Economic Viability of a 6.5kW Off-grid Solar PV with Various Sun-Tracking Systems in Northern Cyprus: A Case Study

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ABSTRACT

In this paper, an in-depth analysis of small-scale PV in Northern Cyprus is conducted for the first time at 37 locations in Northern Cyprus. No previous study has investigated the viability of off-grid PV systems with various sun-tracking systems in Northern Cyprus. In order to achieve this, NASA POWER data were used for the evaluation of the solar resource in the selected locations. The results showed that the selected locations are suitable for the installation of various scales of PV systems due to the high global horizontal solar radiation. The mathematical modeling method was utilized for the design and analysis of PV systems with various sun-tracking systems and for the assessment of their economic viability and feasibility. Energy production, capacity factor, payback period, and cost of energy production were calculated. The results indicate that the proposed systems are very promising for all the selected locations. The PV projects with a 2-axis sun-tracking system produce a large amount of energy and have a low electricity cost. It was found that the electrical energy cost of the developed systems was within the range of 0.4851-0.6641TL/kWh. The payback periods varied from 4.57 years to 8.49 years, depending on the type of solar PV panel and sun-tracking system. This study provides some useful recommendations for decision-makers regarding the development and deployment of PV energy technology in the country in order to achieve sustainable development goals.

Keywords-Northern Cyprus; solar energy potential; off-grid; small-scale PV system; sun-tracking system; mathematical modeling method

I. INTRODUCTION

Population growth and the rising of people's living standards have led to the growing global demand for energy, primarily electrical, from fossil fuels. It is known that environmental pollution impacts human health through the emissions of harmful gases caused by conventional energy generation from fossil fuels. Thus, finding alternative energy sources to reduce fossil fuel consumption and environmental pollution is essential [1]. Solar energy has been widely utilized globally to generate electricity and reduce harmful gas emissions. It is clean energy from an inexhaustible and environmentally friendly energy source. Generally, solar photovoltaic (PV) panels produce electrical power directly from the sunlight. Authors in [2] found that solar power will reduce gas emissions by about 69-100 million tons of CO_2, 68-99 thousand tons of NO_X, and 126-184 thousand tons of SO_2 by 2030. Authors in [3] reported that solar energy has a significant potential to meet the global electricity requirements in the future. Authors in [4] found that solar energy technologies have a huge potential to mitigate climate change by reducing energy-related emissions. The solar power system is most commonly used today due to improvements in the harvesting of solar energy [5], greater awareness about this energy [6], and low electricity cost compared to feed-in tariffs [7]. Generally, PV power systems are classified into two types (on-grid and off-grid PV systems). They, especially small-scale PV systems, are an effective solution to generate electricity for urban and rural regions [8, 9]. Globally, the share of PV generation capacity could be increased from 2% in 2017 with nearly 400GW installed to 10% in 2040 due to falling PV costs [10].

In Northern Cyprus, fossil fuels are the main source of electrical energy. The electrical energy is produced by steam power plants (Teknecik Steam Unit No. 1 and Teknecik Steam Unit No. 2), diesel electricity generating plants (Kalecik Diesel and Teknecik Diesel), and Serhatköy PV plant [11]. According to Cyprus Turkish Electricity Authority (KIB-TEK), 44.17%, 26.53%, 11.67%, and 11.95% of electricity is generated by Kalecik Diesel, Teknecik Diesel, Teknecik Steam Unit No. 1, and Teknecik Steam Unit No. 2, respectively, whereas the rest of the energy is produced by Serhatköy PV plant (0.1%) in 2021. The total electricity production increased from 1444.01GWh in 2015 to 1551.06GWh in 2019 with an average annual increase percentage of 7.41%. Furthermore, the average annual increase is approximately 3.4% in terms of electricity consumption per capita. Besides, the total installed capacity for these plants is 482.3MW according to KIB-TEK and Northern Cyprus Renewable Energy Board (YEK-Kurulu). Recently, Northern Cyprus has experienced outages with duration of more than one to two hours [12] due to the fast growth of population and constructions. According to T-VINE [13], Northern Cyprus has suffered multiple blackouts due to outages at the power plants inability to produce sufficient electricity to cope with the excessive demands during the intense summer heat. In addition, approximately 30% of total energy consumption and 20% of electricity consumption are spent on residential and commercial buildings, respectively, according to KIB-TEK. Table I lists the costs of electricity in Northern Cyprus according to KIB-TEK. KIB-TEK utilizes the net metering system for allowing end users to generate and export energy surplus to the utility grid.

Four new solar PV plants have been constructed and utilized at various locations in Northern Cyprus [14]. Northern Cyprus's climate is moderate and suitable for investing in solar energy, as there are 300 sunny days throughout the year. This increases the efficiency of relying on solar energy as an energy source. Global Horizontal Irradiation (GHI) and Direct Normal Irradiation (DNI) values are within the range of 4.80-5.44kWh/m^2/day and 4.89-6.15kWh/m^2/day, respectively according to the solar atlas map. Numerous studies have investigated the solar energy potential in various locations in Northern Cyprus as shown in Table II. Based on the results of the previous studies, the following can be concluded: (1) solar energy is expected to contribute to electricity generation in Northern Cyprus in the future, (2) PV systems can be a good solution for reducing the fossil fuel consumption and CO_2 emissions in the island, (3) the use of solar power systems could help the island to become more independent from fossil fuels, and (4) PV systems have the ability to reduce the household electricity bills in Northern Cyprus.

TABLE I. ENERGY COSTS IN NORTHERN CYPRUS

Before March 2022	
Energy consumption based on time	
Period	Cost
0.7:00-17:00	0.98 TL/kWh
17:00-22:00	1.29 TL/kWh
22:00-07:00	0.65 TL/kWh
22:00-00:00 (Weekend)	0.98 TL/kWh
Presently	
Energy consumption based on kW	
Energy consumption	Cost
0-250 kW	0.98 TL/kWh
250-500kW	1.70 TL/kWh
501-750 kW	2 TL/kWh
751-1000kW	2.25 TL/kWh
Greater than 1000kW	3.3TL/kWh

Therefore, this paper represents a first effort to use a strategic perspective to explore how viable solar energy systems are in Northern Cyprus. The present study aims to investigate the techno-economic and environmental sustainability of rooftop PV systems and large-scale PV in various locations in Northern Cyprus. To achieve this, the solar radiation data are analyzed to classify the solar resource in the selected locations. Moreover, the techno-economic viability of an off-grid PV system with different sun-tracking systems including fixed tilt and 2-axis systems is evaluated using the mathematical modeling approach.

II. MATERIALS AND METHODS

The proposed methodology aims to assess the solar energy potential in 37 locations in Northern Cyprus to identify suitable locations for future installations of solar PV systems. The economic viability of these PV systems is evaluated. Figure 1 illustrates the methodology used in this study.

A. Study Area

This study aims to identify the best locations for installing solar PV power systems in Northern Cyprus. Figure 2 shows the selected locations. Table III provides the names and geographical coordinates of the selected locations. Due to the lack of actual weather data, satellite database helps in estimating the potential of wind and solar energy. It has led to the development of satellite-generated or interpolated synthetic meteorological data, which are available in grids with various spatiotemporal resolutions [39]. The gridded database NASA/POWER provides global coverage of complete weather data with a horizontal resolution of 1° of latitude and longitude [40] thus being a potential source for the study of the potentiality of renewable (wind and solar) energies [41, 42].

