A Techno-Economic Viability Analysis of the Two-Axis Tracking Grid-Connected Photovoltaic Power System for 25 Selected Coastal Mediterranean Cities

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Abstract—**Generating energy from renewable sources, particularly solar energy, offers significant benefits and achieves a more clean and sustainable development. In the present paper, the potential of developing a 4.2kW grid-connected rooftop two-axis tracking PV system in 25 selected coastal Mediterranean cities located in different Arabic countries is evaluated using RETScreen software. The proposed system is serving the basic household energy needs according to the load profile from monthly electrical bills. It is found that the proposed system produces about 8824kW annually, which helps to reduce CO_2 emissions. Also, the average energy production cost is assumed to range from 0.0337 to 00.0475$/kWh. It is concluded that the proposed system can provide an effective solution for energy poverty in developing regions with a very positive socio-economic and environmental impact. The small-scale grid-connected PV system will provide the domestic energy needs at a lower energy production cost than the electricity price grid-connected consumers pay. This study demonstrated that generating electricity from solar energy will help reduce the electricity tariff rates and the dependence on fossil fuels.**

Keywords-coastal Mediterranean cities; two-axis sun tracking system; solar energy potential; grid-connected; small scale PV system; RETScreen

I. INTRODUCTION

The energy sector is the most prominent of the economic crisis and the environmental disaster in Arabic countries such as Lebanon, Syria, Palestine, and Libya [1]. This sector is the biggest waste producer and the primary cause of budget deficits and debt ballooning, in addition to being the primary cause of air pollution and related deaths. Moreover, the electricity crisis has been increased in many Arabic countries due to the population growth, the rising living standards, and the growing industry sectors, which have led to an increase of the energy demand, and the increased electricity cost associated with fossil fuel-based electrical energy production [2]. Generally, most Arabic countries do not suffer from poverty in electrical energy sources, such as oil, gas, sunlight, and wind. For instance, Libya is a rich country in natural resources, however, it has faced power outages for several years due to the poor maintenance and civil war. The electricity crisis is not new in most developing countries and the electricity sector has suffered from decades of mismanagement, weak policies, and the absence of proper planning. This problem has been increased due to the dilapidation of old power stations, accompanied by sabotage operations. As a result, the hours of power cuts increased, ranging from 8 to 20 hours per day. For this reason, citizens are dependent on domestic power generators or small home generators, both of them adding financial burdens to the residents.

Nowadays, all countries are looking to utilize renewable energy resources instead of fossil fuels to mitigate climate change [3]. Additionally, the utilization of renewable energies, such as solar, as power sources, can be an alternative solution for solving the electricity crisis in most countries and reducing the consumption of fossil fuels [4, 5]. Globally, solar energy is one of the most popular alternative energy resources for electricity production. Photovoltaic (PV) panels are used to convert sunlight into electricity. In the literature, utilizing the PV systems helps to meet the basic domestic needs globally, especially in the developing countries [6]. PV systems can be categorized as stand-alone systems or grid-tied systems for domestic and commercial settings. The grid-tied PV systems

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are generally installed with no mandatory requirement for storage in the regions/countries with stable grids [7]. The benefits of these systems are that they are simple to design, easily manageable, require less maintenance, and are cost-effective. The disadvantage of a grid-tilt system is that its energy production is lower than the power produced by tracking PV systems. To maximize the amount of output power of the PV system, it must be adjusted to the changing position of the sun throughout the day [6]. Solar tracking systems are utilized to maximize energy production by the PV systems [8]. Solar tracking systems are classified based on movement capability (single-axis and two-axis) and control system (astronomically controlled systems and sensor-controlled systems) [9]. According to [10-12] the tracking systems (single-axis and two-axis) increased the energy production from 20 to 40%. The performance of grid-connected PV systems with various sun-tracking systems has been investigated by several scientific studies [13-15]. For instance, authors in [13] investigated the feasibility of a 5kW grid-connected PV system under different tracking systems and PV technologies in Nahr El-Bared, Lebanon. The results demonstrated that the two-axis tracking solar system was an economical option for electricity production compared to other systems. Authors in [14] evaluated the performance of the grid-connected solar system under different tracking systems in Gulf Cooperation Council countries. The results showed that the vertical-axis and two-axis tracker system could produce 20% and 34% more power than the fixed-tilt systems.

The benefit of grid-connected systems is that the excess electricity produced by these systems can be given back to the grid, which can help to reduce the electricity bills and solve the electricity crisis. The main scope of the current study is to present a techno-economic feasibility evaluation for 4.2kW grid-connected PV systems on the rooftops of household/residential buildings in coastal Mediterranean cities in some Arabic countries. The performance of the two-axis – tracking system for a grid-connected PV system has been analyzed using the RETScreen software to show the benefits of solar energy utilization as a power source for solving the electricity crisis in developing countries.

