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GHG EMISSIONS AND ENERGY PERFORMANCE OF 1MW GRID-CONNECTED SOLAR PV PLANT AT LEFKE IN NORTHERN CYPRUS: CASE STUDY

Youssef Kassem*[1], Hüseyin Gökçekuş[1]

ABSTRACT

The present study aimed to evaluate and analyze the techno-economic of proposing a 1MW grid-connected PV power plant in Lefke town. The potential of proposed a PV plant was also assessed from environmental viewpoints by calculating the annual total amount of CO2. Three different tracking systems (Open surface, Vertical-axis, and Two-axis) were investigated. The analysis showed that the LCOE for an Open surface, Vertical-axis, and Two-axis tracking systems were 0.150$/kWh, 0.115$/kWh and 0.109$/kWh, respectively. The resulting GHG emissions were varied between 1321 and 1829 tCO2/year while the energy performance, assessed as EP, was varied between 11.2 and 16.8 years. This study concluded that the PV plant could be used as a viable alternative to reduce the GHG emissions in Northern Cyprus and generating electricity from environmentally friendly scours.
Keywords: Economic viability; GHG emissions; Lefke town; PV power plant; Sun-tracking systems.

1. INTRODUCTION

One of the most critical issues in the world is global warming [1]. The amount of carbon dioxide (CO_2) emission are increasing significantly and can be considered as the primary pollutant responsible for the greenhouse gas (GHG) emission according to the World Bank Report [2].
Furthermore, according to the IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [3], generating electricity from renewable energies such as wind or solar power offers significant potential for reducing GHG emissions. Solar energy is an essential source for reducing the greenhouse gas emissions and consumption of fossil fuel [4-6]. Also, solar energy is clean, environmentally friendly and inexhaustible energy source [7,8]. Sunlight can be converted directly into electricity using solar photovoltaic (PV) [9]. It is a considerable power source for meeting electricity demand in many countries [10-12].
In Northern Cyprus, the electricity is currently produced using diesel generators power stations and PV power plant, which installed in Serhatköy with the capacity of 212MW and 1.27MW, respectively [13,14]. Moreover, the growth of the population has led to an increase in energy demand, where nearly all of the energy production is currently dependent on fossil fuels. Increasing demand in conventional sources has encouraged the authors to investigate in the field of renewable energy sources especially solar energy for electricity generating in Northern Part of Cyprus.
The main objective of this study is to evaluate the economic and environmental effects of solar energy that influence electricity cost and CO_2 emission in most of the regions, in particular, the case study of Lefke town.

* Corresponding Author: yousseuf.kassem@neu.edu.tr
[1] Near East University, Faculty of Engineering, Nicosia / TRNC Mersin 10 - Turkey

2. LEFKE, NORTHERN CYPRUS

Lefke is a small town whose outer margins encompass a stretch of picturesque coastline in the north west of Cyprus and situated on the northern foot of the Troodos Mountains. It is surrounded by the green covered mountains with its cool climate in summer and rather cold in the winter due to being close to the high range of mountains. Lefke is geographically located at a Latitude: 35.11199 N, Longitude: 32.84997 E and the elevation from the sea level is about 129m. The total area of the lefke town is about 15.9 km² (3928acres). The location of the city is also shown in Figure 1.

Figure 1. The geographic location of the study area

Figure 2 shows that wind speeds are mostly seen south part of Cyprus and only on the top of the Beşparmak Mountains in the north part. Additionally, it is noticed that the average wind speeds in Lefke are ranged from 2.75m/s to 2m/s. Furthermore, Figure 3 demonstrates that Cyprus has a huge solar potential compared to wind energy. It can be seen that global horizontal irradiation in Lefke is ranged from 2000kW/m2 to 2100kW/m2. Photovoltaic system implementation still limited in Cyprus but a substantial solar use as sources for generating electricity.