TABLE II. SUMMARY OF PREVIOUS STUDIES FOCUSING ON SOLAR ENERGY POTENTIAL IN NORTHERN CYPRUS

Reference	Year	Description/aim	Remarks and Key Findings
[15]	2011	Investigation of the feasibility of a 1M grid-connected PV plant in 3 locations (Lefkoşa, Güzelyurt, Dipkarpaz) in Northern Cyprus.	The feasibility of the developed system increased when the 2-axis PV system was utilized.
[16]	2012	Assessment of the performance of Parabolic Trough (PT) and Fresnel PV systems in Northern Cyprus.	Fresnel systems have higher absorption o solar radiation, lower CO_2 emissions, and operating cost compared to PT systems.
[17]	2014	Installation of 30MW hypothetical solar chimney power plant under Northern Cyprus conditions.	The annual electricity production of the proposed system was found to be 94.5GWh, which can provide for the annual electricity needs of over 22,128 residences without any CO_2, NO_x, and SO_x emissions.
[18, 19]	2015	Build 1.275GW PV plant in Serhatköy site.	The plant will improve the electricity sector and will be able to reduce emissions to an acceptable level.
[20]	2016	Design and techno-economic analysis of a standalone PV system to meet the electricity of a house in the rural fringe of Famagusta.	The electricity generation cost was found to be 0.43TL/kWh and the developed system is a viable technology for the electrification of a house in Cyprus.
[21]	2016	Techno-economic and environmental feasibility of 40MW PV power plant and 40MW PT power plant in Nicosia and Famagusta.	Power plants in Nicosia have higher profitability than in Famagusta and the utilizing solar power plant will reduce large amounts of CO_2 emissions.
[22]	2017	Development of a hybrid system to generate electricity for a household in Nicosia	The PV-wind hybrid system needs less capital cost, which is considered a more attractive option to set up in the selected location.
[11]	2018	Development of a 12MW grid-connected wind farms and fixed-tilt PV power plants in Lefkoşa and Girne.	The selected locations were found suitable to build a PV system for energy production and reduce the fuel consumption
[23]	2018	Proposing a 1MW grid-connected PV power plant with various sun-tracking systems in Lefke town.	The electricity cost was found within the range of 0.109-0.150 $/kWh and annual GHG emission reduction varied from 1321 to 1829 tCO_2.
[24]	2018	Investigation of the utilization of solar energy in Famagusta.	Famagusta has a huge solar energy potential, but the city is not able to generate the required amount of solar energy due to its inappropriate urban design.
[25]	2018	Finding the best location for installing a PV power plant based on the highest profitability of the project.	Among 19 locations, Güzelyurt was the best to install a PV power plant due to the net present value, payback period and internal rate of return, and levelized cost of electricity.
[26]	2018	Proposal of a 4.85 kW grid-connected PV rooftop systems in Nicosia, Morphou, and Dipkarpaz	All selected locations have a high solar energy potential.
[27]	2019	Development of a 6.4kW grid-connected PV wind system for a household in Lefkoşa, Girne, and Gazimağusa	The PV systems are a more economical option for generating electricity in the selected locations compared to wind systems due to the low electricity production cost
[28]	2019	Proposition of a 45kW rooftop-building grid-connected PV power system in Lefke town.	The electricity cost of the proposed system was found to be 0.056$/kWh, which is lower than the energy cost of traditional energy (0.15$/kWh)
[29]	2019	Using of PV as a shading device for solving the heating problems in the residential sector in Famagusta.	Utilizing the PV as a shading device can provide up to 50% of the electricity demand of the single-family building and raises the comfort level of the building by about 20%.
[30]	2019	Evaluation of the performance of a 110kW grid-connected PV system with different PV technologies based on performance ratio, CF, and energy cost.	CdTe PV system has a higher performance ratio compared to other PV technologies and the proposed system can help reduce green gas emissions and supply electricity to the Near East University.
[31]	2019	Evaluation of the performance of a 110kW grid-connected PV system in 25 locations.	The annual average performance ratio was within the range of 75-80%.
[32]	2019	Techno-economic feasibility evaluation of a solar-powered seawater desalination plant in Güzelyurt.	Solar desalination could be a profitable investment with governmental incentives and can be considered a sustainable option for solving water scarcity and reducing greenhouse gas emissions.
[33]	2019	Technical, environmental, and economic aspects for developing PV/wind hybrid system in the Middle East Technical University Northern Cyprus Campus	The proposed system will reduce the annual fuel consumption of the island by 9920 barrels which will also reduce the annual CO_2 emissions by 3622 tons.
[34]	2020	Development of a 30kW grid-connected PV system for Near East University grand library with various types of PV systems used in building PV technologies.	The performance of a freestanding mounting position system with thin film (CdTe) was found better than building-integrated PV.
[35]	2020	Techno-economic feasibility of 100MW grid-connected PV system in Lefkoşa.	The proposed system would reduce fuel consumption, electricity tariffs, and greenhouse gas emissions.
[36]	2020	Development of a 6kW PV-wind hybrid system to meet a single household electricity demands in Güzelyurt.	The proposed system provided alternative incentives to the consumers and it is economically feasible.
[37]	2021	Investigation of the techno-economic feasibility of small-scale PV systems with different sun-tracking systems for producing household electricity and desalination systems in the Güzelyurt region.	The small-scale grid-connected PV systems will reduce the electricity bill.
[14]	2021	Design of a PV system for covering the power demands in Near East University Hospital	The PV system will help solve the electricity crisis and reduce the fossil fuel consumption.
[38]	2021	Evaluation of the techno-economic feasibility of a PV-battery system for a house in Güzelyurt.	The electricity generation cost is less than the grid tariff rate.

TABLE III. SUMMARY OF PREVIOUS STUDIES FOCUSING ON SOLAR ENERGY POTENTIAL IN NORTHERN CYPRUS

Location No.	Name	Elevation [m]	Latitude [°N]	Longitude [°E]	Optimum orientation angles			
					Fixed-tilt		Vertical	Inclined
					Slope angle [°]	Azimuth angle [°]	Slope angle [°]	Slope angle [°]
1	Akdeniz	89	35.300	32.965	31.0	2.0	52.0	34.0
2	Camlibel	277	35.316	33.071	31.0	3.0	52.0	33.0
3	Lapta	168	35.336	33.163	29.0	-5.0	51.0	31.0
4	Girne	10	35.342	33.331	31.0	-1.0	52.0	33.0
5	Beylerbeyi	225	35.297	33.354	28.0	-22.0	46.0	29.0
6	Bogaz	300	35.288	33.285	31.0	0.0	52.0	34.0
7	Tatlisu	168	35.225	33.451	32.0	-3.0	52.0	34.0
8	Kantara	480	35.401	33.914	31.0	-4.0	51.0	33.0
9	Esentepe	183	35.333	33.579	31.0	0.0	52.0	33.0
10	Guzelyurt	52	35.189	32.982	31.0	0.0	52.0	34.0
11	Gaziveren	19	35.173	32.922	31.0	0.0	52.0	34.0
12	Lefke	129	35.097	32.841	30.0	-8.0	52.0	32.0
13	Yesilirmak	20	35.166	32.737	30.0	-2.0	52.0	33.0
14	Ercan	119	35.159	33.502	32.0	-4.0	52.0	34.0
15	Serdarli	111	35.252	33.610	32.0	-5.0	52.0	34.0
16	Degirmenlik	168	35.253	33.472	31.0	-1.0	51.0	33.0
17	Gecitkale	45	35.233	33.729	32.0	-2.0	52.0	34.0
18	Gonendere	75	35.270	33.657	32.0	-3.0	52.0	34.0
19	Vadili	54	35.139	33.652	32.0	-2.0	52.0	34.0
20	Beyarmudu	87	35.047	33.696	31.0	0.0	52.0	34.0
21	Cayirova	67	35.349	34.031	31.0	2.0	52.0	34.0
22	Iskele	39	35.286	33.884	31.0	0.0	52.0	34.0
23	Mehmetcik	99	35.422	34.078	31.0	2.0	52.0	34.0
24	Gazimagusa	10	35.136	33.936	31.0	2.0	52.0	34.0
25	Salamis	6	35.181	33.897	31.0	1.0	52.0	34.0
26	Alevkaya	623	35.286	33.535	31.0	2.0	51.0	33.0
27	Zumrutkoy	129	35.174	33.049	31.0	0.0	52.0	34.0
28	Alaykoy	166	35.185	33.257	32.0	-2.0	53.0	34.0
29	Lefkosa	134	35.196	33.352	32.0	-3.0	52.0	34.0
30	Ziyamet	82	35.454	34.125	30.0	3.0	51.0	33.0
31	Dipkarpaz	136	35.599	34.379	31.0	5.0	51.0	33.0
32	Yenierenkoy	123	35.536	34.189	31.0	5.0	52.0	33.0
33	Dortyol	54	35.179	33.759	32.0	-1.0	52.0	34.0
34	Kalecik	7	35.334	33.981	29.0	49.0	55.0	36.0
35	Sınırüstü	28	35.276	33.856	34.0	49.0	55.0	36.0
36	Sadrazamköy	68	35.383	32.949	32.0	51.0	54.0	35.0
37	Selvilitepe	879	35.321	33.158	27.0	49.0	54.0	35.0

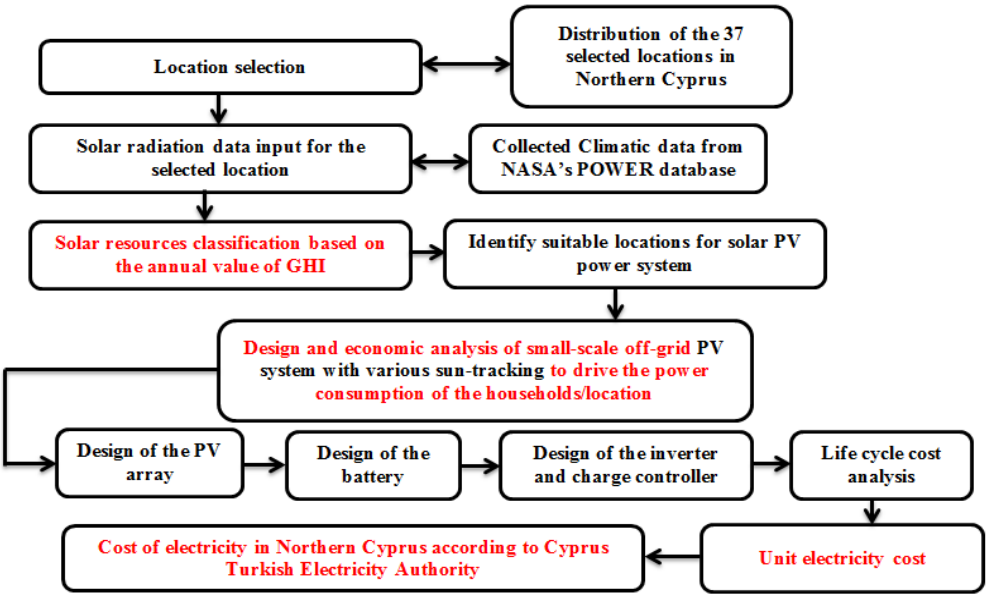

Fig. 1. Flowchart of the proposed methodology.

Fig. 2. The selected locations.

B. Classification of Solar Potential

The potential of solar energy is divided into two classifications, namely geographical potential and technical potential [43]. In general, the annual amounts of total solar radiation at a specific location, factoring in existing geographical, social, environmental, and cultural constraints, are the factors that define the geographical potential. At the same time, the technical potential of a specific location is defined as the amount of geographical potential that can be translated into electricity using a PV [43]. According to [44], the solar energy potential was classified based on the annual value of GHI and DNI. In general, global solar radiation is considered applicable for the evaluation of the energy generation for the flat PV system. Table IV shows the classification of solar energy.

TABLE IV. CLASSIFICATION OF SOLAR ENERGY

Class	Annual GHI [kWh/m^2]	Annual DNI [kWh/m^2]
1 (poor)	<1191.8	<936.9
2 (marginal)	1191.8-1419.7	936.9-1255.7
3 (fair)	1419.7-1641.8	1255.7-1546.8
4 (good)	1641.8-1843.8	1546.8-1840.9
5 (excellent)	1843.8-2035.9	1840.9-2149.9
6 (outstanding)	2035.9-2221.8	2149.9-2533.7
7 (superb)	>2221.8	>2533.7

TABLE V. DEFINITION OF THE FREQUENCY DISTRIBUTION TYPE ACCORDING TO THE RANGE OF THE SKEWNESS AND KURTOSIS VALUES

Distribution type number	Distribution curve	Skewness range	Kurtosis range
I	Normal	-0.4 < S < 0.4	-0.8<K< 0.8
II	Almost normal with positive tail	S≥0.4	-0.8<K< 0.8
III	Narrow peak with positive tail	S≥0.4	K≤-0.8 K≥0.8
IV	Almost normal with a negative tail	S≤-0.4	-0.8<K< 0.8
V	Narrow peak with negative tail	S≤-0.4	K≥0.8
VI	Bimodal, symmetrical with a flat peak	-0.4 < S < 0.4	K≤-0.8

C. Statistical Analysis

Different distribution functions have been utilized to study the characteristics of solar radiation. For example, authors in [11] utilized normal, logistic, Nakagami, and Rician distribution models to analyze the characteristics of global solar radiation in urban regions in Northern Cyprus. Authors in [45] determined the best probability distribution (gamma, generalized extreme value, Weibull, extreme value, logistic, normal, and lognormal) for analyzing the global solar radiation of Ibadan, Nigeria. Authors in [46, 47] defined the frequency distribution type as a function of the range of the skewness and kurtosis values of solar radiation at two locations in Cyprus.

