Atlas of PV Solar Module Technologies Across Libyan Territory

Yasser F. Nassar
Dept. of Mechanical and Renewable Energy Engineering
University of Wadi Alshatti
Brack, Libya
y.nassar@wau.edu.ly

Samer Y. Alsadi
Dept. of Electrical Engineering
Palestine Technical Univ.-Kadoorie
Tulkarm-Palestine
s.alsadi@ptuk.edu.ps

Guzlan M. Miskeen
Dept. of Medical Engineering
University of Wadi Alshatti
Brack, Libya
g.miskeen@wau.edu.ly

Hala J. El-Khozondar
Dept. of Electrical Engineering and smart systems
Islamic University of Gaza
Gaza, Palestine
hkhozondar@iugaza.edu.ps

Nassir M. Abuhamoud
Dept. of Electrical and Electronic Engineering
University of Wadi Alshatti
Brack, Libya
n.abuhamoud@wau.edu.ly

Abstract **– Solar energy is one of the most promising renewable energy options in Libya. The electrical yield of the solar PV panel is very sensitive to the cell's temperature. As Libya is a vast and with different terrains, weather parameters such as: temperature, wind, rain and humidity vary significantly across the country. Therefore, this variation must be considered when assessing the feasibility of the PV solar systems, taking into consideration the selection of the appropriate PV technology in terms of the electrical characteristics, and not generalizing the results of a specific region to the whole country. The aim of this work is to assess the performance of several PV technologies to figure out their suitability to work ~~in different~~ under various weather conditions in Libya. Due to the lack of weather data, the research utilized the data provided by Solargis Database Company in analyzing the performance of PV solar field. In this regard, economic parameters of three different kinds of PV solar modules were simulated under real weather conditions of several sites using System Advisor Model software (SAM) simulation tool developed by the NREL-USA. It is successfully determined the most suitable kind of PV solar module for each zone across the Libyan territory. The obtained results can be implemented in the preliminary design steps, especially in the selection of the kind of PV solar modules to be installed in a particular location, where a difference in the LCOE values up to 45% was remarked between several types of PV solar modules for the same location.**

Index Terms -   Libya, PV solar module, Monocrystalline, Multicrystalline, Thin Film, temperature coefficients.

I. INTRODUCTION

Beyond 2011, the economic situation of Libya becomes worse than before. The Libyan dinar exchange rate fell down, fuel prices rose dramatically, and with a shortage of electricity generation, the hours of electricity cuts increased, reaching more than 50% in some times, and this situation continued to nowadays. In the southern region of the country the situation is even worse. This is as a result of the severe damage to the power stations and the high voltage transmission lines. These reasons motivated people to turn to solar PV systems as an alternative source of electrical energy [1]. Consequently, market of PV solar modules, inverters and storage batteries in the Libyan market has grown rapidly without any study or even quality control. Based on the Libyan Chamber of Commerce, the value of solar energy equipment within the Libyan market exceeds 300 million Libyan Dinars. This huge business attracted many companies, as the number of companies importing solar energy equipment has grown up to 34 companies, after this business was limited only to solar energy research centers for scientific purposes in most cases. At the governmental level, Libyan government launched the Renewable Energy Strategic Plan for the upcoming 30 years, which aims to achieve a contribution of renewable energy to the electric energy mix of 25% by 2025 and 30% by 2030. By 2050, Libya will be using renewable energy more than fossil energy unlike the current situation .This will come from wind, Concentrated Solar Power, solar PV and solar heat [2].

On the other hand, the Libyan government intends to participate in international events to reduce carbon dioxide emissions, which is considered as the primary cause of the dangerous climatic phenomena that humanity suffers from [3]. Considering that the energy industry in Libya is the largest contributor to the environment pollution, due to its full-dependence on fossil fuels [4]. The switch into an alternative and environmentally friendly power generation system is considered as an appropriate measure to reduce pollution on one hand and to preserve the oil wealth, which is the main source of national income in the country on the other hand [5].

Popularly, PV solar systems can be considered an appropriate and quick solution to eliminate all problems related to the shortage in the electrical and fuel supplies to people. PV systems are also considered an economic and environmental alternative to mobile electric generators in the event of fuel supply lack, and this case was in the Gaza Strip - Palestine where people were able to partially fulfill the energy requirements by adopting PV solar energy systems in the residential, industrial, medical and service sectors [6]. This experiment can be successfully applied in Libya.