II. MATERIALS AND METHODS

The solar energy potential in 25 coastal locations under Mediterranean climate conditions is discussed based on a National Aeronautics and Space Administration (NASA) database, which includes Solar Radiation (SR) and air temperature data. Besides, the performance of the two-axis tracking system for grid-connected rooftop PV systems as a solution for the electricity crisis and reducing the electricity bills is investigated with the help of the RETScreen software.

A. Location Details and Collected Data

In this work, 25 coastal Mediterranean cities located in Libya, Lebanon, Syria, Palestine, Tunisia, and Algeria have been taken into consideration. The geographical coordinates of the selected cities are listed in Table I. In the literature, the solar potential of different regions is usually evaluated using the NASA database. For example, authors in [16] assessed the potential of solar energy in various locations in Nigeria using the NASA database. Authors in [17] found that the NASA database showed good agreement with the measurement data of global solar irradiation. Therefore, the solar potential of 25 coastal locations is assessed using the monthly NASA database.

TABLE I. COORDINATES OF THE SELECTED CITIES

Country	City	Latitude [°]	Longitude [°]
Libya	Az Zawiyah	32.76	12.74
	Tripoli	32.89	13.19
	Al khums	32.65	14.27
	Misratah	32.33	15.10
	Surt	31.19	16.57
	Benghazi	32.12	20.09
	Turbruq	32.07	23.94
Lebanon	Tripoli	34.43	35.84
	Beirut	33.89	35.50
Syria	Tartus	34.90	35.89
	Al Ladhiqiyah	35.61	36.00
Palestine	Gaza Strip	31.35	34.31
Egypt	Port Said	31.27	32.30
	Alexandria	31.20	29.92
	Marsa Matrch	31.36	27.22
Tunisia	Djerba Modoun	33.81	10.85
	Gabes	33.89	10.10
	Sfax	34.74	10.76
	Sousse	35.82	10.63
	Tunis	36.81	10.18
Algeria	Annaba	36.91	7.74
	Skikda	36.87	6.91
	Bejaia	36.75	5.06
	Algiers	36.70	3.06
	Oran	35.70	-0.63

B. Two-Axis Tracking PV Arrays

In general, solar tracking systems are utilized to maximize energy production by the PV system due to the maximization of the incident beam radiation [18]. The rotation of these systems can be about a single axis or about two axes. Maximum energy can be achieved using a two-axis solar system due to its total freedom of movement. In two-axis PV systems, the solar panels are mounted on the structure, which can move the modules in two axes [19] as shown in Figure 1. For a two-axis PV system, two motors are required for the rotation of the axes [19]. Thus, the panel's orientation with the two-axis tracker system is dependent on the solar position. Generally, this system is required a control module to direct it. The solar tracker PV systems utilize a SR sensor to control the system orientation [20]. Moreover, the performance of the PV system depends on the parameters of the system components and weather. Additionally, existing power producers are trying to increase the output power of the PV system by improving Operation and Maintenance (O&M) activities [20]. The O&M is considered one of the important aspects of a PV solar system. Improving the O&M can help reduce the energy production cost and improve the impact returns on investment. Furthermore, there are several issues that the PV system faces during its lifecycle, such as natural degradation, component failures, weather conditions, etc. [21]. Therefore, a holistic approach can address these issues under the O&M aspect, which is divided into three categories (preventative maintenance, corrective maintenance, and condition-based maintenance). In fact, the tracking PV systems increase the O&M) due to the requirement of periodic checking to ensure the optimal performance of the system.

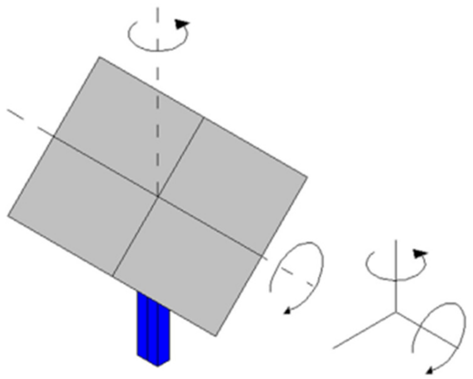

Fig. 1. Characteristics of two-axis tracker movements.

C. Design of the PV Power System

To build the 4.2kW PV system, a mono-Si-CS6X-300M PV module was selected. It is made of mono-crystalline-silicon cells with a maximum power of 300Wp. A total number of 14 modules are required with an area of about 28m^2. A FRONIUS SYMO 4.5-3-M LIGHT 4.5 KW SOLAR INVERTER with a capacity of 4.5kW and 98.6% efficiency was chosen in this study. The specifications of the selected PV panel and inverter are available at [22, 23].