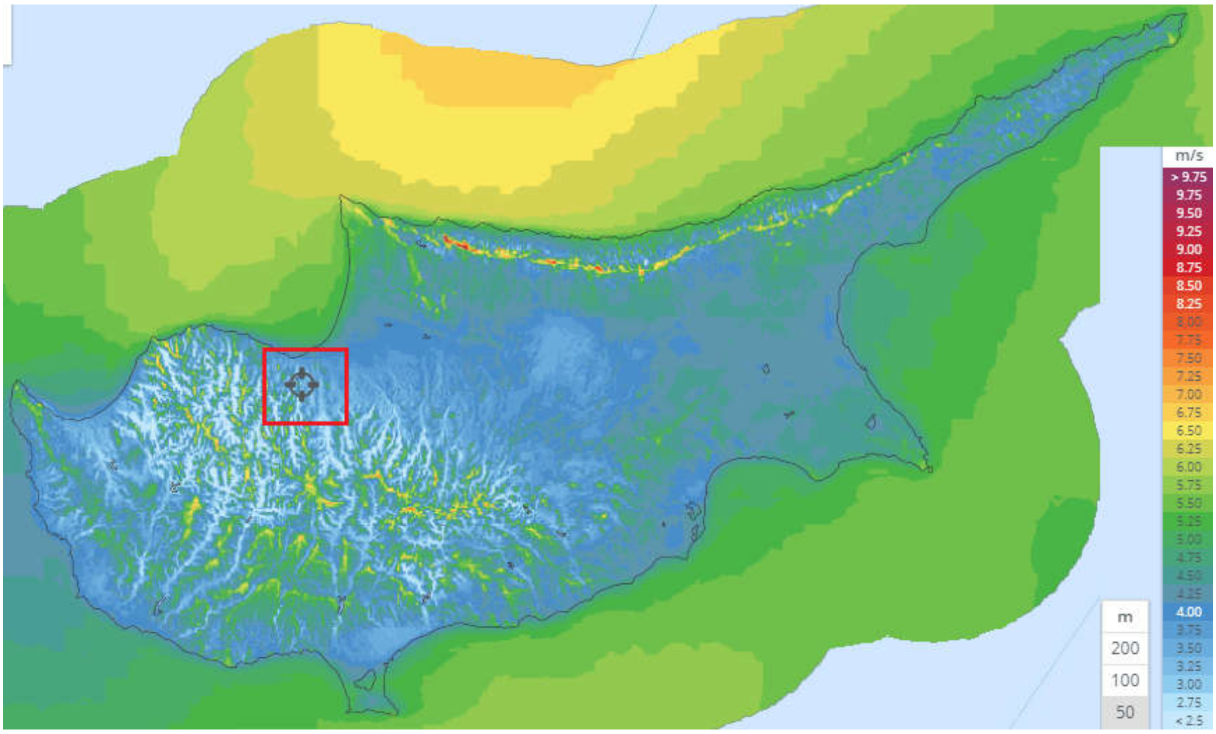

Figure 2. Wind atlas for Cyprus at 50m height

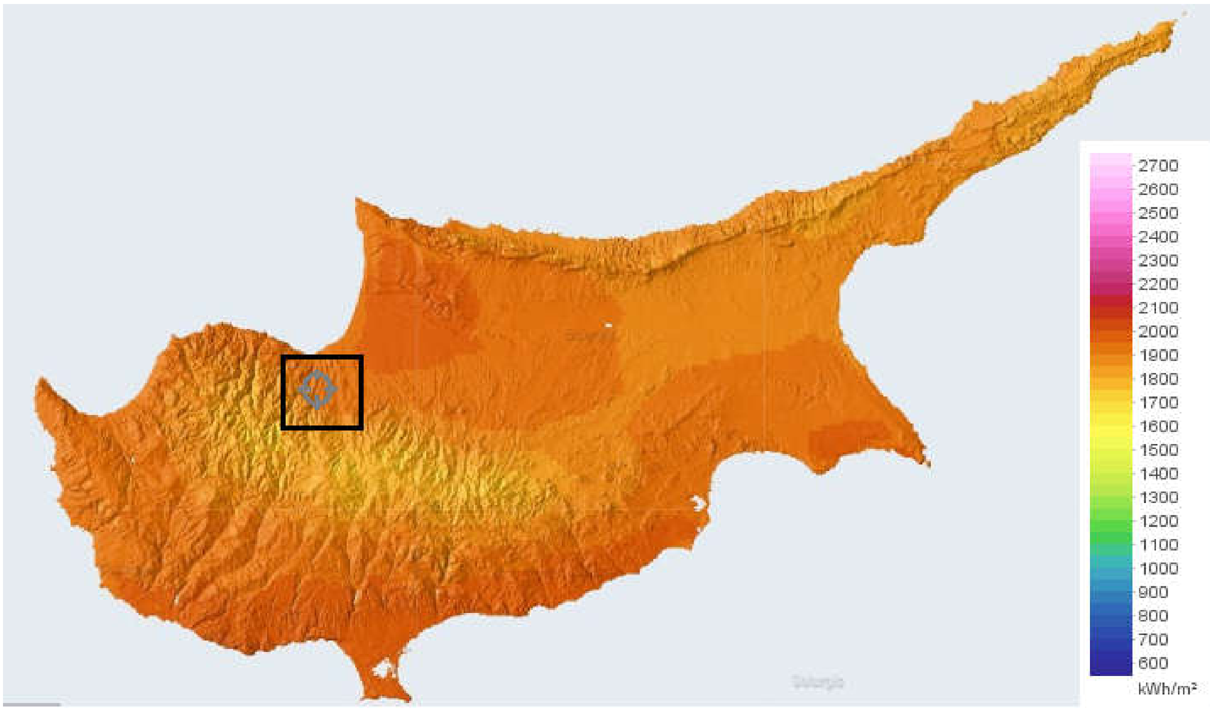

Figure 3. Solar atlas for Cyprus

3. SOLAR PLANT PROJECT: CASE STUDY

3.1. Component of Solar Plant

The parts of the grid-connected solar PV plants (according to [15]) are

- **Solar module:** the present solar module manufacturing industries produce different types of solar panels categorized based on materials used. However, in the large-scale PV plant installations, crystalline solar modules are widely used.
- **Inverters:** inverters are chosen based on the rating of the solar power plant.
- **Mountings:** include structures on which PV panels, inverters, and other accessories are placed. Mounting of PV panels is a major one to be considered here, make sure that they are mounted in optimal angles as per the site conditions.
- **Grid connection:** includes sub-station and its components like transformers, net metering systems, protection systems, etc.
- **DC/AC cables:** cables are required for connecting panels, inverter and to the grid.

3.2 Plant layout

A total area of lefke is around 15.9 km^2 (3928acres). A typical 1 MW solar PV plant requires 5 acres (20234m^2 or 0.02km^2) of the land area, 4284 PV panels each having the 235W capacity by Yingli Solar make, four THEIA series inverters each rated at 250 kW, and two power transformers.

3.3 Tilt angle

The tilt angle proposed for the solar PV plant is almost very close to the latitude of the location, as it is best for the maximum absorption of the solar radiation. The tilt angle for this proposed plant is considered as the optimized value from the simulation study carried out in PVGIS software tool.

3.4 Solar panel and Inverter

The proposed solar panel for 1MW PV plant is a crystalline one. Mono-Si - Panda - YL265C-30b PV (265W) module, manufactured by Yingli Solar Company was chosen as it is an efficient PV module. The specification of the used module is given in Ref. [16]. To build the 1MW grid-connected PV plant, a total of 4100 PV panels are required. The proposed inverter for a 1MW solar power plant is a THEIA series inverter (the specification of the used inverter is shown in Ref. [17]). Four units of central inverters with a capacity of each inverter is 250kW, were used for the proposed PV power plant.

3.5 Solar resource potential variation using PVGIS simulation tool

In this study, the solar resource potentials at the selected location are taken from the radiation databases available from the PVGIS. During the PV plant modeling in PVGIS simulation tool, solar radiation considered is from the PVGIS-CMSAF database.