The outcome power from a PV panel is influenced by several parameters such as weather condition (solar irradiance, air temperature, wind speed, rain, sand storms), and the manufacturing characteristics (type of technology such as monocrystalline silicon (m-Si) and polycrystalline silicon (p-Si and amorphous silicon (a-Si)), efficiency, temperature coefficients. However, the global solar irradiance and the cell's temperature are considered as the critical parameters that control the PV panel performance [7]. It is also obvious that the site location plays a crucial role in this context.

The literature is abound with comparisons of different technologies on PV solar modules performances under different weather conditions and locations around the world. Fig. 1 shows the world map which indicating countries conducted studies to determine the most suitable PV solar module type for the environmental conditions.

Despite the vast geographical area of Libya and the existence of various topographies and weather conditions, this topic did not receive the attention it deserves from the researchers. To the best of our knowledge, only one research study was conducted to investigate the suitability of several technologies of PV solar modules to the climatic conditions of Benghazi city. More specifically, Almaktar et al. evaluated the performance of 1 MW PV solar field with four different solar photovoltaic technologies by using PVsys software under Benghazi's weather condition. The study then recommended polycrystalline silicon type PV solar module technology especially for strategic PV projects [8].

Fig. 1: Countries that have tested the appropriateness of several PV solar modules technologies to work on their territories

In MENA region; Mirzaei and Mohiabadi monitored over a year in semi-arid area of Iran the performance of two different, commercially available photovoltaic modules; m-Si and p-Si.

The m-si module outperformed the p-Si module in terms of obtained efficiency and total energy outcome, according to the performance evaluation of both technologies.

for the considered geographic site [9]. In Kuwait, Mabrouk et al., provided a comparative performance evaluation of eight technologies of PV solar modules, namely: (m-Si), (p-Si), Heterojunction (HIT), and Thin Film (T-F); Cadmium Telluride (CdTe), Copper Indium Gallium Diselenide (CIGS), and Amorphous Silicon (a-Si). The study concluded that m-Si, p-Si and HIT modules performed well for high- level irradiance. For the case of the cylindrical CIGS module, good performance can be achieved in low irradiance level. Moreover (a-Si and CdTe) technologies have the lowest performance among other technologies and this might be due to capture losses. Finally, the HIT technology was shown to performed better than m-Si and p-Si technologies [10].

In Errachidia, Morocco, Bouaichi et al. tested and compared the performance of three PV technologies, namely: m-Si, p-Si and a-Si under desert climate conditions, aiming to determine the most appropriate module technology. The key results indicate that p-Si technology tends to degrade faster with $0.92 \pm 0.11\%$/year compared with $0.45 \pm 0.11\%$/year for m-Si and $0.72 \pm 0.11\%$/year for a-Si. While the Lelevized Cost Of Energy (LCOE) show that the lowest LCOE value is noticed for p-Si system compared to other technologies [11].

Chikh et al. investigated the behavior of four PV module technologies which are m-Si, p-Si, a-Si and the Telluride Cadmium presented a 400kWp pilot plant sub-system installed within the Sahara desert of Ghardaia -Algeria. The obtained results indicate that the plant performs better when operating with irradiance between 5.56 kWh/m2 and 7.04 kWh/m2 and ambient temperature between 2 °C and 45 °C. Thin-film PV technology was recommended for large implementation for regions characterized by Arid climate [12].

This conclusion has been confirmed later by Ihaddadene et al.[13]. In addition, Hossam-Eldin and Gabra investigated experimentally and theoretically the effects of ambient air temperature on performance of different PV panel technologies (TF, m-Si and p-Si) under real outdoor conditions at different locations inside Egypt (Alexandria, Cairo, Assiut and Aswan). They concluded that (m-Si) modules have the highest output at all zones [14].