D. Simulation Tool

There are many simulation tools such as HOMER energy, RETScreen, etc. that may be utilized to evaluate the energy production and Levelized Cost Of Energy (LCOE). The comparison between these simulation tools is available at [24]. In this study, HOMER is utilized to evaluate the economical feasibility of the proposed systems. RETScreen is developed by Natural Resources Canada (NRC). It utilizes the long-term monthly average meteorological data from the NASA database as a source of meteorological information for a specific location [3, 16]. In the present study, the most important economic indicators of financial analysis including Net Present Cost (NPC), Cost Of Energy (COE), Simple Payback (SP), and Equity Payback (EP) are estimated with the RETScreen software. Also, the Greenhouse Gas (GHG) emission reduction, energy production, and Capacity Factor (CF) for the proposed system are determined.

III. RESULTS AND DISCUSSION

A. Characteristics of Solar Energy in the Selected Locations

Generally, regarding PV panels and inverters, the characteristics of the installation, and the meteorological conditions (relative humidity, air temperature, solar radiation, etc.) are the major factors that influence the performance of the PV system. The meteorological conditions affecting the generating power by the PV system are mainly solar irradiance [25-27]. Therefore, global SR data were analyzed to estimate the potential of solar energy in the selected cities. Table II summarizes the average horizontal monthly daily SR for the selected locations. It is found that the average horizontal monthly daily SR varied from 2.01kWh/m^2/day to 8.50kWh/m^2/day. The maximum and minimum values of SR are recorded in Port Said (in June) and Skikda (in December) respectively. The highest and lowest annual SR are 5.87kWh/m^2/day and 4.51kWh/m^2/day for Alexandria and Skikda, respectively as shown in Figure 2. The highest value of Average Temperature (AT) was recorded in Port Said (21.23°C) and the next highest in Alexandria (20.79°C). Based on the value of SR at the selected locations, it is found that the solar resource of the selected locations is categorized as excellent (class 5) according to [16]. Therefore, these locations are suitable for installing a PV system in the future due to their high value of SR.

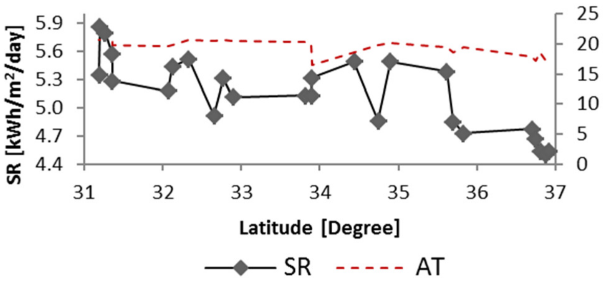

Fig. 2. Average SR and air temperature as a function of location.

B. Electricity Generation and Capacity Factor

SR and the number of clear sunny days are essential factors that influence the performance of the PV system including output power and CF [28, 29]. The monthly Electricity Generation (EG) from the proposed system is shown in Table III. It is found that the monthly EG is within the range of 390kWh-1125kWh. The maximum average EG occurs at Alexandria during July with a value of 1125kWh, while the minimum value of 390kWh was recorded at January in Beirut. Furthermore, Figure 3 shows the annual EG and CF from the proposed systems. It is found that the value of EG is within the range of 7628-10333kWh for PV systems with two-axis tracking systems. The maximum value of EG is recorded in Alexandria while the minimum value is obtained in Algiers. Besides, it is found that the CF values vary from 20.73% to 28.08%. These observations can be supported by other scientific researches who analyzed the feasibility of a grid-connected PV system. For instance, authors in [30] found that the CF of their proposed PV system in Oman was within the range of 16-23%. Also, authors in [31] found that the CF of grid-connected PV systems with various technologies varied from 15.37% to 15.75%. Authors in [32] found that the value of CF of grid-connected PV systems with different sun-tracking modes was within the range of 17.54 to 27.42%. Moreover, the use of the two-axis instead of the fixed-tilt option significantly increases the generated electricity [32, 33]. Therefore, it can be concluded that the value gotten from the present study for each location is compatible with the generally acceptable values. Consequently, it is technically sustainable to build a grid-connected rooftop PV system in these locations. The results indicate that the variation of the EG and CF is a function of location.