To simulate using PVGIS, few assumptions and inputs were applied. The Latitude and Longitude for the selected location are Latitude: 35.11199 and Longitude: 32.84997 for Lefke. Figure 3 shows the framework of the simulation study using PVGIS carried out on the 5MW solar PV plant. Table 1 is summarized the input and output results of PVGIS software. PVGIS allows the user to input the parameters required for RETScreen software such as slope or tilt angle and azimuth angle of the PV module.

Considering the PVGIS Simulation, maximum solar radiation potential at Lefke is achieved in the month of July, i.e. 239 kWh/m^2 for Fixed, 343kWh/m^2 for Vertical-axis tracking system and 363 kWh/m^2 for two-axis tracking system, followed by August, i.e. 237 kWh/m^2 for open surface, 325kWh/m^2 for Vertical-axis tracking system and 339 kWh/m^2 for Two-axis tracking system. The minimum potential is observed in January, i.e., 126 kWh/m^2 for Fixed, 156kWh/m^2 for the Vertical-axis tracking system and 159 kWh/m^2 for the Two-axis tracking system. It can be concluded that the use of the Two-axis-tracking system had maximum annual solar irradiation and energy production compared to Vertical-axis and fixed (open surface) mounting options as shown in Table 1 and Figure 4.

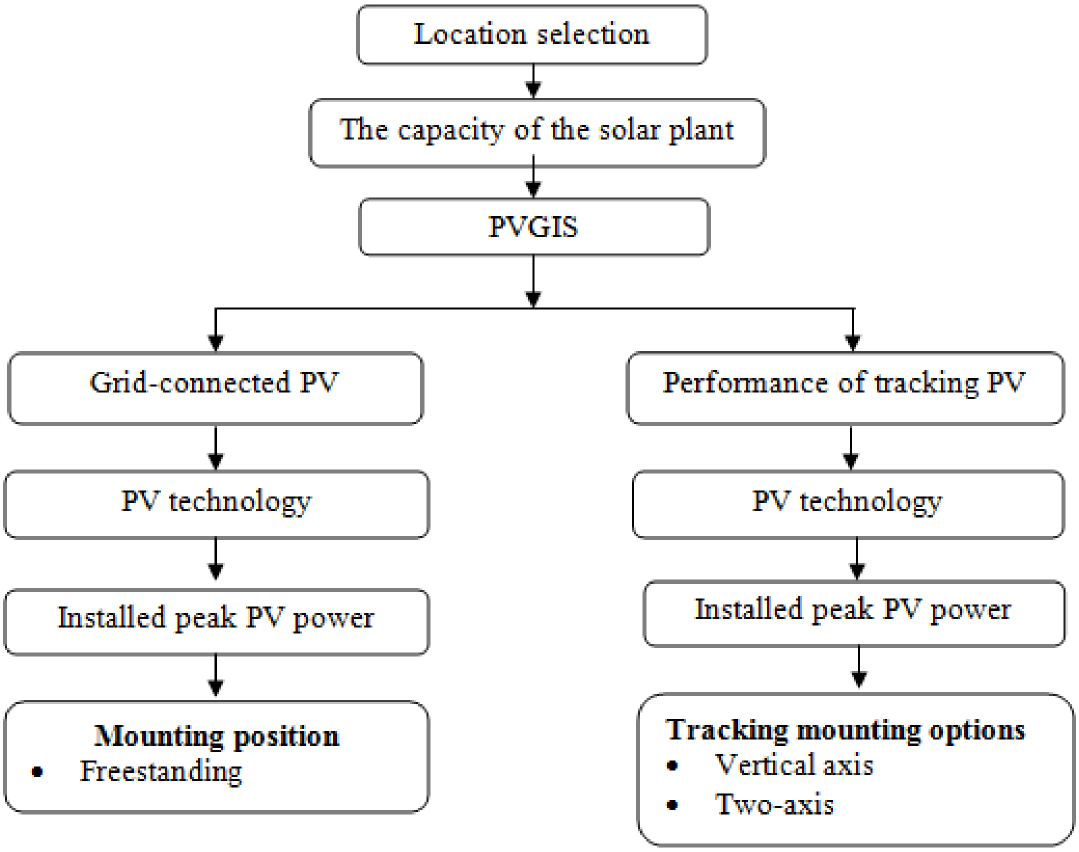

Figure 3. The framework of the simulation study using PVGIS

Table 1. Summary of grid-connected performance of 5-MW PV plant using PVGIS

Input			