In cold zones; Kafui et al. assessed the performance of different types of PV solar module technologies under real outdoor conditions of Gödöllő, Hungary. The tested PV solar Modules include amorphous silicon (a-Si), (m-Si) and (p-Si). The study concluded that, under the given outdoor conditions, the highest average performance ratio was obtained for the (mc-Si) module, while (p–Si) module showed the least average performance ratio [15]. Žnidarec et al. empirically analyzed and estimated the performance of 5 PV modules made of seveal technologies: m-Si, p-Si, a-Si, copper indium selenide and heterojunction with intrinsic layer in Osijek city-Croatia. The corresponding results revealed that the copper indium selenide PV module outperformed other modules; hence it is the most suitable PV module for the European humid continental climate. It was also found that p-Si PV module has the worst performance among all studied PV modules [16].

In hot zones; In Paraná – Brazil, Siqueira et al., analysed a stand–alone water pumping system powered by amorphous and (p-Si) PV panels. The research showed with regard to the amount of water pumping and also the efficiency at solar radiation 0.8 $kWhm^{-2}$ in favor of the system to the (p-Si) systems. However, the first one presented lower voltage drop with panel's temperature increasing. It obtained higher flow and overall efficiency in the (p-Si) system [17]. In India, Chakraborty and Sadhu examined the performance of nine different manufacturing materials and technologies PV solar modules under the environmental conditions of the Coal City of India. The obtained results provided performance comparison of different PV technologies which helps to choose the most suitable PV technology for a specific location [18]. In addition, Dash et al provided a detail analysis of techno-economic performance of four photovoltaic (PV) technologies. The study reveals that around 60% of time the PV Module will be at a temperature higher than the standard test condition temperature of 25°C [19]. In Pakistan, Bashir et al., conducted empirical experiments to compare performance measurements of three commercially available PV modules (m-Si, p-Si, and single junction amorphous silicon) during the winter season in Taxila city. The study concluded that the (m-Si) module showed higher monthly average module efficiency and was found to be more efficient at this site. Furthermore they remarked that the module efficiency and performance ratio showed a decreasing trend with increase of irradiance and PV module surface temperature [20]. In Kumasi, Ghana, Takyi evaluated the performance of (m-Si) and (p-Si) PV modules under low and high irradiance conditions. The results show that the (p-Si) modules have good response for both low and high irradiances [21]. Fuentealba et al. compared two PV solar technologies (TFs and p-Si), with regard to the energy yield at the coastal zone of the Atacama Desert, Chile, and they were monitored for 21 months. The study concluded that the TFs had more benefit after cleaning than p-Si modules [22].

The present work aims to determine the kinds of solar PV module technologies that are suitable for the climatic conditions of each region of Libya identified on the map. To achieve this goal, performance of 42 solar PV modules from several manufacturers and several technologies that available in the Libyan market will be simulated using the SAM simulation software. The LCOE was considered as the critical indicator of the analysis.

This work has the following scientific and practical significants:

i. A division of the country was created based on the average and highest temperatures into 8 different zones. This division will be utilized in investigating the heating and cooling loads and developing a classification of local energy consumption for the country.
ii. The PV solar energy market in the country was studied and the characteristics and nature of this market were determined.
iii. It has shown that the crystalline PV solar modules group (m-Si and p-Si) are more affected by the atmospheric temperature in hot zones rather than the TF technology types.
iv. It has determined the most suitable kind of PV solar module technology to the nature of a certain city.
v. A map has been created according to the technology of PV solar modules for any site across the Libyan territory.

The rest of the paper is organized as follows: The selected locations and source of the climatic data are described in section 2. The approach that followed in the simulation process has been explained in section 3. The obtained results are illustrated, analyzed and discussed in section 4. Finally, section 5 outlines key conclusions drawn from the conducted study besides recommendations for future directions.

II. CLIMATIC DATA AND SITES

Libya is a vast country (1,760,000 km^2) locates on the "Sun belt" region (longitude 9°-25°E and latitude 18°-33°N) with high solar radiation potential, where the average annual brightness is about 3,200 hours and the average global horizontal solar radiation is 6 kWh per square meter per day [23]. The country was divided according to the topography of the regions (such as mountains, plains, valleys, desert regions, coastal regions) and the air temperatures. Accordingly, eight zones have been identified which represent diverse climatic conditions and topographical variations of the country [24], as shown in Fig. 2.