TABLE II. AVERAGE DAILY SOLAR RADIATION [kWh/m^2/day]

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Az Zawiyah	2.69	3.86	5.14	6.41	7.15	7.90	8.10	7.26	5.74	4.18	2.99	2.38
Tripoli-Libya	2.67	3.66	4.79	6.15	6.98	7.67	7.79	7.05	5.52	3.96	2.75	2.35
Al khums	2.79	3.67	4.75	5.83	6.52	7.14	7.34	6.50	5.17	3.97	2.89	2.45
Misratah	3.07	4.09	5.36	6.57	7.24	7.90	8.07	7.37	5.96	4.60	3.31	2.77
Surt	3.41	4.25	5.23	6.18	6.54	7.42	7.26	6.86	5.77	4.67	3.49	3.06
Benghazi	2.87	3.87	5.18	6.56	7.26	7.92	7.94	7.26	5.96	4.55	3.26	2.63
Turbruq	2.69	3.65	4.90	6.18	6.89	7.52	7.63	6.96	5.86	4.38	3.05	2.47
Tripoli-Lebanon	2.76	3.68	5.03	6.37	7.62	8.31	8.08	7.37	6.32	4.65	3.24	2.49
Beirut	2.67	3.51	4.80	6.18	7.45	8.08	7.83	7.16	6.07	4.53	3.15	2.41
Tartus	2.76	3.68	5.03	6.37	7.62	8.31	8.08	7.37	6.32	4.65	3.24	2.49
Al Ladhiqiyah	2.65	3.63	4.96	6.28	7.45	8.22	7.99	7.29	6.20	4.56	3.06	2.38
Gaza Strip	3.08	3.90	5.29	6.58	7.50	8.07	7.90	7.23	6.22	4.67	3.50	2.87
Port Said	3.24	4.08	5.46	6.79	7.77	8.44	8.10	7.54	6.53	5.02	3.68	2.96
Alexandria	3.21	4.14	5.56	6.92	7.79	8.50	8.35	7.72	6.56	5.04	3.64	2.97
Marsa Matrch	2.74	3.66	4.98	6.24	7.05	7.89	7.82	7.16	5.94	4.35	3.12	2.50
Djerba Modoun	2.62	3.64	4.90	6.27	7.02	7.67	7.82	7.07	5.51	3.87	2.82	2.32
Gabes	2.62	3.64	4.90	6.27	7.02	7.67	7.82	7.07	5.51	3.87	2.82	2.32
Sfax	2.58	3.53	4.57	5.87	6.85	7.38	7.44	6.63	5.06	3.47	2.68	2.36
Sousse	2.37	3.29	4.33	5.67	6.72	7.38	7.60	6.53	4.97	3.34	2.48	2.16
Tunis	2.30	3.20	4.22	5.22	6.34	6.94	7.31	6.29	4.69	3.37	2.47	2.09
Annaba	2.28	3.15	4.25	5.21	6.25	6.98	7.14	6.08	5.00	3.57	2.45	2.02
Skikda	2.27	3.15	4.26	5.22	6.20	6.91	7.08	6.12	4.94	3.53	2.42	2.01
Bejaia	2.38	3.31	4.44	5.46	6.41	7.12	7.23	6.38	5.08	3.66	2.51	2.06
Algiers	2.48	3.38	4.59	5.69	6.49	7.20	7.13	6.44	5.28	3.82	2.63	2.15
Oran	2.72	3.64	4.74	5.94	6.55	7.08	6.92	6.26	5.25	3.94	2.80	2.40

TABLE III. AVERAGE MONTHLY EG [kWh]

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Az Zawiyah	558	593	754	771	847	860	910	868	732	625	541	430
Tripoli-Libya	561	595	755	772	847	860	910	868	733	627	543	432
Al khums	520	522	701	745	855	888	955	872	677	616	483	465
Misratah	592	602	821	865	979	1011	1078	1028	811	753	581	553
Surt	656	606	735	703	804	855	886	834	739	625	535	592
Benghazi	536	558	785	859	975	1007	1056	1008	811	742	568	510
Turbruq	483	511	725	799	918	950	1006	954	794	702	513	460
Tripoli-Lebanon	554	571	786	849	1055	1083	1085	1043	905	810	610	520
Beirut	390	438	630	672	845	901	887	849	720	660	508	419
Tartus	474	480	655	731	930	979	978	930	781	678	507	444
Al Ladhiqiyah	546	574	779	835	1021	1061	1066	1029	890	806	585	511
Gaza Strip	581	557	751	805	919	989	988	967	827	792	602	582
Port Said	613	583	827	891	1065	1094	1079	1053	903	831	647	580
Alexandria	606	597	849	913	1070	1107	1125	1089	911	840	641	585
Marsa Matrch	532	540	794	854	979	1007	1031	993	837	754	572	519
Djerba Modoun	499	550	744	822	941	969	1030	973	743	609	487	453
Gabes	581	564	745	763	905	897	945	873	724	686	586	572
Sfax	508	542	690	766	917	926	970	902	675	535	471	488
Sousse	466	505	651	739	899	928	999	888	668	518	436	446
Tunis	498	479	680	754	869	921	971	911	739	695	572	518
Annaba	463	493	649	675	830	874	933	823	688	591	449	426
Skikda	457	490	649	675	821	864	924	829	676	579	438	420
Bejaia	491	525	688	715	857	897	949	876	701	611	463	436
Algiers	434	456	616	623	789	757	914	881	706	526	513	414
Oran	598	594	772	830	936	939	991	946	788	679	551	525

