-economic and environmental sustainability of solar PV technology in Nigeria using RETScreen Experts to assess its

viability," *Sustainable Energy Technologies and Assessments*, vol. 36, Dec. 2019, doi: 10.1016/j.seta.2019.100542, Art no. 100542.

[6] N. M. Kumar, K. Sudhakar, and M. Samykano, "Techno-economic analysis of 1 MWp grid connected solar PV plant in Malaysia," *International Journal of Ambient Energy*, vol. 40, no. 4, pp. 434–443, May 2019, doi: 10.1080/01430750.2017.1410226.

[7] A. Poullikkas, "Parametric cost–benefit analysis for the installation of photovoltaic parks in the island of Cyprus," *Energy Policy*, vol. 37, no. 9, pp. 3673–3680, Sep. 2009, doi: 10.1016/j.enpol.2009.04.037.

[8] K. Mohammadi, M. Naderi, and M. Saghafifar, "Economic feasibility of developing grid-connected photovoltaic plants in the southern coast of Iran," *Energy*, vol. 156, pp. 17–31, Aug. 2018, doi: 10.1016/j.energy.2018.05.065.

[9] Y. Kassem, R. Al Zoubi, and H. Gokcekus, "The Possibility of Generating Electricity Using Small-Scale Wind Turbines and Solar Photovoltaic Systems for Households in Northern Cyprus: A Comparative Study," *Environments*, vol. 6, no. 4, Apr. 2019, doi: 10.3390/environments6040047, Art no. 47.

[10] S. Rehman, M. A. Ahmed, M. H. Mohamed, and F. A. Al-Sulaiman, "Feasibility study of the grid connected 10MW installed capacity PV power plants in Saudi Arabia," *Renewable and Sustainable Energy Reviews*, vol. 80, pp. 319–329, Dec. 2017, doi: 10.1016/j.rser.2017.05.218.

[11] M. S. Adaramola, "Viability of grid-connected solar PV energy system in Jos, Nigeria," *International Journal of Electrical Power & Energy Systems*, vol. 61, pp. 64–69, Oct. 2014, doi: 10.1016/j.ijepes.2014.03.015.

[12] A. Asheibe and A. Khalil, "The Renewable Energy in Libya: Present Difficulties and Remedies," in *Proceedings of the World Congress on Renewable Energy, Australia*, 2013.

[13] "Global Solar Atlas." https://globalsolaratlas.info/map?s=27,17&m=site&c=27,17,11 (accessed Apr. 27, 2020).

[14] A. M. A. Mohamed, A. Al-Habaibeh, and H. Abdo, "An investigation into the current utilisation and prospective of renewable energy resources and technologies in Libya," *Renewable Energy*, vol. 50, pp. 732–740, Feb. 2013, doi: 10.1016/j.renene.2012.07.038.

[15] S. Alweheshi, A. Abdelali, Z. Rajab, A. Khalil, and F. Mohamed, "Photovoltaic Solar Energy Applications in Libya: A Survey," in *2019 10th International Renewable Energy Congress (IREC)*, Mar. 2019, pp. 1–6, doi: 10.1109/IREC.2019.8754527.

[16] A. Khalil, Z. Rajab, M. Amhammed, and A. Asheibi, "The benefits of the transition from fossil fuel to solar energy in Libya: A street lighting system case study," *Applied Solar Energy*, vol. 53, no. 2, pp. 138–151, Apr. 2017, doi: 10.3103/S0003701X17020086.

[17] M. Zuheir *et al.*, "A comparison between solar thermal and photovoltaic/thermal (PV/T) systems for typical household in Libya," in *2017 4th IEEE International Conference on Engineering Technologies and Applied Sciences (ICETAS)*, Nov. 2017, pp. 1–6, doi: 10.1109/ICETAS.2017.8277877.

[18] A. Kadem, Z. Rajab, A. Khalil, A. Tahir, A. Alfergani, and F. A. Mohamed, "Economic feasibility, design, and simulation of centralized PV power plant," in *2018 9th International Renewable Energy Congress (IREC)*, Mar. 2018, doi: 10.1109/IREC.2018.8362448.

[19] H. S. A. Embirsh and Y. A. M. Ikshadah, "Future of Solar Energy in Libya," *International Journal of Scientific and Research Publications*, vol. 7, no. 10, pp. 33–35, 2017.

[20] A. Bodetti, "Could solar power be the answer to Libya's energy problems?," *alaraby*. https://english.alaraby.co.uk/english/indepth/2019/9/6/developing-solar-power-energy-in-libya (accessed Apr. 28, 2020).

[21] O. A. Mohamed and S. H. Masood, "A brief overview of solar and wind energy in Libya: Current trends and the future development," *IOP Conference Series: Materials Science and Engineering*, vol. 377, Jun. 2018, Art no. 012136, doi: 10.1088/1757-899X/377/1/012136.

[22] Y. Aldali, D. Henderson, and T. Muneer, "A 50 MW very large-scale photovoltaic power plant for Al-Kufra, Libya: energetic, economic and environmental impact analysis," *International Journal of Low-Carbon Technologies*, vol. 6, no. 4, pp. 277–293, Dec. 2011, doi: 10.1093/ijlct/ctr015.

[23] "Libya aims to get about fifth of power from solar by 2020," *Reuters*, Apr. 11, 2013.

[24] "LIBYA: Government launches construction of a solar power plant in Kufra," *Afrik 21*, Mar. 16, 2020. https://www.afrik21.africa/en/libya-government-launches-construction-of-a-solar-power-plant-in-kufra/ (accessed Apr. 27, 2020).

[25] Y. Kassem, H. Camur, and S. M. A. Alhuoti, "Solar Energy Technology for Northern Cyprus: Assessment, Statistical Analysis, and Feasibility Study," *Energies*, vol. 13, no. 4, pp. 1–29, 2020.

[26] B. Shiva Kumar and K. Sudhakar, "Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India," *Energy Reports*, vol. 1, pp. 184–192, Nov. 2015, doi: 10.1016/j.egyr.2015.10.001.

[27] A. Mehmood, F. A. Shaikh, and A. Waqas, "Modeling of the solar photovoltaic systems to fulfill the energy demand of the domestic sector of Pakistan using RETSCREEN software," in *2014 International Conference and Utility Exhibition on Green Energy for Sustainable Development (ICUE)*, Pattaya, Thailand, Mar. 2014, pp. 1–7.

[28] A. Gungah, N. V. Emodi, and M. O. Dioha, "Improving Nigeria's renewable energy policy design: A case study approach," *Energy Policy*, vol. 130, pp. 89–100, Jul. 2019, doi: 10.1016/j.enpol.2019.03.059.

[29] J.-H. Yoon and K. Sim, "Why is South Korea's renewable energy policy failing? A qualitative evaluation," *Energy Policy*, vol. 86, pp. 369–379, Nov. 2015, doi: 10.1016/j.enpol.2015.07.020.

[30] R. Haas, C. Panzer, G. Resch, M. Ragwitz, G. Reece, and A. Held, "A historical review of promotion strategies for electricity from renewable energy sources in EU countries," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 2, pp. 1003–1034, Feb. 2011, doi: 10.1016/j.rser.2010.11.015.