Due to the lack of climate data, Sebha University signed an agreement with Solargis database company No. ICO: 45354766 under which Solargis database company was given complete access to the climate data for 22 cities in Libya. These cities were carefully selected by specialists to cover all Libyan territory. Fifteen years (from 2004 to 2019), 15 minutes time series validated histyrical weather data of all considered sites were provided. These valubale data included: solar irradiance (global horizontal, beam direct, sky-diffuse, direct normal, global inclined, albedo, and exterretional) Ambient temperature, wind speed and direction, rainfall, relative humidity and pressure. Table A1 tabulated key weather data for the considered cities.

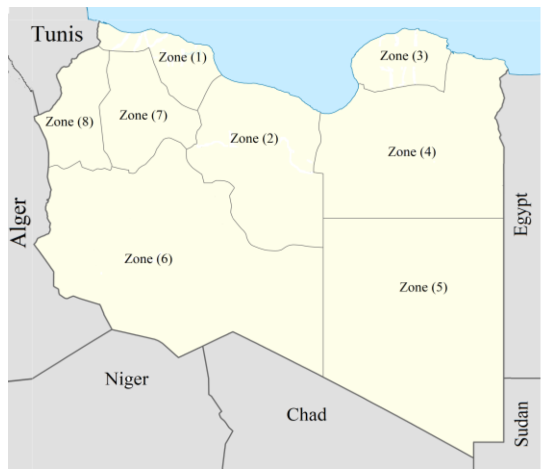

Fig.2: The considered districts in the study

III. METHODOLOGY AND THEORETICAL APPROACH

SAM software is used as a tool for simulating the feseability of a virtual 1,000 kW capacity PV solar field compsites from one type of PV module (m-Si, p-Si or T-F) locates in various zones as it illustrates in Fig. 2, and it experinces to realistic weather conditions, in order to reveal the most realistic type of PV module corresponding to each zone The simulation is performed under different weather conditions that results from the division of Libyan territory to different regions according to the weather conditions.

In each time, the type of PV solar module according to manufacturing company and technology is selected and then the simulation is repeated for all the selected cities. The obtained results have been recorded, analyzed and then graphically presented. Fig. 3 illustrates the flowchart of the approach that followed in the present study.

A. Assumptions, limitations and uncertainties

The following assumptions are considered in the present work to facilitate the analysis:

i. The heat transfer model proposed by SAM simulator was used because the experimental mathematical model was not known for each region.
ii. The optimum tilt angles of the PV solar modules were estimated according to [25, 26].
iii. Liu & Jordan transposition model has been selected for estimating the global tilted solar radiation [27].

The key limitations of the proposed approach is that it does not provide sensitivity analysis related to the impact of various weather parameters on the behavior of a PV solar module.

The major sources of uncertainty are the data availability, model selection and the price of the facilities. Nassar and Alsadi reported a variation in the price of PV modules that exceeded 360% [28].

IV. RESULTS AND DISCUSSIONS

The obtained results tabulated in Tables 1 which tabulates the zone and the corresponding technology that acheives minimum LCOE. It is clear that there is a variety between the performance indicators of several technologies of PV solar modules, and this in turn indicates a confirmed relationship between the optimal choice of the type of PV solar module technology with the climatic nature of a particular location.

In fact, the performance of a solar modules depend more on their electrical characteristics than on the technology itself. Over 500 types of solar modules appended in the SAM library were analyzed, with many of them being of the same technology but it marked substantiality difference in their electrical-thermal characteristics. It is absolutely not suitable to recommend the use of a specific technology, on the contrary, a recommendation cab be made for a specific manufacturer with concrete electrical-thermal characteristics of the PV modules. In this context, manufacturers must provide these characteristics especially the power, voltage and efficiency temperature coefficients on the manufacturing label attached to each PV solar module.

The results of this study showed a large variation in the value of LCOE according to the type of selected solar cells as it illustrated in Fig.5. Which demonstrates the LCOE for Sebha city (zone 6) when using several types of PV solar modules.

From Fig. 5 shows the variation in LCOE for the same location as high as 45% due to the inappropriate selection of the type of PV solar module.

Therefore, we recommend the necessity of conducting extensive research when examining the economic feasibility of solar fields for any region.