C. Performance of the Proposed System

The environmental impact and economic performance of the proposed system were evaluated. In this study, the financial parameters (Table IV) are assumed based on other previous scientific studies in different countries. In the present study, the system cost is around $5000, with the estimation being based on recent market data. The estimation is consistent with cost prices available in the literature.

TABLE IV. FINANCIAL PARAMETERS

Factor	Unit	Value
Inflation rate	%	2.5
Discount rate	%	3
Reinvestment rate	%	9
Project life	year	25
Debt ratio	%	50
Debt interest rate	%	7
Debt term	year	20
Electricity export escalation rate	%	5

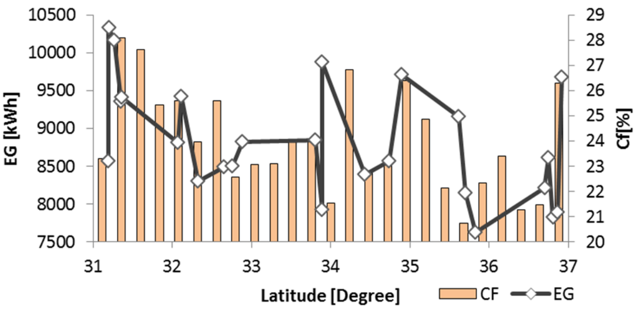

Fig. 3. Annual EG and CF as a function of location.

Table V lists the results of the economic performances of the proposed system. The obtained results showed that the value of NPV is positive, which makes the project to be financially and economically feasible. Moreover, it is observed that the developed PV system in Algiers has the longest value of EP of 4.0 years, while Alexandria and Port Said have the lowest EP value (2.8 years). Besides, the maximum and minimum values of SP are recorded in Algiers and Alexandria. These results indicate that the PV projects in all locations make financial sense. Additionally, the lowest value of EPC is found in Alexandria with a value of 0.0334$/kWh followed by Tripoli-Lebanon with a value of 0.0336$/kWh. It is found that Tripoli-Libya and Algiers have the highest value of LCOE compared to other selected regions with a value of 0.0475 $/kWh and 0.0453 $/kWh respectively.

In general, the electricity price depends on the amount of energy consumption. For instance, the energy cost calculation in Lebanon starts from 0.0255$/kWh for 0-100kWh energy consumption, 0.04$/kWh for 100-300kWh, 0.0584$/kWh for 300-400kWh, 0.0875$/kWh for 400-500kWh, and 0.146$/kWh for energy consumption over 500kWh. In Syria, it starts from 0.005$/kWh for 1-100kWh energy consumption, 0.007$/kWh for 101-200kWh, 0.01$/kWh for 200-400kWh, 0.015$/kWh for 401-600kWh, 0.015$/kWh for 601-800kWh, 0.061$/kWh for 801-1000kWh, 0.071$/kWh for 1001-2000kWh, and 0.081$/kWh for energy consumption over 2000kWh. In Palestine, it ranges from 0.15$/kWh to 0.17$/kWh for energy consumption over 200kWh. The households are charged a flat rate at 0.045, 0.04, and 0.077$/kWh respectively in Egypt, Algeria, and Tunisia. Hence, the energy production cost of the proposed systems is competitive with the electricity company tariff in the selected countries except for Libya.