In this study, the best frequency distribution type for modeling the monthly solar radiation is selected based on the range value of Skewness and Kurtosis as shown in Table V.

D. Off-grid Photovoltaic System

The off-grid solar PV system is a common configuration. This system requires a battery for storing the remaining produced energy. Therefore, evaluating the daily electrical load and daily solar energy are important parameters for performing the optimal modeling of the PV array. The peak power of PV (P_{PV}) is the first parameter that should be estimated. According to [48], PV power array ($P_{PV(t)}$) depends upon solar radiation and it can be expressed as:

$$P_{PV(t)} = P_{PV(rate)} \times f_{loss} \times \frac{G_{sr}(t)}{IP} \quad (1)$$

where $P_{PV(rate)}$ is the nominal power of the panel under standard test conditions (STC), f_{loss} is the derating factor of the solar PV panel due to shade, dirt, temperature, and so on, $G_{sr}(t)$ is the hourly/daily/monthly global solar radiation at the surface of the solar PV panel in kWh/m^2 and IP is the standard incident radiation (1 kW/m^2).

Additionally, $P_{PV(t)}$ depends on absorption capacity, panel area, and cell temperature [49]:

$$P_{PV(t)} = \frac{G_{sr}(t)}{IP} \times P_{PV(rate)} \times \eta_{PV} \times \left[1 - \beta_T\left(T_C - T_{C,STC}\right)\right] \quad (2)$$

where η_{PV} is the percentage of the power reduction factor of the PV panels, $T_{C,STC}$ is cell the temperature under STC, β_T is the PV temperature coefficient, and T_C is the cell temperature under operating conditions:

$$T_C = \frac{G_{sr}(t)}{800} \times (NOCT - 20) + T_{amb} \quad (3)$$

where $NOCT$ is the Normal Operation Cell Temperature and T_{amb} is the ambient temperature.

Furthermore, the $P_{PV(t)}$ can be expressed as [50]:

$$\mathrm{P}_{PV(t)} = G_{sr}(t) \times A_{surface} \times f_{activ} \times \eta_{cell} \times \eta_{invert} \times N[1 - (t-1) \times d_{PV}] \quad (4)$$

where $A_{surface}$ is the net surface area of PV modules, f_{activ} is the fraction of the surface area with active solar cells, η_{cell} is the module conversion efficiency, which can be determined from the manufacturers' specifications, η_{invert} is the inverter conversion efficiency, N is the quantity of the PV modules, t is the time expressed in years ($t \geq 1$), and d_{PV} is the degradation rate of the PV system.

The power output of the PV array can be estimated by [17]:

$$P_{PV(t)} = A_{surface} \times \eta_{PV} \times \eta_{invert} \times f_{loss} \times [B_T + R_T + D_T] \quad (5)$$

where η_{ref} is the referenced efficiency of the PV panels, B_{ref} is the temperature coefficient of the PV panel, I_{NOCT} is the incident solar radiation for the *NOCT* test, T_a is the ambient temperature, T_{ref} is the reference temperature of the PV panels, T_{NOCT} is the nominal operating cell temperature at test conditions, $T_{a,NOCT}$ is the ambient *NOCT*, B_T, R_T, and D_T are the hourly beam, reflected and diffuse component of the solar radiation on a tilted surface, and η_{PV} is the efficiency of the solar panels provided by:

$$\eta_{PV} = \eta_{ref}\left[1 - B_{ref}\left[T_a - T_{ref} + \left(T_{NOCT} - T_{a,NOCT}\right)\frac{I_T}{I_{NOCT}}\right]\right] \quad (6)$$

$P_{PV(t)}$ is considered the first parameter that needs to be estimated. It can be expressed as [51]:

$$P_{PV(t)} = \left(\frac{E_{AC}}{G_{sr}T_c\eta_{PV}\eta_{inv}\eta_B}\right)P_i\eta_{PV} \quad (7)$$

where η_{PV} is the PV modules efficiency, η_{inv} is the inverter efficiency; T_c is the temperature coefficient, and η_B is the battery efficiency.

Moreover, designing a battery system is required due to the limitation of daily hours of sunshine and the stochastic nature of solar energy and to support electricity generation sustainability and energy storage [52]. Consequently, the number of autonomy dat (N_{ad}), the battery efficiency (η_B), the inverter efficiency (η_{inv}), the depth of discharge (D_{dod}), and the size of the electrical load (E_{AC}) should be considered for designing the battery system. Equation (18) is used to determine the Battery Storage Capacity (*BSC*) in Wh [51]:

$$BSC = \frac{E_{AC}N_{ad}}{D_{dod}\eta_{inv}\eta_B} \quad (8)$$

Furthermore, the number of autonomy hours (N_{ah}) can be determined by [53]:

$$N_{ah} = \frac{K_B\eta_{invert}\eta_{dech}D_{dod}}{E_{AC}} \quad (9)$$

where η_{dech} is the battery storage system discharging efficiency (%), D_{dod} is the battery storage system depth of discharge, V_B is the voltage of the battery block, and K_B is the battery storage system's nominal capacity in kWh provided by:

$$K_B = \frac{N_{ah}E_{AC}}{\eta_{inv}\eta_{dech}D_{dod}} \quad (10)$$

Additionally, a Charge Controller (CC) has been designed to support the battery of the off-grid system. The CC should be designed with at least 25% more of the $P_{P(PV)}$ current to permit cold temperatures [20]. The CC is equipped with a Maximum Power Point Tracker (MPPT) that is required to charge and protect the batteries avoiding both the risk of overcharging and reaching excessive discharge level [20]. The main function of CC is to support electrical load power consumption and promote the battery's lifespan [54].

As mentioned above, an inverter is a component of the system. The capacity of the inverter should be higher than $P_{P(PV)}$ by 20% in order to be able to handle the maximum power of electric loads [55].

E. Off-Grid Photovoltaic System

In the literature, several methods and software simulations have been utilized for the evaluation of the life cycle cost of standalone and hybrid PV systems [17, 20, 51, 55-59]. For instance, authors in [17] developed an economic model to evaluate the cost-benefit of an off-grid PV system in rural Gusau, Nigeria. Author in [20] used mathematical modeling to assess the techno-economic feasibility of an off-grid PV system to electrify a house in the rural fringe of Famagusta, Cyprus. Authors in [51] examined the feasibility of an off-grid PV system to drive the electricity consumption of a residential building in Jos, Nigeria using mathematical modeling. Authors in [58] used HOMER software to evaluate the feasibility of wind–PV–diesel hybrid power systems for a village in Saudi Arabia. Authors in [57] investigated the economic viability of a hybrid system that can be used to supply electricity to a rural community in Sri Lanka using HOMER. Authors in [58] evaluated the performance of residential solar PV systems with utility backup in Nagpur, India using mathematical modeling and software simulation. Authors in [55] utilized mathematical modeling to evaluate the feasibility of an off-grid PV system for the electrification of a single residential household in Faisalabad, Pakistan. Authors in [59] investigated the techno-economic feasibility of a stand-alone solar PV system for an isolated locality in Bangladesh using spreadsheet modeling.

The mathematical equations that are used in the current study to evaluate the life cycle analysis, which covers all the PV system life stages including the initial capital cost or acquisition cost and the operation and maintenance costs, are expressed below.

Cost of a PV array (C_{PV}) in US$:

$$C_{PV} = P_{P(PV)} \times \text{unit price of PV module} \quad (11)$$

Initial cost of batteries (*ICB*) in US$:

$$ICB = \text{BSC} \times \text{unit price of battery} \quad (12)$$

Present worth of the battery for various battery lifespans (N):

$$ICB = CB \times \left(\frac{1+i}{1+d}\right)^N \quad (13)$$

where i is the inflation rate, d is the discount rate, and CB is the cost of the battery in US$.

Cost of an inverter system (C_{inv}) in US$:

$$C_{inv} = P_{P(PV)} \times \text{unit price of inverter} \quad (14)$$

Cost of a charge controller (C_{CC}) in US$:

$$C_{CC} = \text{Size of charge controller} \times \text{unit cost of charge controller} \quad (15)$$

Cost of a PV installation (C_{PVI}) is US$:

$$C_{PVI} = 10\% \times \text{initial cost of PV} \quad (16)$$

Maintenance cost (C_m):

$$C_m = 2\% \times \text{initial cost of PV} \quad (17)$$

Furthermore, the Present Worth (PW) of the C_m is estimated by considering the depreciation rate, the inflation rate, and the PV system life span.

$$PWC_m = \left(\frac{Month}{year}\right) \times \left(\frac{1+i}{1+d}\right) \times \left(\frac{1-\left(\frac{1+i}{1+d}\right)^N}{1-\left(\frac{1+i}{1+d}\right)}\right) \quad (18)$$

where d is the depreciation rate percentage.