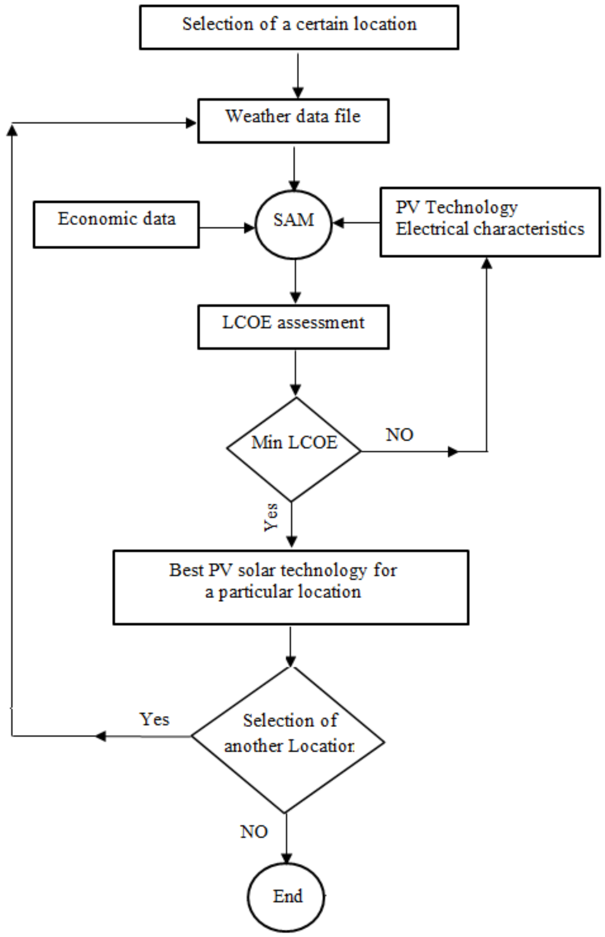

Fig. 3: Flowchart of the approach

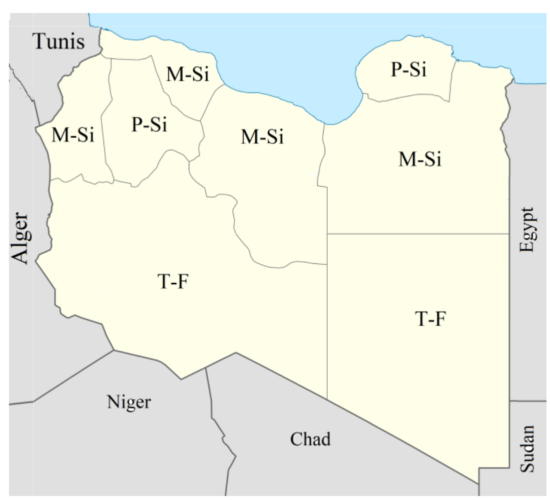

Fig. 4: Classification of PV solar modules technology across the Libyan territory

TABLE 1
THE BEST TECHNOLOGY PV SOLAR MODULE CORRESPONDING TO EACH ZONE

	Technology	Annual Energy; GWh	Capacity factor; %	Performance ratio	LCOE ¢/kWh	Capital Cost US$	M. Company
Zone (1)	M-Si	1.619	18.5	0.81	8.34	1,620,572	Aleo solar S59Y310
Zone (2)	M-Si	1.607	18.3	0.80	8.40	1,620,567	Aleo solar S59Y310
Zone (3)	P-Si	1.597	18.2	0.79	8.45	1,620,354	Canadian solar Inc. SC3W-435PB-AG
Zone (4)	M-Si	1.623	18.5	0.80	8.31	1,620,539	Aleo solar S59Y310
Zone (5)	T-F	1.624	18.5	0.85	8.30	1,620,474	SRS Energy SPT16
Zone (6)	T-F	1.630	18.6	0.80	8.28	1,620,575	Stion SN-115
Zone (7)	P-Si	1.635	18.7	0.79	8.25	1,620,327	Canadian solar Inc. SC3W-435PB-AG
Zone (8)	M-Si	1.636	18.7	0.78	8.25	1,620,377	JA Solar JAM6(k)-72-335/PR