TABLE V. ECONOMIC PERFORMANCE OF THE PROPOSED PV SYSTEM FOR ALL SELECTED LOCATIONS

Location	NPV [$]	SP [Year]	EP [Year]	ALCS [$/year]	COE[$/kWh]	GA-GHG [tCO_2]
Az Zawiyah	21505.8	5.9	3.5	1235.0	0.0407	5.40
Tripoli-Libya	14927.7	5.9	3.5	1003.4	0.0475	5.40
Al khums	20883.3	6.0	3.6	1199.3	0.0416	5.27
Misratah	25344.5	5.2	3.0	1455.5	0.0357	6.15
Surt	21762.4	5.8	3.5	1249.8	0.0403	5.45
Benghazi	24505.5	5.3	3.1	1407.3	0.0367	5.98
Turbruq	22554.1	5.7	3.3	1295.2	0.0392	5.60
Tripoli-Libya	26215.9	5.1	3.1	1505.5	0.0336	6.98
Beirut	19655.3	6.3	3.8	1128.8	0.0436	5.60
Tartus	21747.5	5.8	3.5	1248.9	0.0403	5.15
Al Ladhiqiyah	25442.0	5.2	3.0	1461.1	0.0356	5.84
Gaza Strip	24324.8	5.3	3.1	1396.9	0.0369	4.28
Port Said	26941.3	4.9	2.8	1547.2	0.034	4.65
Alexandria	27477.5	4.8	2.8	1578.0	0.0334	4.73
Marsa Matrch	24493.0	5.3	3.1	1406.6	0.0367	4.30
Djerba Modoun	22569.0	5.7	3.3	1296.1	0.0391	4.02
Gabes	22640.7	5.7	3.3	1300.2	0.039	4.03
Sfax	21175.8	6.0	3.6	1216.1	0.0412	3.82
Sousse	20382.1	6.1	3.7	1170.5	0.0424	3.71
Tunis	21883.5	5.8	3.4	1256.7	0.0401	3.92
Annaba	19575.6	6.3	3.8	1124.2	0.0437	4.39
Skikda	19340.5	6.4	3.9	1110.7	0.0441	4.35
Bejaia	20601.0	6.1	3.6	1183.1	0.042	4.56
Algiers	18710.7	6.6	4.0	1074.5	0.0453	4.24
Oran	23642.9	5.5	3.2	1357.8	0.0377	5.09

The results demonstrated that the proposed system can help in solving the electricity crisis while simultaneously reducing GHG emissions. Consequently, it can be concluded that the developed system provides a very good insight into the economic viability of the project for all regions. Additionally, the obtained results demonstrated that the development of the proposed 4.2kW PV power system is economically acceptable due to the obtained favorable economic results.

IV. LIMITATIONS AND CONCLUSIONS

Installing PV systems has become increasingly attractive for residential consumers due to increasing electricity tariff rates while it reduces a country's dependence on fossil fuels. The objective of the current study was to investigate the feasibility of a two-axis tracking PV system in coastal Mediterranean cities located in different countries using the RETScreen software. Before starting the main conclusions in the present study, it is essential to acknowledge the limitations of this work. First, the assumed financial parameters were based on historical values in the literature. Second, the influence of various parameters such as dust, irradiation intensity, air temperature, and relative humidity was neglected due to the limitations of the software. Third, the cost of the proposed projects was estimated based on the existing cost in the literature.

The findings from the present study showed the annual value of SR for the selected regions is within the range of 1645.85 to 2141.33kWh/m^2. Based on these data, the analysis indicates that the selected regions selected cities have the potential for the distribution of PV power systems in household/residential applications. Moreover, the average annual energy output showed that the 4.2kW grid-connected PV system could produce 8824kWh, indicating that it can cover the required electricity needs for one house located in each selected city. These results are supported by the findings in [13].

Based on the financial assumptions used in this study, the average energy production cost ranges from 0.0334 to 0.0475$/kWh for the developed system. Thus, the energy production cost of the proposed system is competitive with the electricity company tariff in the selected countries, except for Libya. The results of this paper demonstrate that a small-scale grid-connected rooftop PV system has the potential to solve the electricity crisis, reduce the consumption of fossil fuel, and reduce the environmental pollution by minimizing the emissions of CO_2. The conducted analysis showed that the small-scale grid-connected rooftop PV systems are found to be technically, economically, and environmentally feasible solutions for generating electricity and reducing the dependency on fossil fuels.

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REFERENCES

[1] A. J. McMichael, "The urban environment and health in a world of increasing globalization: issues for developing countries," *Bulletin of the World Health Organization*, vol. 78, no. 9, pp. 1117–1117, Sep. 2000.

[2] A. Shahsavari and M. Akbari, "Potential of solar energy in developing countries for reducing energy-related emissions," *Renewable and Sustainable Energy Reviews*, vol. 90, pp. 275–291, Jul. 2018, https://doi.org/10.1016/j.rser.2018.03.065.

[3] Y. Kassem, H. Camur, and O. A. M. Abughinda, "Solar Energy Potential and Feasibility Study of a 10MW Grid-connected Solar Plant in Libya," *Engineering, Technology & Applied Science Research*, vol. 10, no. 4, pp. 5358–5366, Aug. 2020, https://doi.org/10.48084/etasr.3607.