Levelized cost (LCC) in US$:

$$LCC = C_{PV} + \text{CB} + C_{inv} + C_{CC} + C_m + C_{PVI} \quad (19)$$

Annualized life cycle cost ($ALCC$):

$$ALCC = LCC\left(\frac{1-\left(\frac{1+i}{1+d}\right)}{1-\left(\frac{1+i}{1+d}\right)N}\right) \quad (20)$$

Unit electricity cost (U_{EC}) in US$/kWh:

$$U_{EC} = \frac{ALCC}{365 \times E_{AC}} \quad (21)$$

Annual Savings (AS) in US$:

$$AS = \text{Annual Energy Generation}$$
$$\times \text{ feedin tariff rate for solar power purchase} \quad (22)$$

Payback Period (PP):

$$PP = \frac{\text{Initial Investment}}{AS} \quad (23)$$

F. Solar Panel and Inverter

A large number of PV modules with different specifications are available on the market. Mono-crystalline PV modules have the highest efficiency compared to poly-crystalline cells and amorphous silicon modules [54]. Furthermore, cell type, system cost, warranty, size, and power are important factors to select the best PV panel [60]. Therefore, a selection criterion is needed to select a specified PV module to be used in a specific project. A survey of the characteristics of most of the available PV modules from different manufacturers and technologies is done (Table VI). Based on the previous studies, several Panel Selection (PS) criteria are used to select the suitable PV module:

$$PS = \frac{\text{PV module capacity} \times \text{Module efficiency}}{\text{module price} \times \text{frame area of module}} \quad (24)$$

$$PS = \frac{\text{PV module capacity}}{\text{Frame area of module}} \quad (25)$$

$$PS = \frac{\text{PV module capacity}}{\text{module price} \times \text{frame area of module}} \quad (26)$$

$$PS = \frac{\text{Cost of 1kW PV system}}{\text{Energy production of 1 kW PV system}} \quad (27)$$

Based on the calculations (Figure 3), UZ158MHC340-60, AE410HM6-72, and NS-290P6 solar modules offer a better ratio compared to other models. It should be noted that these models have been selected based on the selection criteria among the PV modules surveyed.

TABLE VI. CHARACTERISTICS OF MOST AVAILABLE PV MODULES

Module No	Manufacturer	Module type	Maximum Power [W]	Efficiency	Module area [m^2]	Module Price [$]
1	Jinko	JKM330M-60-V	330	19.78	1.668	115
2	Solar Fabrik	-	340	20.14	1.687	237
3	Panasonic	-	325	19.4	1.674	257
4	Ankara Solar	AS-M60-310W	310	19	1.63	77
5	AXITEC	AC-430MH/144V	430	19.33	2.174	120.4
6	Suntech	STP325-24/ Vfw	335	17.2	1.944	81
7	SunLink	-	435	20	2.1073	105
8	AE Solar	AE410HM6-72	410	20.69	1.674	115
9	Tide Solar	-	450	20.4	2.208	90
10	Regitec Solar	RMH60/380S1	380	20.9	1.853	110
11	Austa Energy	AU410-27V-MHB	410	20.97	1.955	99
12	Horay Solar	HS166-380-120M	380	20.5	1.823	84
13	München Energieprodukte GmbH	-	440	19.9	2.209	110
14	Fortunes Solar	FDS-M6M-60-355BK	355	19.26	1.868	82
15	Sunket	SKT375M6-20/HC	375	20.1	1.868	90
16	Smart Solar System	HCM60X9-345W	345	20.4	1.689	72.75
17	Mysolar	MS400PM5-66SA	400	21.3	1.876	83.51
18	AE solar	AE M6-60 320W	320	19.27	1.661	62.42
19	UzinSemi	UZ158MHC340-60	340	20.1	1.695	57
20	Betop (EU) Tech GmbH	SR-325-340-120M	340	20	1.6873	64.89
21	Exiom Solution	EX340M-120	340	20.1	1.692	70.98
22	EnergyPal	ASP345P6-72	345	17.8	1.94	64.02
23	Betop (EU) Tech GmbH	NS-290P6	290	17.8	1.626	47.24
24	Ankara Solar	AS-P60-290W	290	17.83	1.63	30
25	Ankara Solar	AS-P72-345W	345	17.78	1.94	35
26	Ankara Solar	AS-B60 -320W	320	21	1.61	47
27	Canadian Solar	mono-Si - CS6X-300M	300	15.63	1.919	249
28	Canadian Solar	poly-Si - CS6X-310P	310	16.16	1.918	248

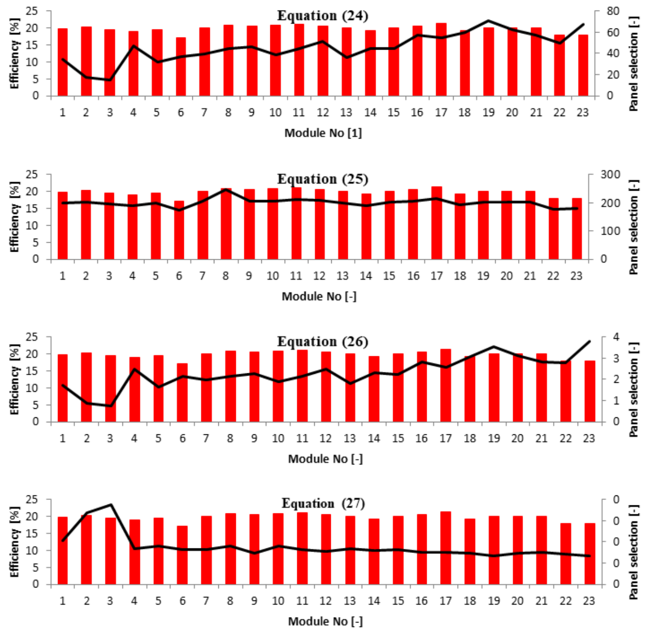

Fig. 3. PS criteria and efficiency of the surveyed PV modules.

Furthermore, output AC power, DC-AC conversion efficiency, and capital cost of the inverter are the main factors to select a suitable inverter. As mentioned above, this study aims to design a small-scale on-grid and off-grid PV system, thus, a hybrid inverter, the combination of an on-grid and off-grid solar inverter, is selected in this study.

III. RESULTS AND DISCUSSION

Mathematical modeling methods and RETScreen Expert software were utilized to evaluate the viability of small-scale rooftop and large-scale PV systems in different locations in Northern Cyprus.

A. Solar Irradiation Characteristics Analysis

In this section, the GHI data were analyzed. GHI is an essential parameter to analyze the solar resource at the project location to evaluate power generation for flat-panel PVs [51, 61]. The statistical description of GHI for the period of 2005-2020 is listed in Table VII. The description includes the mean, standard deviation (SD), coefficient of variation (CV), minimum (Min.), maximum (Max.), Kurtosis (K), and Skewness (S). It can be seen that the mean monthly value of GHI is within the range of 142.0-162.3kWh/m^2. The maximum and minimum values of mean GHI are recorded in Ercan and Beylerbeyi, respectively. The CV values are moderately low, ranging from 36.6% to 47.53%. Additionally, all S values are negative, indicating that all distributions are left skewed. The K values varied from -1.7 to -1.68. Moreover, Type VI, which is bimodal, and symmetrical with a flat peak, characterizes the mean monthly GHI. Figure 4 illustrates the annual value of GHI for all selected locations. It is seen that the annual GHI values varied from 1704.07 (Beylerbeyi) to 1948.00 (Ercan) kWh/m^2, respectively. Furthermore, the solar resources at project locations are categorized as good, excellent, outstanding, and superb as shown in Table VIII. Based on the value of GHI, it is observed that the solar resource of all selected locations expect Beylerbeyi is categorized as class 5 (excellent). It is concluded that the selected locations are suitable for the installation of large- or small-scale PV systems due to the values of GHI and DNI. Accordingly, all selected areas are suitable for the installation of PV/flat panels and CSP systems.

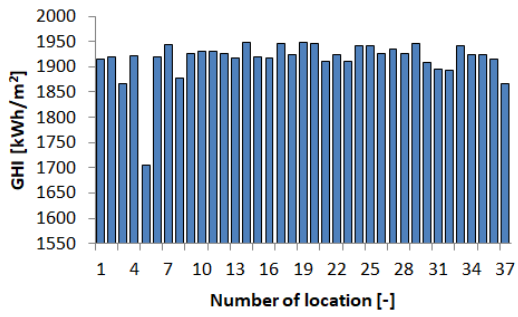

Fig. 4. Annual value of GHI for all selected locations.

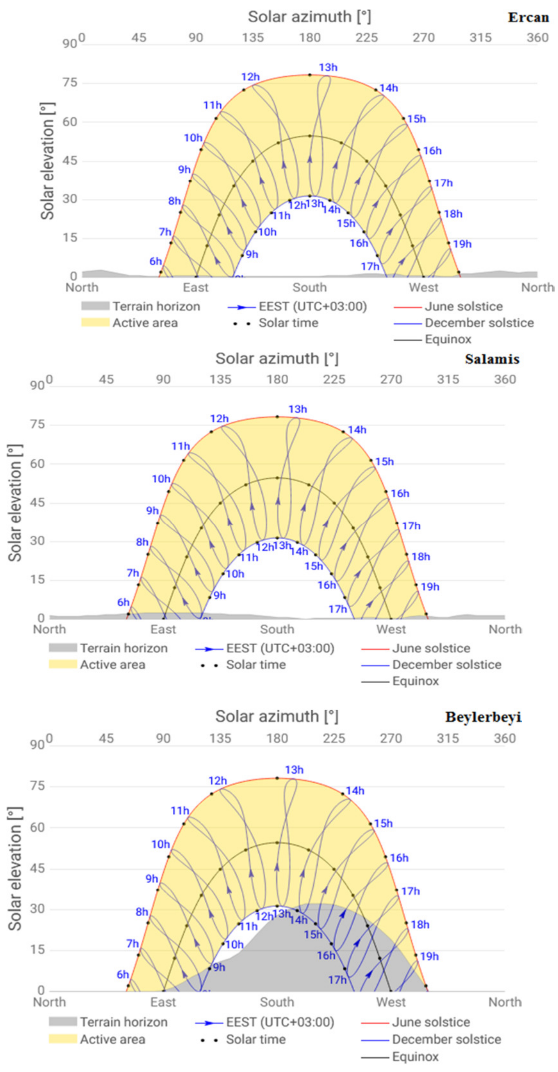

Fig. 5. Sun's path over a year for some selected locations.