Location [Lat/Lon]	35112 32.850	**PV technology**	Crystalline silicon
Database used	PVGIS-CMSAF	**System loss [%]**	14%
Simulation output of tracking mode			
Parameters	**Fixed (open surface**	**Vertical-axis**	**Two-axis**
Slope angle [°]	31	52	-
Azimuth angle [°]	-11	-	-
Yearly PV energy production [MWh]	1760	2350	2430
Yearly in-plane irradiation [kWh/m^2]	2280	3030	3150

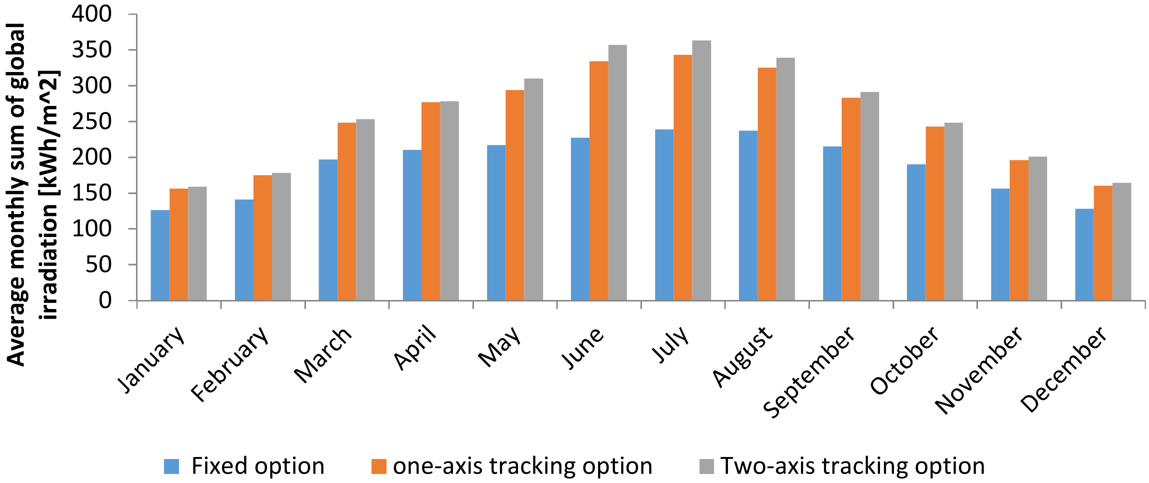

Figure 4. Monthly in-plane irradiation for Lefke at various mounting options

4. ECONOMIC ANALYSIS

In this study, the economic analysis of 1MW grid-connect PV power plants is done according to the technical, economic parameters (Table 2), which assumed based on previous scientific research [9,10,18].

Table 2. Parametric cost–benefit analysis data and assumptions

Parameters	Value
Technical data	
Plant capacity	1000kW
Annual solar potential	See Table 1
PV module type	Mono-Si -
Losses	15%
Capital data	
Specific capital cost	1000-8000Euro/kW
O&M cost	
Open surface	1.5 c$/kWh
Vertical-axis	1.8 c$/kWh
Two-axis	1.8 c$/kWh
Other parameters	
Inflation rate	7
Discount rate	6
Project life	25
Electricity export escalation rate	5

RETScreen software is used to estimate the important economic measures, which are:
Net present value (NPV)

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

Levelized cost of energy (LCOE)

$$LCOE = \frac{sum\ of\ cost\ over\ lifetime}{s\ of\ electricity\ generated\ over\ the\ lifetime} \quad (2)$$