[4] F. Chermat, M. Khemliche, A. E. Badoud, and S. Latreche, "Techno-Economic Feasibility Study of Investigation of Renewable Energy System for Rural Electrification in South Algeria," *Engineering, Technology & Applied Science Research*, vol. 8, no. 5, pp. 3421–3426, Oct. 2018, https://doi.org/10.48084/etasr.2253.

[5] F. Chien, H. W. Kamran, G. Albashar, and W. Iqbal, "Dynamic planning, conversion, and management strategy of different renewable energy sources: A Sustainable Solution for Severe Energy Crises in Emerging Economies," *International Journal of Hydrogen Energy*, vol. 46, no. 11, pp. 7745–7758, Feb. 2021, https://doi.org/10.1016/j.ijhydene.2020.12.004.

[6] A. Abdulmula, K. Sopian, C. H. Lim, and A. Fazlizan, "Performance evaluation of standalone double axis solar tracking system with maximum light detection MLD for telecommunication towers in Malaysia," *International Journal of Power Electronics and Drive Systems*, vol. 10, no. 1, pp. 444–453, Mar. 2019, https://doi.org/10.11591/ijpeds.v10n1.pp444-453.

[7] K. N. Nwaigwe, P. Mutabilwa, and E. Dintwa, "An overview of solar power (PV systems) integration into electricity grids," *Materials Science for Energy Technologies*, vol. 2, no. 3, pp. 629–633, Dec. 2019, https://doi.org/10.1016/j.mset.2019.07.002.

[8] H. Mousazadeh, A. Keyhani, A. Javadi, H. Mobli, K. Abrinia, and A. Sharifi, "A review of principle and sun-tracking methods for maximizing solar systems output," *Renewable and Sustainable Energy Reviews*, vol. 13, no. 8, pp. 1800–1818, Oct. 2009, https://doi.org/10.1016/j.rser.2009.01.022.

[9] A. Z. Hafez, A. M. Yousef, and N. M. Harag, "Solar tracking systems: Technologies and trackers drive types – A review," *Renewable and Sustainable Energy Reviews*, vol. 91, pp. 754–782, Aug. 2018, https://doi.org/10.1016/j.rser.2018.03.094.

[10] G. C. Lazaroiu, M. Longo, M. Roscia, and M. Pagano, "Comparative analysis of fixed and sun tracking low power PV systems considering energy consumption," *Energy Conversion and Management*, vol. 92, pp. 143–148, Mar. 2015, https://doi.org/10.1016/j.enconman.2014.12.046.

[11] M. S. Ismail, M. Moghavvemi, and T. M. I. Mahlia, "Analysis and evaluation of various aspects of solar radiation in the Palestinian territories," *Energy Conversion and Management*, vol. 73, pp. 57–68, Sep. 2013, https://doi.org/10.1016/j.enconman.2013.04.026.

[12] S. A. S. Eldin, M. S. Abd-Elhady, and H. A. Kandil, "Feasibility of solar tracking systems for PV panels in hot and cold regions," *Renewable Energy*, vol. 85, pp. 228–233, Jan. 2016, https://doi.org/10.1016/j.renene.2015.06.051.

[13] H. Camur, Y. Kassem, and E. Alessi, "A Techno-Economic Comparative Study of a Grid-Connected Residential Rooftop PV Panel: The Case Study of Nahr El-Bared, Lebanon," *Engineering, Technology & Applied Science Research*, vol. 11, no. 2, pp. 6956–6964, Apr. 2021, https://doi.org/10.48084/etasr.4078.

[14] H. Z. Al Garni, A. Awasthi, and M. A. M. Ramli, "Optimal design and analysis of grid-connected photovoltaic under different tracking systems using HOMER," *Energy Conversion and Management*, vol. 155, pp. 42–57, Jan. 2018, https://doi.org/10.1016/j.enconman.2017.10.090.

[15] A. A. Bayod-Rujula, A. M. Lorente-Lafuente, and F. Cirez-Oto, "Environmental assessment of grid connected photovoltaic plants with 2-axis tracking versus fixed modules systems," *Energy*, vol. 36, no. 5, pp. 3148–3158, May 2011, https://doi.org/10.1016/j.energy.2011.03.004.

[16] 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, Art. no. 100542, https://doi.org/10.1016/j.seta.2019.100542.

[17] K. Belkilani, A. Ben Othman, and M. Besbes, "Assessment of global solar radiation to examine the best locations to install a PV system in Tunisia," *Applied Physics A*, vol. 124, no. 2, Jan. 2018, Art. no. 122, https://doi.org/10.1007/s00339-018-1551-3.