TABLE VII. STATISTICAL ESTIMATORS OF THE MONTHLY GHI IN KWH/m^2 FOR THE 2005-2020 PERIOD

Location	Mean	SD	CV	Min.	Max.	S	K	Distribution type
Akdeniz	159.5	61.1	38.3	75.4	238.2	-0.11	-1.68	Bimodal, symmetrical with a flat peak
Camlibel	159.9	61.1	38.23	75.8	238.7	-0.11	-1.68	Bimodal, symmetrical with a flat peak
Lapta	155.4	65.7	42.29	63.6	238.2	-0.15	-1.69	Bimodal, symmetrical with a flat peak
Girne	160	61	38.1	76.1	238.5	-0.11	-1.68	Bimodal, symmetrical with a flat peak
Beylerbeyi	142	67.5	47.53	51.5	227.8	-0.09	-1.7	Bimodal, symmetrical with a flat peak
Bogaz	159.9	60.5	37.84	76.4	237	-0.12	-1.69	Bimodal, symmetrical with a flat peak
Tatlisu	162	60.5	37.33	78.2	239.2	-0.12	-1.68	Bimodal, symmetrical with a flat peak
Kantara	156.5	57.2	36.55	76.1	227.7	-0.16	-1.69	Bimodal, symmetrical with a flat peak
Esentepe	160.5	60.8	37.87	76.2	238.6	-0.11	-1.68	Bimodal, symmetrical with a flat peak
Guzelyurt	160.8	60.8	37.79	77.3	239.2	-0.11	-1.68	Bimodal, symmetrical with a flat peak
Gaziveren	160.8	60.8	37.81	77.3	239.4	-0.1	-1.68	Bimodal, symmetrical with a flat peak
Lefke	160.4	60.3	37.61	77.3	237.2	-0.12	-1.69	Bimodal, symmetrical with a flat peak
Yesilirmak	159.7	60.1	37.66	76.8	236	-0.12	-1.69	Bimodal, symmetrical with a flat peak
Ercan	162.3	60.2	37.11	78.4	238.8	-0.13	-1.68	Bimodal, symmetrical with a flat peak
Serdarli	160	60.6	37.86	76.2	237.3	-0.12	-1.69	Bimodal, symmetrical with a flat peak
Degirmenlik	159.7	60.7	37.99	75.8	237	-0.12	-1.69	Bimodal, symmetrical with a flat peak
Gecitkale	162.2	60.3	37.17	78.1	238.7	-0.13	-1.68	Bimodal, symmetrical with a flat peak
Gonendere	160.4	60.7	37.86	76.2	238.3	-0.11	-1.68	Bimodal, symmetrical with a flat peak
Vadili	162.3	60.2	37.13	78.2	238.7	-0.13	-1.68	Bimodal, symmetrical with a flat peak
Beyarmudu	162.2	60.2	37.13	78.2	238.6	-0.13	-1.68	Bimodal, symmetrical with a flat peak
Cayirova	159.2	60.2	37.81	75.6	235.7	-0.12	-1.68	Bimodal, symmetrical with a flat peak
Iskele	160.3	60.6	37.78	76.2	237.8	-0.12	-1.68	Bimodal, symmetrical with a flat peak
Mehmetcik	159.2	60.2	37.82	75.6	235.7	-0.12	-1.68	Bimodal, symmetrical with a flat peak
Gazimagusa	161.8	60	37.1	77.8	237.5	-0.13	-1.68	Bimodal, symmetrical with a flat peak
Salamis	161.8	60	37.1	77.8	237.5	-0.13	-1.68	Bimodal, symmetrical with a flat peak
Alevkaya	160.5	60.8	37.88	76.3	238.6	-0.11	-1.68	Bimodal, symmetrical with a flat peak
Zumrutkoy	161.2	60.7	37.66	77.7	239.3	-0.11	-1.68	Bimodal, symmetrical with a flat peak
Alaykoy	160.5	60.8	37.88	76.3	238.6	-0.11	-1.68	Bimodal, symmetrical with a flat peak
Lefkosa	162.1	60.4	37.28	78.6	239.3	-0.12	-1.68	Bimodal, symmetrical with a flat peak
Ziyamet	159	60.2	37.85	75.5	235.2	-0.12	-1.69	Bimodal, symmetrical with a flat peak
Dipkarpaz	158	60	38	74.2	232.9	-0.13	-1.69	Bimodal, symmetrical with a flat peak
Yenierenkoy	157.8	60.4	38.29	74	234.6	-0.12	-1.68	Bimodal, symmetrical with a flat peak
Dortyol	161.9	60	37.09	77.9	237.5	-0.13	-1.68	Bimodal, symmetrical with a flat peak
Kalecik	160.3	60.6	37.8	76.1	237.7	-0.12	-1.68	Bimodal, symmetrical with a flat peak
Sınırüstü	160.3	60.6	37.78	76.2	237.8	-0.12	-1.68	Bimodal, symmetrical with a flat peak
Sadrazamköy	159.5	61.1	38.33	75.4	238.3	-0.11	-1.68	Bimodal, symmetrical with a flat peak
Selvilitepe	155.5	59	37.96	74.9	230.4	-0.11	-1.74	Bimodal, symmetrical with a flat peak

TABLE VIII. SOLAR ENERGY CLASSIFICATION FOR ALL LOCATIONS BASED ON THE ANNUAL GHI IN KWh/m^2.

Location	GHI	Class	Location	GHI	Class
Akdeniz	1914.023	5	Beyarmudu	1946.873	5
Camlibel	1918.425	5	Cayirova	1910.374	5
Lapta	1865.277	5	Iskele	1923.826	5
Girne	1920.575	5	Mehmetcik	1910.203	5
Beylerbeyi	1704.069	4	Gazimagusa	1941.646	5
Bogaz	1919.021	5	Salamis	1941.734	5
Tatlisu	1944.539	5	Alevkaya	1925.431	5
Kantara	1877.795	5	Zumrutkoy	1933.877	5
Esentepe	1925.804	5	Alaykoy	1925.431	5
Guzelyurt	1929.479	5	Lefkosa	1945.419	5
Gaziveren	1929.953	5	Ziyamet	1908.114	5
Lefke	1925.094	5	Dipkarpaz	1896.059	5
Yesilirmak	1916.061	5	Yenierenkoy	1893.448	5
Ercan	1948.001	5	Dortyol	1942.426	5
Serdarli	1920.338	5	Kalecik	1923.242	5
Degirmenlik	1916.306	5	Sınırüstü	1923.958	5
Gecitkale	1946.526	5	Sadrazamköy	1913.993	5
Gonendere	1924.809	5	Selvilitepe	1866.323	5
Vadili	1947.005	5			

The sun's direction for one year is illustrated in Figure 5 for some selected locations. The gray fills represent the terrain horizon, while the unit horizon (represented by blue fill) may have a shading effect on solar radiation. The black dots represent true solar time, while the blue markers indicate the local hourly time. A gray line is used in the illustration to depict three paths of the sun in three curves. The sun's lowest gray path is at the winter solstice, the mean curvature at the equinox, and the upper curvature at the summer solstice. The curves of the sun show that in winter, the sun has a low horizon and in summer, the sun has a high horizon.

B. Electric Energy Production and Capacity Factor of 6.5kW Off-Grid PV Systems

In this study, the PV system is designed according to the minimum value of GHI to satisfy the occupants' electricity demands for the whole year for the selected household. Based on the previous section, the maximum PV power is estimated to be 14.783kWh based on the minimum value of GHI on the horizontal surface for Beylerbeyi. According to the renewable energy board (Yek-Kurulu), the customers can install 5kW single-phase grid-connected and up to 8kW three-phase grid-connected PV systems. Consequently, the capacity of the developed system is assumed to be 6.5kW. Accordingly, the economic viability of off-grid PV systems with various sun-tracking systems is discussed in this section. Based on the selection criteria, UZ158MHC340-60, AE410HM6-72, and NS-290P6 with 340W, 410W, and 290W peak capacity are selected in this study. In the following sections, the results obtained from the mathematical model are summarized.

The performance of the PV systems in terms of PV output and Capacity Factor (CF) is dependent on the orientation angles [14]. Thus, the Electric Energy Production (EEP) and CF were estimated for the different sun-tracking systems. It should be noted that EEP and CF for the fixed-tilted, vertical axis and inclined system are determined at the optimum orientations angles. The mean annual values of EEP for all selected locations are shown in Figure 6. It is found that the maximum and minimum values of EEP are recorded in Sadrazamköy and Beylerbeyi, respectively. It should be noted that the monthly (*MPVP*) and annual (*APVP*) PV energy production can be determined by (28) and (29), respectively. As an example, the annual PV electrical energy production for Beylerbeyi and Sadrazamköy is shown in Figure 7.

$$MPVP = \eta_{PV} \times A_{PV} \times Monthly\ GHI \quad (28)$$

$$APVP = \sum_{i=1}^{12} \eta_{PV} \times A_{PV} \times Monthly\ GHI \quad (29)$$

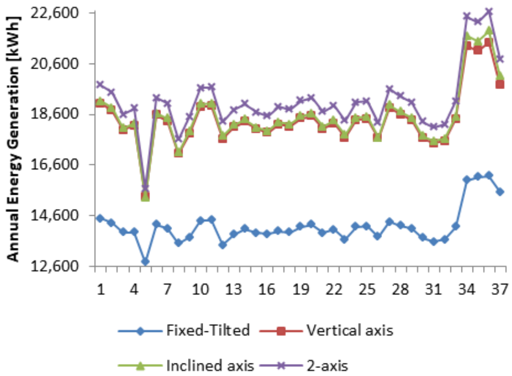

Fig. 6. Annual EEP value of all selected locations.

Among the PV models, the results indicate that the highest monthly/annual EEP is achieved when NS-290P6 is used, as shown in Figure 7. Besides, the solar tracking system can increase the annual energy production up to 20% and 40% using single-axis and 2-axis systems, respectively according to [62, 63]. It can be noticed that the amount of output power increases when the sun-tracking system is used. These results are supported by the findings in [54, 64].