The internal rate of return (IRR)

$$O = \sum_{n=0}^{N} \frac{C_n}{(1+IRR)^n} \quad (3)$$

Simple payback (SP)

$$SP = \frac{C - IG}{\left(C_{ener} + C_{capa} + C_{RE} + C_{GHG}\right) - \left(C_{o\&M} + C_{fuel}\right)} \quad (4)$$

Equity payback (EP)

$$EP = \sum_{n=0}^{N} C_n \quad (5)$$

Annual life cycle savings (ALCS)

$$ALCS = \frac{NPV}{\frac{1}{r}\left(1 - \frac{1}{(1+r)^N}\right)} \quad (6)$$

GHG emission reduction cost (GRC)

$$GRC = \frac{ALCS}{\Delta_{GHG}} \quad (7)$$

Benefit-Cost ratio (B-C)

$$B - C = \frac{NPV + (1 - f_d)C}{(1 - f_d)C} \quad (8)$$

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

The annual capacity factor and generated electricity of the proposed project for different tracking system are shown in Table 3. It is observed that the highest generated electricity and CF is obtained from the two-axis tracking system, while, the lowest one obtained from the open surface system as shown in Table 3.

Furthermore, Table 3 summarized the results of the economic performance of the 1MW PV plants. The results showed that the proposed 1MW PV plants power is very promising in the selected location due to the obtained results of economic performance. Additionally, it is noticed that the highest value of NPV, BCR, ALCS, and IRR, as well as the lowest values of EB, SB, and LCOE values, are obtained from the Two-axis tracking system. Thus, it can be concluded that the most economical option for generating electricity in the studied town is PV power plant with a Two-axis tracking system.

Table 3. Capacity factor, generated electricity, and economic performance of 1MW PV plant

Tracking mode	CF [%]	Generated electricity [MWh/year]		Electricity export revenue [$]		
Open surface	19.0	1804		180374		
Vertical-axis	24.9	2368		236829		
Two-axis	26.2	2498		249758		
Economic performance							
Tracking mode	**NPV [$]**	**EPB [year]**	**SPB [year]**	**LCOE [$/kWh]**	**BCR**	**ALCS [$/year]**	**IRR [%]**
Open surface	532558	16.8	18.2	0.150	1.5	41660	8.1
Vertical-axis	1772752	12.3	13.9	0.115	2.8	138677	12.9
Two-axis	2059164	11.2	13.2	0.109	3.1	161082	14

5. ENVIRONMENTAL EFFECTS

Greenhouse gas (GHG) emission of the proposed renewable projects in terms of total amount of annual GHG reduction in terms of tons of CO_2 per year (tCO_2/year) and cost ($/$tCO_2$) were estimated using RETScreen software. The total amount and cost of GHG that could be reduced with PV plants are shown in Table 4. The obtained results demonstrated that a significant amount of CO_2 could be reduced by the proposed projects in the studied location. It can be observed that the maximum total amount of CO_2 that can be reduced with the proposed projects obtained from the PV plants for two-axis tracking with the value of 1829 tCO_2/year.

Table 4. GHG reduction

Project	Gross GHG reduction [tCO_2/year]	Gross GHG reduction [tCO_2]	GHG reduction cost [$/$tCO_2$]
Fixed	1321	33024	32
Vertical-axis	1734	43361	80
Two-axis	1829	45728	88

6. CONCLUSIONS

The present study was aimed to evaluate the feasibility of proposed 1MW grid-connected PV power plants in Lefke town. To fulfill this objective, PVGIS was used to find the optimal angles for sun tracking systems. Besides, LCOE and GHG reduction of PV plants were calculated using RETScreen software. The simulation results demonstrated that the maximum and minimum generated electricity are obtained from the Two-axis tracking system and Fixed-axis (open surface) system, respectively. Moreover, Based on RETScreen results, it is found that the lowest LCOE is obtained from the Two-axis tracking system. Furthermore, the obtained results showed that a significant amount of CO_2 could be reduced by the proposed PV power plants in the studied location. Overall, development of grid-connected PV power plant in the Northern part of Cyprus shows huge potential and actual market opportunity for investors.

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