[18] L. M. Fernandez-Ahumada, J. Ramirez-Faz, R. Lopez-Luque, M. Varo-Martinez, I. M. Moreno-Garcia, and F. Casares de la Torre, "Influence of the design variables of photovoltaic plants with two-axis solar tracking on the optimization of the tracking and backtracking trajectory," *Solar Energy*, vol. 208, pp. 89–100, Sep. 2020, https://doi.org/10.1016/j.solener.2020.07.063.

[19] J. Reca-Cardena and R. Lopez-Luque, "Design Principles of Photovoltaic Irrigation Systems," in *Advances in Renewable Energies and Power Technologies*, I. Yahyaoui, Ed. Amsterdam, Netherlands: Elsevier, 2018, pp. 295–333.

[20] T.-C. Cheng, W.-C. Hung, and T.-H. Fang, "Two-Axis Solar Heat Collection Tracker System for Solar Thermal Applications," *International Journal of Photoenergy*, vol. 2013, Nov. 2013, Art. no. e803457, https://doi.org/10.1155/2013/803457.

[21] H. Iftikhar, E. Sarquis, and P. J. C. Branco, "Why Can Simple Operation and Maintenance (O&M) Practices in Large-Scale Grid-Connected PV

Power Plants Play a Key Role in Improving Its Energy Output?," *Energies*, vol. 14, no. 13, Jan. 2021, Art. no. 3798, https://doi.org/10.3390/en14133798.

[22] Y. Kassem, H. Camur, and R. A. F. Aateg, "Exploring Solar and Wind Energy as a Power Generation Source for Solving the Electricity Crisis in Libya," *Energies*, vol. 13, no. 14, Jan. 2020, Art. no. 3708, https://doi.org/10.3390/en13143708.

[23] "Fronius Symo 4.5-3-M Light 4.5 kW Solar Inverter," *0Bills DIY Solar, Panels, Complete Systems, 12V, 24V and 48V Batteries For Energy Independence.* https://www.zerohomebills.com/product/fronius-symo-4-5-3-m-light-4-5-kw-solar-inverter/ (accessed Aug. 06, 2021).

[24] K. Ram, P. K. Swain, R. Vallabhaneni, and A. Kumar, "Critical assessment on application of software for designing hybrid energy systems," *Materials Today: Proceedings*, Mar. 2021, https://doi.org/10.1016/j.matpr.2021.02.452.

[25] B. Brahma and R. Wadhvani, "Solar Irradiance Forecasting Based on Deep Learning Methodologies and Multi-Site Data," *Symmetry*, vol. 12, no. 11, Nov. 2020, Art. no. 1830, https://doi.org/10.3390/sym12111830.

[26] B. Amrouche, L. Sicot, A. Guessoum, and M. Belhamel, "Experimental analysis of the maximum power point's properties for four photovoltaic modules from different technologies: Monocrystalline and polycrystalline silicon, CIS and CdTe," *Solar Energy Materials and Solar Cells*, vol. 118, pp. 124–134, Nov. 2013, https://doi.org/10.1016/j.solmat.2013.08.010.

[27] W. D. Lubitz, "Effect of manual tilt adjustments on incident irradiance on fixed and tracking solar panels," *Applied Energy*, vol. 88, no. 5, pp. 1710–1719, May 2011, https://doi.org/10.1016/j.apenergy.2010.11.008.

[28] 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 *International Conference and Utility Exhibition on Green Energy for Sustainable Development*, Pattaya, Thailand, Mar. 2014, pp. 1–7.

[29] A. Khandelwal and V. Shrivastava, "Viability of grid-connected solar PV system for a village of rajasthan," in *International Conference on Information, Communication, Instrumentation and Control*, Indore, India, Aug. 2017, pp. 1–6, https://doi.org/10.1109/ICOMICON.2017.8279175.

[30] H. A. Kazem and M. T. Chaichan, "Status and future prospects of renewable energy in Iraq," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 8, pp. 6007–6012, Oct. 2012, https://doi.org/10.1016/j.rser.2012.03.058.

[31] M. Obeng, S. Gyamfi, N. S. Derkyi, A. T. Kabo-bah, and F. Peprah, "Technical and economic feasibility of a 50 MW grid-connected solar PV at UENR Nsoatre Campus," *Journal of Cleaner Production*, vol. 247, Feb. 2020, Art. no. 119159, https://doi.org/10.1016/j.jclepro.2019.119159.

[32] 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, https://doi.org/10.1016/j.energy.2018.05.065.

[33] M. A. Vaziri Rad, A. Toopshekan, P. Rahdan, A. Kasaeian, and O. Mahian, "A comprehensive study of techno-economic and environmental features of different solar tracking systems for residential photovoltaic installations," *Renewable and Sustainable Energy Reviews*, vol. 129, Sep. 2020, Art. no. 109923, https://doi.org/10.1016/j.rser.2020.109923.