As mentioned above, CF is an important parameter to evaluate the performance of PV systems. Figure 8 illustrates the annual value of CF for all selected locations. It is found that the CF values range from 22.43 to 39.77%. The highest average annual value of CF was recorded in Sadrazamköy while the lowest value was obtained in Beylerbeyi for a 2-axis PV system and a fixed-tilted PV system, respectively. Other researchers who analyzed the performance of off-grid PV systems in terms of CF can support these observations. Authors in [65] found that the annual value of CF for the solar off-grid system is 24.6%. Authors in [66] found that the CF values of off-grid PV/hydrogen fuel cells are within the range of 16.4–31.2%. Moreover, authors in [67] found that the value of CF lies in the range of 16.2-30.3%. Based on these findings, it can be concluded that the value gained during the current study for each location is consistent with the accepted values. Thus, it is technically sustainable to install off-grid PV systems at all the selected locations in Northern Cyprus.

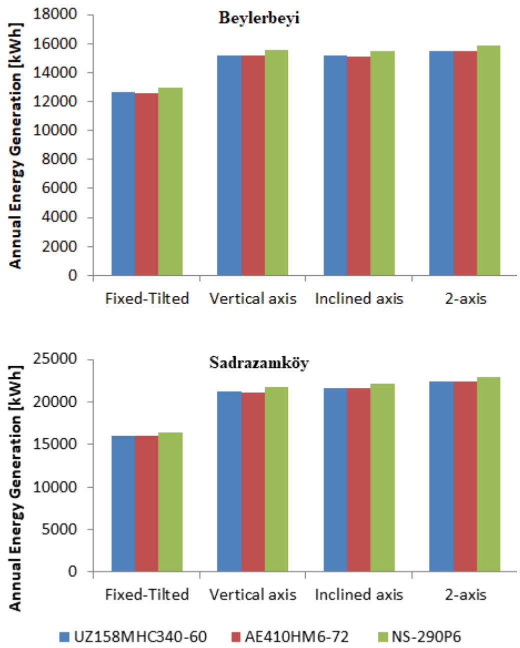

Fig. 7. Monthly PV energy production using UZ158MHC340-60 for Beylerbeyi and Sadrazamköy with various sun-tracking systems.

C. Economic Viability of 6.5kW Off-Grid PV Systems

The performance of the proposed systems is evaluated by estimating the economic factors of each system. In this study, the value of T_c is assumed to be 80% due to a 15–20% loss in efficiency as a result of increasing cell temperature to around 60°C [20]. Moreover, the efficiency of the selected battery is 85% and the efficiency of the PV panels is listed in Table VI.

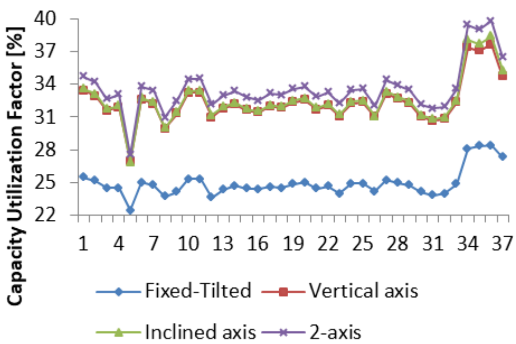

Fig. 8. Annual CF value of all selected locations.

Additionally, the required BSC is determined based on the assumption value of the N_{ad} as 2 days and maximum D_{dod} as

80%. Moreover, Trojan SAGM batteries were utilized in this study (nominal voltage = 12V, round trip efficiency = 85%, throughput = 2285.1kWh, capital cost = 538 USD, replacement cost = 500USD, and operating and maintenance cost = 8 USD/year).

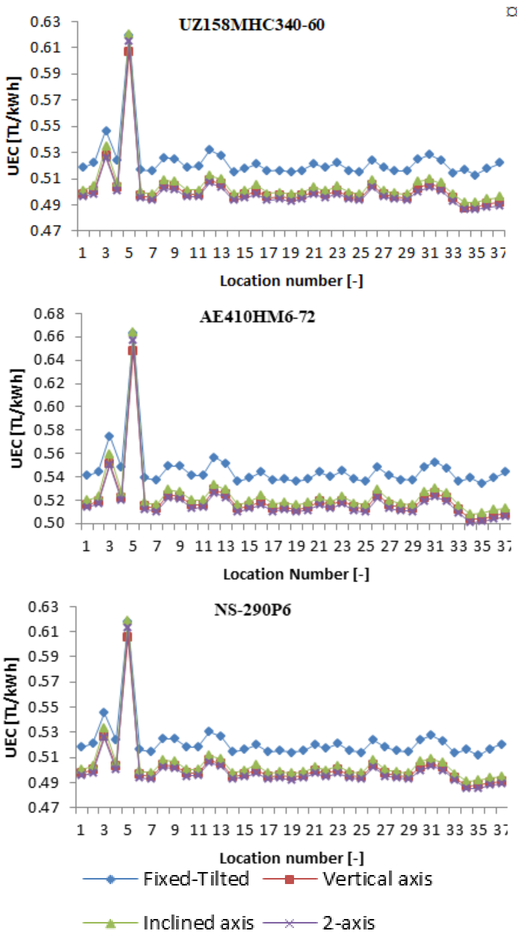

Fig. 9. Unit electricity cost for all the proposed PV systems (the prices are estimated based on the US dollar exchange rate during the wrtiting of the paper).

Generally, assessing the economic viability of the proposed system is important. Based on the mathematical modeling method, the costs of PV modules, inverter, battery, charge controller, installation, and operation and maintenance were calculated. Further, the LCC, ALCC, PP, and U_{EC} are mathematically estimated for various PV technologies and sun-tracking systems. It should be noted that the initial investment, battery replacement, and operation and maintenance of the system are determined using current market prices. Additionally, the financial parameters inflation rate and discount rate are 8% and 6%, respectively. The total Life Cycle Cost (LCC) of the proposed PV systems including the initial investment cost, the present value of battery replacement cost, and the present value of operation and maintenance cost was estimated. It was found that LCC values are within the range of 286903.39-656408.00 USD. Moreover, Figure 9 illustrates the value of PP and U_{EC} for all selected locations. It was found that the U_{EC} values varied from 0.4851TL/kWh to 0.6641TL/kWh. The lowest U_{EC} value of 0.4851TL was obtained from the proposed system with a 2-axis system. These values are compared with the current electricity prices in Northern Cyprus (see Table I) and [20]. Authors in [20] estimated U_{EC} to 0.43TL/kWh. Therefore, it is clear that the price of the electricity generating by PV systems is less than that of a conventional system. It can be concluded that the developed systems provide a significant insight into the economic feasibility of the project for all locations.

Moreover, the *PP* for the off-grid PV systems with various sun-tracking systems and PV technologies is determined. It should be noted that the feed-in tariff rate varied from one country to another. For example, the value of the feed-in tariff during the first year after the system installation in Iran is 0.247$/kW for a PV system with a capacity smaller than 20kW [68]. According to [69, 70], the feed-in tariff for PV systems in Turkey is 13.3 $ cents/kWh, for an application period of 10 years. In this study, the feed-in tariff rate for solar power purchase is assumed to be 0.133 USD/kWh. It is observed that *PP* values varied from 4.57 to 8.49 years, depending on the type of the panel and the sun-tracking system, as shown in Figure 10.

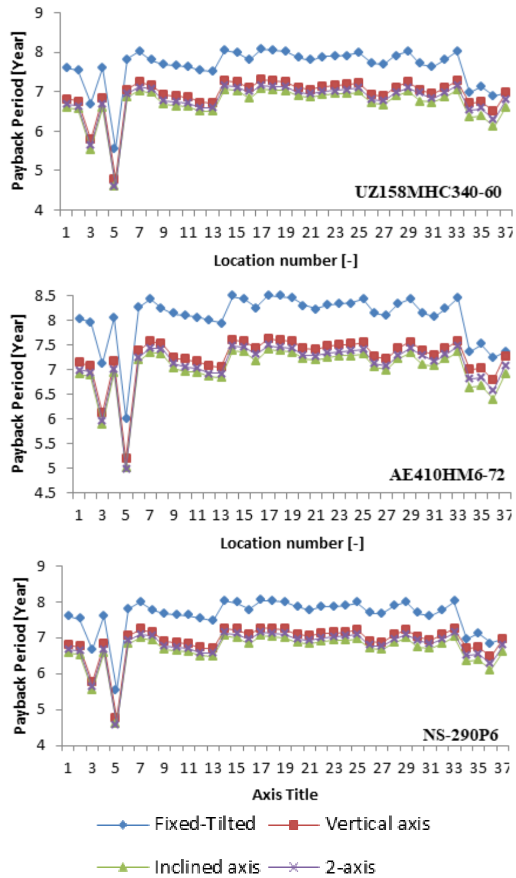

Fig. 10. Payback period of all the proposed PV systems.

IV. CONCLUSIONS

The current study is one of the first attempts to assess the techno-economic validity of using an off-grid PV system with various sun-tracking modes in Northern Cyprus. To fulfill this objective, NASA POWER data were used to categorize the solar resource in the selected locations. Additionally, the mathematical modeling method was used to estimate the energy production, capacity factor, payback period, and the cost of energy production of the proposed systems. The main results of the current study are:

- Ercan is the most suitable location for the installation of various sizes of PV systems.
- The conducted analysis showed that the development of the proposed 6.5kW off-gird PV power system is very promising in all the selected locations.
- An economic comparison between different tracking modes revealed that the use of a 2-axis tracking system is the most economical option for all locations.
- The electricity price of the developed systems was found within the range of 0.4851-0.6641TL/kWh for off-grid PV systems. These values were compared with the current electricity prices in Northern Cyprus and previous scientific studies regarding Northern Cyprus (0.43TL/kWh [20], 0.286-0.826TL/kWh [27], 1.376TL/kWh [35], 1.617-2.217TL/kWh [23], and 1.711-1.788TL/kWh [38]).

The results demonstrated that the technical and economic viability of the proposed systems for power production can serve as a model for the successful development of real applications of the systems. Further, the model can encourage the stakeholders in the renewable sector to provide support mechanisms for the adoption of PV systems in residential buildings.

REFERENCES

[1] E. A. Al-Ammar, N. H. Malik, and M. Usman, "Application of using Hybrid Renewable Energy in Saudi Arabia," *Engineering, Technology & Applied Science Research*, vol. 1, no. 4, pp. 84–89, Aug. 2011, https://doi.org/10.48084/etasr.33.