TABLE 2
ELECTRICAL CHARACTERISTICS OF SEVERAL KINDS OF PV SOLAR MODULES TECHNOLOGIES

	Kinds Of solar module	Manufacturing Country	Technology	Efficiency %	Pmax (W)	Vmp (V)	Imp (A)	βp (%/°c)	βv (%/°c)	βI (%/°c)
1	Aleo solar S59Y310	Germany	M-Si	18.91	310	31.7	9.8	-0.396	-0.280	0.036
2	Canadian solar Inc. SC3W-435	Canada	P-Si	20.05	435	40.1	10.8	-0.361	-0.270	0.039
3	SRS Energy SPT16	USA	T-F	15.00	16	4.5	3.5	-0.221	-0.410	0.084
4	Stion SN-115	USA	T-F	11.40	125	41.0	3.0	-0.400	-0.360	0.007
6	JA Solar JAM6(k)-72-335/PR	GERMANY	M-Si	17.55	340	38.2	8.9	-0.377	-0.290	0.049

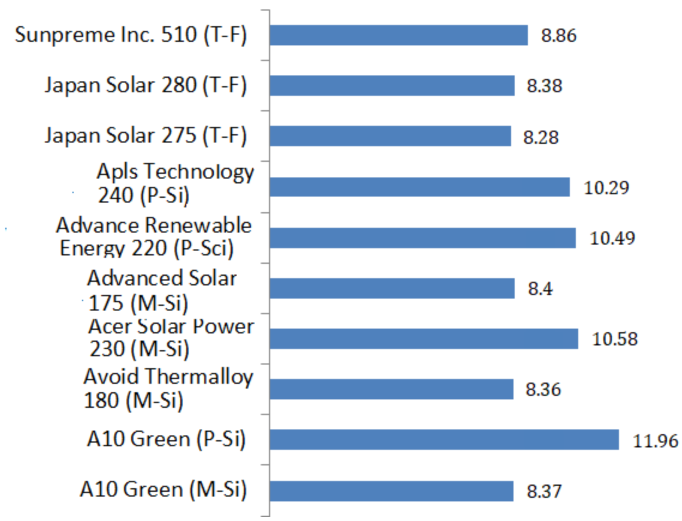

Fig.5: LCOE in ¢/kWh for Sebha City locates in Zone (6) by using several types of PV solar modules

V. CONCLUSIONS AND FUTURE INVESTIGATIONS

A new classification scheme has been developed to map the performance of PV solar module across Libyan territory. In this scheme, sites have been classified according to the minimum LCOE of several types of PV solar modules (m-Si, p-Si and T-F modules). According to the performed analysis and obtained results, the best technology fitted economically for each site in Libya has been determined.

Key Findings of the study are presented below:

i. The critical parameter for the PV solar modules is the power temperature coefficient [*W/°C*], The smaller value, the lower energy losses;

ii. The critical parameter from the weather conditions side is the air temperature in the first position. Lower air temperature leads to more cooling of the PV cells, and consequently, the lower cells surface temperature become, and this will improve PV cells performance.

iii. The effect of the solar irradiation is more complicated. In general, it correlates with the PV module efficiency and the ambient temperature. For low efficiencies, the productivity of the PV module is degraded with the increased solar irradiance.

iv. When designing PV solar fields, the appropriate PV module type must be determined first before making a decision. A difference in the LCOE value up to 45% was remarked among several types of PV modules for the same location.

As future directions, authors plan to conduct an experimental study of the sensitivity of performance of large types of PV solar modules taking into consideration the weather conditions (solar irradiation, temperature, wind speed, rain and air pollutions), and thus it can recommend a particular type of PV solar module for each climatic zone.

REFERENCES

[1] Y. Nassar, K. Amer, M. Irhouma, S. Ahmad, "Economical and environmental assessment of electrical generators: A case study of southern region of Libya." *International Journal of Energy Policy and Management* , vol. 1, no. 4. pp. 64-71, 2015.

[2] O. Mohamed and M. Masood, "A brief overview of solar and wind energy in Libya: Current trends and the future development," in *This will come from wind, Concentrated Solar Power, solar PV and solar heat.*, Victoria, Australia, 2020.