[2] M. Hosenuzzaman, N. A. Rahim, J. Selvaraj, M. Hasanuzzaman, A. B. M. A. Malek, and A. Nahar, "Global prospects, progress, policies, and environmental impact of solar photovoltaic power generation," *Renewable and Sustainable Energy Reviews*, vol. 41, pp. 284–297, Jan. 2015, https://doi.org/10.1016/j.rser.2014.08.046.

[3] J. Khan and M. H. Arsalan, "Solar power technologies for sustainable electricity generation – A review," *Renewable and Sustainable Energy Reviews*, vol. 55, pp. 414–425, Mar. 2016, https://doi.org/10.1016/j.rser.2015.10.135.

[4] 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.

[5] E. Kabir, P. Kumar, S. Kumar, A. A. Adelodun, and K.-H. Kim, "Solar energy: Potential and future prospects," *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 894–900, Feb. 2018, https://doi.org/10.1016/j.rser.2017.09.094.

[6] W. Al-Marri, A. Al-Habaibeh, and M. Watkins, "An investigation into domestic energy consumption behaviour and public awareness of renewable energy in Qatar," *Sustainable Cities and Society*, vol. 41, pp. 639–646, Aug. 2018, https://doi.org/10.1016/j.scs.2018.06.024.

[7] D. Wen, W. Gao, S. Kuroki, Q. Gu, and J. Ren, "The effects of the new Feed-In Tariff Act for solar photovoltaic (PV) energy in the wake of the Fukushima accident in Japan," *Energy Policy*, vol. 156, Sep. 2021, Art. no. 112414, https://doi.org/10.1016/j.enpol.2021.112414.

[8] S. Baurzhan and G. P. Jenkins, "Off-grid solar PV: Is it an affordable or appropriate solution for rural electrification in Sub-Saharan African countries?," *Renewable and Sustainable Energy Reviews*, vol. 60, pp. 1405–1418, Jul. 2016, https://doi.org/10.1016/j.rser.2016.03.016.

[9] F. Mansouri Kouhestani, J. Byrne, D. Johnson, L. Spencer, P. Hazendonk, and B. Brown, "Evaluating solar energy technical and economic potential on rooftops in an urban setting: the city of Lethbridge, Canada," *International Journal of Energy and Environmental Engineering*, vol. 10, no. 1, pp. 13–32, Mar. 2019, https://doi.org/10.1007/s40095-018-0289-1.

[10] I. S. Freitas Gomes, Y. Perez, and E. Suomalainen, "Coupling small batteries and PV generation: A review," *Renewable and Sustainable Energy Reviews*, vol. 126, Jul. 2020, Art. no. 109835, https://doi.org/10.1016/j.rser.2020.109835.

[11] Y. Kassem, H. Gokcekus, and H. Camur, "Economic assessment of renewable power generation based on wind speed and solar radiation in urban regions," *Global Journal of Environmental Science and Management*, vol. 4, no. 4, pp. 465–482, Oct. 2018, https://doi.org/10.22034/gjesm.2018.04.007.

[12] M. M. Dakyen, M. Dagbasi, and M. Ozdenefe, "Energy models for cost-optimal analysis: Development and calibration of residential reference building models for Northern Cyprus," *Indoor and Built Environment*, vol. 31, no. 3, pp. 657–681, Mar. 2022, https://doi.org/10.1177/1420326X211013076.

[13] "Greek Cypriots to the rescue following severe electricity problems in North Cyprus." https://www.t-vine.com/greek-cypriots-to-the-rescue-following-severe-electricity-problems-in-north-cyprus/ (accessed Mar. 19, 2023).

[14] Y. Kassem, H. Gokcekus, and A. Guvensoy, "Techno-Economic Feasibility of Grid-Connected Solar PV System at Near East University Hospital, Northern Cyprus," *Energies*, vol. 14, no. 22, Jan. 2021, Art. no. 7627, https://doi.org/10.3390/en14227627.

[15] S. Abbasoglu, "Techno-economic and environmental analysis of PV power plants in Northern Cyprus," *Energy Education Science and Technology Part A: Energy Science and Research*, vol. 28, pp. 357–368, Oct. 2011.

[16] M. Yenen, F. Ercan, and M. Fahrioglu, "Solar Thermal System Analysis of Northern Cyprus," presented at the EECS'12 - 7th International Symposium on Electrical and Computer Systems, Nov. 2012, https://doi.org/10.13140/2.1.5088.9601.

[17] C. O. Okoye and U. Atikol, "A parametric study on the feasibility of solar chimney power plants in North Cyprus conditions," *Energy Conversion and Management*, vol. 80, pp. 178–187, Apr. 2014, https://doi.org/10.1016/j.enconman.2014.01.009.

[18] F. Maltini and R. Minder, "The Serhatkoy photovoltaic power plant and the future of renewable energy on the Turkish Republic of Northern Cyprus: Integrating solar photovoltaic and wind farms into electricity transmission and distribution networks," in *Eco-Friendly Innovation in Electricity Transmission and Distribution Networks*, J.-L. Bessede, Ed. Sawston, UK: Woodhead Publishing, 2015, pp. 377–402.

[19] O. C. Ozerdem, S. Tackie, and S. Biricik, "Performance evaluation of Serhatkoy (1.2 MW) PV power plant," in *9th International Conference on Electrical and Electronics Engineering*, Bursa, Turkey, Nov. 2015, pp. 398–402, https://doi.org/10.1109/ELECO.2015.7394510.

[20] S. Kamali, "Feasibility analysis of standalone photovoltaic electrification system in a residential building in Cyprus," *Renewable and Sustainable Energy Reviews*, vol. 65, pp. 1279–1284, Nov. 2016, https://doi.org/10.1016/j.rser.2016.07.018.

[21] M. Dagbasi, O. Bamisile, and C. Adii, "The techno-economic comparison of solar power generation methods for Turkish Republic of North Cyprus," in *HONET-ICT*, Nicosia, Cyprus, Oct. 2016, pp. 17–23, https://doi.org/10.1109/HONET.2016.7753430.

[22] N. Cabacaba and S. Abbasoglu, "Evaluation of Wind–Solar Hybrid System for a Household in Northern Cyprus," in *Towards 100%*

Renewable Energy, New York, NY, USA, 2017, pp. 313–321, https://doi.org/10.1007/978-3-319-45659-1_34.

[23] Y. Kassem and H. Gokcekus, "GHG Emissions and Energy Performance of 1MW Grid-Connected Solar PV Plant at Lefke In Northern Cyprus: Case Study," *Disaster Science and Engineering*, vol. 4, no. 2, pp. 90–98, Dec. 2018.

[24] M. Ouria and H. Sevinc, "Evaluation of the potential of solar energy utilization in Famagusta, Cyprus," *Sustainable Cities and Society*, vol. 37, pp. 189–202, Feb. 2018, https://doi.org/10.1016/j.scs.2017.10.036.

[25] L. Al-Ghussain, M. Abujubbeh, and M. Fahrioglu, "Assessment of PV investments in Northern Cyprus," in *16th International Conference on Clean Energy*, Famagusta, N. Cyprus, Dec. 2018, pp. 1–5.

[26] M. Hastunc and N. Tekbıyık-Ersoy, "Optimizing Residential Renewable Energy Utilization in North Cyprus: Case Study of Solar Energy," in *16th International Conference on Clean Energy*, Famagusta, N. Cyprus, Dec. 2018, pp. 1–8.

[27] 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, Art. no. 47, https://doi.org/10.3390/environments6040047.

[28] Y. Kassem, H. Gokcekus, and S. M. Alsayas, "Freestanding PV solar system- -example of Lefke town in Northern Cyprus," *International Journal of Applied Engineering Research*, vol. 14, no. 11, pp. 2522–2526, 2019.

[29] J. E. Ogbeba and E. Hoskara, "The Evaluation of Single-Family Detached Housing Units in terms of Integrated Photovoltaic Shading Devices: The Case of Northern Cyprus," *Sustainability*, vol. 11, no. 3, Jan. 2019, Art. no. 593, https://doi.org/10.3390/su11030593.

[30] Y. Kassem, H. Gokcekus, and A. Guvensoy, "Solar Potential assessment in Near East University, Northern Cyprus," *International Journal of Engineering Research and Technology*, vol. 12, no. 12, pp. 3061–3069, 2019.

[31] H. Gökçekuş, Y. Kassem, and S. Abdi, "Simulation and performance analysis of 110 KWP grid-connected photovoltaic (PV) systems for residential building in Northern Cyprus," *International Journal of Innovative Technology and Exploring Engineering*, vol. 8, no. 8, pp. 3082–3091, 2019.

[32] H. Oner, "Economic feasibility assessment of solar powered seawater desalination plants: Unconventional fresh water supply for Guzelyurt, Northern Cyprus," M.S. thesis, Middle East Technical University, Ankara, Turkey, 2019.

[33] L. Al-Ghussain and O. Taylan, "Sizing methodology of a PV/wind hybrid system: Case study in cyprus," *Environmental Progress & Sustainable Energy*, vol. 38, no. 3, 2019, Art. no. e13052, https://doi.org/10.1002/ep.13052.

[34] Y. Kassem, H. Gokcekus, and U. Burcu Filitoglu, "Performance Characteristics of Building Integrated and Freestanding Photovoltaic System with Various PV Technologies and Angles: A Case Study in NEU Grand Library, North Nicosia," *Journal of Engineering and Applied Sciences*, vol. 15, no. 4, pp. 1027–1042, Nov. 2019, https://doi.org/10.36478/jeasci.2020.1027.1042.

[35] 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, Jan. 2020, Art. no. 940, https://doi.org/10.3390/en13040940.

[36] F. Al-Turjman, Z. Qadir, M. Abujubbeh, and C. Batunlu, "Feasibility analysis of solar photovoltaic-wind hybrid energy system for household applications," *Computers & Electrical Engineering*, vol. 86, Sep. 2020, Art. no. 106743, https://doi.org/10.1016/j.compeleceng.2020.106743.

[37] Y. Kassem, H. Gokcekus, A. Iravanian, and R. Gokcekus, "Predictive suitability of renewable energy for desalination plants: the case of güzelyurt region in northern Cyprus," *Modeling Earth Systems and Environment*, vol. 8, no. 3, pp. 3657–3677, Sep. 2022, https://doi.org/10.1007/s40808-021-01315-0.