[3] Y. Nassar, K. Aissa and S. Alsadi, "Air Pollution Sources in Libya.," *Research & Reviews: Journal of Ecology and Environmental Sciences,* vol. 6, no. 1, pp. 63-79, 2018.

[4] Y. Nassar, K. Aissa, S. Alsadi, "Estimation of Environmental Damage Costs from CO2e Emissions in Libya and the Revenue from Carbon Tax Implementation." *Low Carbon Economy*, 8, 118-132, 2017.

[5] Y. Nassar, M. Salem, K. Iessa, I. AlShareef , K. Amer, M. Fakher, "Estimation of CO2 emission factor for the energy industry sector in libya: a case study." *Environment Development and Sustainability*, vol. 23, no.1, pp.13998–14026, 2021.

[6] Y. Nassar and S. Alsadi, S. "Economical and environmental feasibility of the renewable energy as a sustainable solution for the electricity

crisis in the Gaza Strip," *International Journal of Engineering Research and Development*, vol. 12, no. 3, pp. 35-44, 2016.

[7] Y. Nassar and A. Salem, "The reliability of the photovoltaic utilization in southern cities of Libya," *Desalination,* vol. 209, no. 1-3, pp. 86-90, 2007.

[8] M. Almaktar, A. Albrek, F. Mohamed, K. Yahya, T. Hussein, "Performance evaluation of different solar photovoltaic technologies in Libya." *The 11th International Renewable Energy Congress (IREC 2020)*, Tunisa, 2021.

[9] M. Mirzaei and M. Mohiabadi, "A comparative Analysis of Long-term field test of Monocrystalline and polycrystalline PV power generation in Semi-Arid Climate Conditions," *Energy for Sustainable Development,* vol. 38, 2017.

[10] Mabrouk, Al-Qattan, B. A.. Alabdulrazzaq and A. Fakhraldeen, "Comparative performance evaluation of different photovoltaicmodules technologies under Kuwait harsh climatic conditions," *Energy Reports,* vol. 6, pp. 2689-2696, 2020.

[11] A. Bouaichi, A. AumeurEl Amrani, M. Ouhadou, A. Lfakir and C. Messaoudi, "In-situ performance and degradation of three different photovoltaic module technologies installed in arid climate of Morocco," *Energy,* vol. 190, 2020.

[12] M. Chikh, S. Berkane, M. A. Berkane, R. S. and Y. Noureddine, "Performance assessment of a 400 kWp multi- technology photovoltaic grid-connected pilot plant in arid region of Algeria," *Renewable Energy,* vol. 172, no. 3, pp. 488-501, 2021.

[13] R. Ihaddadene, M. Jed, N. Ihaddadene and A. Souza, "Analytical assessment of Ain Skhouna PV plant performance connected to the grid under a semi-arid climate in Algeria," *Solar energy,* vol. 232, pp. 52-62, 2022.

[14] A. Hossam-Eldin, C. Gabra, " Analysis of Performance of Different PV modules at Different Locations in Egypt." *International Conference on Power and Energy Engineering*, Ottawa-Canada,September 13-15, 2017

[15] A. Kafui, I. Seres and I. Farkas, "The state of solar PV and performance analysis of different PV technologies grid-connected installations in Hungary," *Renewable and Sustainable Energy Reviews,* vol. 141, 2021.

[16] M. Žnidarec, D. ŠljivacDamir and Š. Došen, "Performance and Empirical Analysis of Photovoltaic Modules Made of Different Technologies Using Capacity Evaluation Method," *Tehnicki Vjesnik,* vol. 26, no. 6, pp. 1585-1592 , 2019.

[17] A. Lenz, B. Zilli, S. Souza, C. Nogueira, J. Siqueira, I. Werncke, "Stand–alone water pumping system powered by amorphous and polycrystalline photovoltaic panels in Paraná - Brazil", *International Journal of Sustainable Engineering*, vol.14, no. 5, pp. 941-952, 2021.

[18] S. Chakraborty and P. Sadhu, "Technical mapping of solar photovoltaic for the Coal City of India," *Renewables: Wind, Water, and Solar,* vol. 2, no. 11, pp. 1-12, 2015.