[38] M. H. Rasool, S. M. M. Raza, M. Musadiq, and A. Zarrar, "IoT Based Enhanced Techno-Economic Feasibility of Photovoltaic-Battery System for a Household in Northern Cyprus," in *International Conference on Artificial Intelligence of Things*, Nicosia, Turkey, Sep. 2021, pp. 43–48, https://doi.org/10.1109/ICAIoT53762.2021.00015.

[39] Y. C. N. Duarte and P. C. Sentelhas, "NASA/POWER and DailyGridded weather datasets—how good they are for estimating maize yields in Brazil?," *International Journal of Biometeorology*, vol. 64, no. 3, pp. 319–329, Mar. 2020, https://doi.org/10.1007/s00484-019-01810-1.

[40] L. A. Monteiro, P. C. Sentelhas, and G. U. Pedra, "Assessment of NASA/POWER satellite-based weather system for Brazilian conditions and its impact on sugarcane yield simulation," *International Journal of Climatology*, vol. 38, no. 3, pp. 1571–1581, 2018, https://doi.org/10.1002/joc.5282.

[41] 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.

[42] Y. Kassem and M. H. A. Abdalla, "Modeling predictive suitability to identify the potential of wind and solar energy as a driver of sustainable development in the Red Sea state, Sudan," *Environmental Science and Pollution Research*, vol. 29, no. 29, pp. 44233–44254, Jun. 2022, https://doi.org/10.1007/s11356-022-19062-9.

[43] Y. Zhang, J. Ren, Y. Pu, and P. Wang, "Solar energy potential assessment: A framework to integrate geographic, technological, and economic indices for a potential analysis," *Renewable Energy*, vol. 149, pp. 577–586, Apr. 2020, https://doi.org/10.1016/j.renene.2019.12.071.

[44] R. Pravalie, C. Patriche, and G. Bandoc, "Spatial assessment of solar energy potential at global scale. A geographical approach," *Journal of Cleaner Production*, vol. 209, pp. 692–721, Feb. 2019, https://doi.org/10.1016/j.jclepro.2018.10.239.

[45] T. R. Ayodele, "Determination of Probability Distribution Function for Modelling Global Solar Radiation: Case Study of Ibadan, Nigeria," *International Journal of Applied Science and Engineering*, vol. 13, no. 3, pp. 233–245, 2015, https://doi.org/10.6703/IJASE.2015.13(3).233.

[46] S. Pashiardis, S. A. Kalogirou, and A. Pelengaris, "Statistical analysis for the characterization of solar energy utilization and inter-comparison of solar radiation at two sites in Cyprus," *Applied Energy*, vol. 190, pp. 1138–1158, Mar. 2017, https://doi.org/10.1016/j.apenergy.2017.01.018.

[47] S. A. Kalogirou, S. Pashiardis, and A. Pashiardi, "Statistical analysis and inter-comparison of erythemal solar radiation for Athalassa and Larnaca, Cyprus," *Renewable Energy*, vol. 111, pp. 580–597, Oct. 2017, https://doi.org/10.1016/j.renene.2017.04.043.

[48] S. Singh, M. Singh, and S. C. Kaushik, "Feasibility study of an islanded microgrid in rural area consisting of PV, wind, biomass and battery energy storage system," *Energy Conversion and Management*, vol. 128, pp. 178–190, Nov. 2016, https://doi.org/10.1016/j.enconman.2016.09.046.

[49] M. H. Amrollahi and S. M. T. Bathaee, "Techno-economic optimization of hybrid photovoltaic/wind generation together with energy storage system in a stand-alone micro-grid subjected to demand response," *Applied Energy*, vol. 202, pp. 66–77, Sep. 2017, https://doi.org/10.1016/j.apenergy.2017.05.116.

[50] J. Zhang, H. Cho, R. Luck, and P. J. Mago, "Integrated photovoltaic and battery energy storage (PV-BES) systems: An analysis of existing financial incentive policies in the US," *Applied Energy*, vol. 212, pp. 895–908, Feb. 2018, https://doi.org/10.1016/j.apenergy.2017.12.091.

[51] O. C. Akinsipe, D. Moya, and P. Kaparaju, "Design and economic analysis of off-grid solar PV system in Jos-Nigeria," *Journal of Cleaner Production*, vol. 287, Mar. 2021, Art. no. 125055, https://doi.org/10.1016/j.jclepro.2020.125055.

[52] A. F. Crossland, O. H. Anuta, and N. S. Wade, "A socio-technical approach to increasing the battery lifetime of off-grid photovoltaic systems applied to a case study in Rwanda," *Renewable Energy*, vol. 83, pp. 30–40, Nov. 2015, https://doi.org/10.1016/j.renene.2015.04.020.

[53] M. Bortolini, M. Gamberi, and A. Graziani, "Technical and economic design of photovoltaic and battery energy storage system," *Energy Conversion and Management*, vol. 86, pp. 81–92, Oct. 2014, https://doi.org/10.1016/j.enconman.2014.04.089.

[54] A. K. Shukla, K. Sudhakar, and P. Baredar, "Design, simulation and economic analysis of standalone roof top solar PV system in India,"

Solar Energy, vol. 136, pp. 437–449, Oct. 2016, https://doi.org/10.1016/j.solener.2016.07.009.

[55] A. Ghafoor and A. Munir, "Design and economics analysis of an off-grid PV system for household electrification," *Renewable and Sustainable Energy Reviews*, vol. 42, pp. 496–502, Feb. 2015, https://doi.org/10.1016/j.rser.2014.10.012.

[56] S. Rehman, Md. Mahbub Alam, J. P. Meyer, and L. M. Al-Hadhrami, "Feasibility study of a wind–pv–diesel hybrid power system for a village," *Renewable Energy*, vol. 38, no. 1, pp. 258–268, Feb. 2012, https://doi.org/10.1016/j.renene.2011.06.028.

[57] M. L. Kolhe, K. M. I. U. Ranaweera, and A. G. B. S. Gunawardana, "Techno-economic sizing of off-grid hybrid renewable energy system for rural electrification in Sri Lanka," *Sustainable Energy Technologies and Assessments*, vol. 11, pp. 53–64, Sep. 2015, https://doi.org/10.1016/j.seta.2015.03.008.

[58] A. S. Werulkar and P. S. Kulkarni, "A case study of residential solar photovoltaic system with utility backup in Nagpur, India," *Renewable and Sustainable Energy Reviews*, vol. 52, pp. 1809–1822, Dec. 2015, https://doi.org/10.1016/j.rser.2015.07.195.

[59] M. M. Rahman, A. K. M. S. Islam, S. Salehin, and M. A. Al-Matin, "Development of a Model for Techno-economic Assessment of a Stand-alone Off-grid Solar Photovoltaic System in Bangladesh," *International Journal of Renewable Energy Research*, vol. 6, no. 1, pp. 140–149, Mar. 2016.

[60] M. Said, M. EL-Shimy, and M. A. Abdelraheem, "Photovoltaics energy: Improved modeling and analysis of the levelized cost of energy (LCOE) and grid parity – Egypt case study," *Sustainable Energy Technologies and Assessments*, vol. 9, pp. 37–48, Mar. 2015, https://doi.org/10.1016/j.seta.2014.11.003.

[61] K. Y. Kebede, "Viability study of grid-connected solar PV system in Ethiopia," *Sustainable Energy Technologies and Assessments*, vol. 10, pp. 63–70, Jun. 2015, https://doi.org/10.1016/j.seta.2015.02.003.

[62] 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.

[63] Y. Kassem, H. Gokcekus, and H. S. A. Lagili, "A Techno-Economic Viability Analysis of the Two-Axis Tracking Grid-Connected Photovoltaic Power System for 25 Selected Coastal Mediterranean Cities," *Engineering, Technology & Applied Science Research*, vol. 11, no. 4, pp. 7508–7514, Aug. 2021, https://doi.org/10.48084/etasr.4251.

[64] A. Awasthi *et al.*, "Review on sun tracking technology in solar PV system," *Energy Reports*, vol. 6, pp. 392–405, Nov. 2020, https://doi.org/10.1016/j.egyr.2020.02.004.

[65] M. K. Shahzad, A. Zahid, T. ur Rashid, M. A. Rehan, M. Ali, and M. Ahmad, "Techno-economic feasibility analysis of a solar-biomass off grid system for the electrification of remote rural areas in Pakistan using HOMER software," *Renewable Energy*, vol. 106, pp. 264–273, Jun. 2017, https://doi.org/10.1016/j.renene.2017.01.033.

[66] Pal and V. Mukherjee, "Off-grid solar photovoltaic/hydrogen fuel cell system for renewable energy generation: An investigation based on techno-economic feasibility assessment for the application of end-user load demand in North-East India," *Renewable and Sustainable Energy Reviews*, vol. 149, Oct. 2021, Art. no. 111421, https://doi.org/10.1016/j.rser.2021.111421.

[67] Z. Said, A. Mehmood, A. Waqas, A. Amine Hachicha, and R. Loni, "Central versus off-grid photovoltaic system, the optimum option for the domestic sector based on techno-economic-environmental assessment for United Arab Emirates," *Sustainable Energy Technologies and Assessments*, vol. 43, Feb. 2021, Art. no. 100944, https://doi.org/10.1016/j.seta.2020.100944.

[68] R. Bakhshi and J. Sadeh, "Economic evaluation of grid–connected photovoltaic systems viability under a new dynamic feed–in tariff scheme: A case study in Iran," *Renewable Energy*, vol. 119, pp. 354–364, Apr. 2018, https://doi.org/10.1016/j.renene.2017.11.093.

[69] B. Karapinar, H. Dudu, O. Geyik, and A. M. Yakut, "How to reach an elusive INDC target: macro-economic implications of carbon taxation and emissions trading in Turkey," *Climate Policy*, vol. 19, no. 9, pp. 1157–1172, Oct. 2019, https://doi.org/10.1080/14693062.2019.1635875.

[70] A. C. Duman and O. Guler, "Economic analysis of grid-connected residential rooftop PV systems in Turkey," *Renewable Energy*, vol. 148, pp. 697–711, Apr. 2020, https://doi.org/10.1016/j.renene.2019.10.157.