[19] P. Dash, N. Gupta, P. Rani, S. Chakraborty and P. Sadhu, "echno-Economic Performance Analysis of Four Photovoltaic Technology at North-East Region of India," in *2018 International Conference on Power Energy, Environment and Intelligent Control (PEEIC)*, Greater Noida, India, 2018.

[20] M. Bashir, H. Ali, S. Khalil, M. Ali and A. Siddiqui, "Comparison of Performance Measurements of Photovoltaic Modules during Winter Months in Taxila, Pakistan," *International Journal of Photoenergy,* vol. 3, pp. 1-8, 2014.

[21] M. Takyi, "Performance Evaluation of Mono-crystalline and Poly-crystalline Silicon Solar PV modules under low and high irradiance conditions in Kumasi, Ghana," *Nigerian Journal of Technology,* vol. 40, no. 3, 2021.

[22] E. Fuentealba, P. Ferrada, F. Araya, A. Marzo, C. Parrado and C. Portillo, "Photovoltaic performance and LCoE comparison at the coastal zone of the Atacama Desert, Chile," *Energy Conversion and Management,* vol. 95, pp. 181-186, 2015.

[23] Y. Nassar, Solar energy engineering active applications, Sebha University, Libya, 2006.

[24] Y. Nassar, M. Abdunnabi, M. Sbeta, A. Hafez, K. Amer, A. Ahmed and B. Belgasim, "Dynamic analysis and sizing optimization of a pumped hydroelectric storage-integrated hybrid PV/Wind system: A case study," *Energy Conversion and Management,* vol. 229, pp. 1-17, 2021.

[25] S. Alsadi andY. Nassar, "General polynomial for optimizing the tilt angle of flat solar energy harvesters based on ASHRAE clear-sky model in mid and high latitudes," *Energy and Power*, Vol. 6, No. 2. 2016.

[26] S. Alsadi and Y. Nassar. "Energy demand based procedure for tilt angle optimization of solar collectors in developing countries," *Journal of Fundamentals of Renewable Energy and Applications*, 7: 225. 2017.

[27] S. Alsadi and Y. Nassar, "Estimation of Solar Irradiance on Solar Fields: An Analytical Approach and Experimental Results." *IEEE Transactions on Sustainable Energy*, vol. 8, no 4, pp. 1601-1608, 2017.

[28] Y. Nassar and S. Alsadi, "Assessment of solar energy potential in Gaza Strip-Palestine," *Sustainable energy technologies and assessments,* vol. 31, pp. 318-328, 2019.

APPENDIX

TABLE A1

KEY WEATHER DATA FOR SEVERAL CITIES IN LIBYA

Zone	City	Daylight, h		Gobal horizontal solar irradiation, W/m^2		Temperatue, °C			Wind speed, m/s		Relative Hummidity, %		Rainfall, mm	
		Avg.	max	Avg.	Max.	Min.	Avg.	Max.	Avg.	Max.	Min.	Avg.	Avg.	Max.
Zone (1)	Ajdabiya	12:10	14:06	471	1057	2	21	40	5	15	15	64	0.02	3
	Tubroq	12:10	14:12	464	1041	1	21	40	5	16	22	70	0.014	2
Zone (2)	Benghazi	12:07	13:48	450	1047	2	19	37	5	18	19	68	0.025	5
Zone (3)	Al-Kufra	12:09	13:54	517	1207	-1	22	47	4	11	2	27	0.001	2
Zone (4)	Ghat	12:09	13.42	503	1200	1	23	46	4	14	4	26	0.003	2
	Murzuq	12:09	13:42	533	1224	1	23	46	5	13	2	27	0.001	4
	Sebha	12:09	13:48	510	1161	-1	23	46	4	15	4	31	0.003	3
Zone (5)	Al-Jufra	12:09	14:00	485	1180	1	21	46	4	16	3	41	0.007	3
	Sirte	12:10	14:06	453	1203	1	21	45	4	17	5	56	0.013	5
Zone (6)	Tripoli	12:10	14:18	437	1030	1	21	39	4	17	16	62	0.03	6
Zone (7)	Ghadamis	12:10	14:06	475	1151	-3	22	48	4	16	4	33	0.007	2
Zone (8)	Gharyan	12:10	14:12	480	1195	-4	19	45	4	18	6	45	0.02	3