Feasibility Study of a Small-Scale Grid-Connected PV Power Plants in Egypt; Case Study: New Valley Governorate

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***Abstract*—The construction of photovoltaic power plants (PVPPs) in the right place is an important task when planning the development of the power system and choosing investors. In this paper, the technical, environmental, the economic feasibility of installing a 50kW solar power plant in different places in the New Valley Governorate in Egypt has been presented using RETScreen Expert software. The input data used in the current study are obtained from the database of the Surface Meteorology and Solar Energy Dataset of NASA. In general, five sites for the construction of 50 kW power stations were assessed which represent the five administrative regions of the New Vally governorate. The study is based on annual electricity production, greenhouse gas (GHG) emissions, and financial analysis. With the proposed PV power plant, up to 100 MWh of electricity can be produced and a minimum of 43.3 tons of GHG emission can be prevented from the exhaust into the local atmosphere annually The obtained results from the RETScreen program proved the viability of installing the proposed 50kW photovoltaic power plant in any of the proposed locations. This study could give a piece of important information and feedback that can be utilized as a database for upcoming investments in the photovoltaic generation projects in Egypt.**

Keywords—RETScreen; new valley; solar energy; energy cost; feasibility analysis; greenhouse gases

I. Introduction

Renewable Energy is the energy that can be extracted and derived from renewable natural resources or that cannot be exhausted or developed (sustainable energy). There are several fundamental differences between renewable energy sources (RES) and fossil fuels, which include "coal, natural gas, and petroleum" or "nuclear fuel that can be used in nuclear reactors". Usually, new and renewable energy does not generate harmful wastes such as carbon dioxide or harmful gases or increase the danger regarding global warming, compared to what can happen when burning fossil fuels or harmful atomic waste and waste from nuclear power reactors Renewable energy can be produced from the sun and wind. And water [1]. It can also be produced from tidal movements and waves, or geothermal energy, in addition to some productive trees and agricultural crops.

Renewable energy has several advantages and benefits, direct or indirect, summarized in the following points: Renewable energy is not running out; It can also provide clean energy free of waste; it aims to protect human health; it can preserve the natural environment; it has Low production cost; it can improve human livelihood and reducing poverty; it can secure new job opportunities. Moreover, renewable energy has extra advantages like Reducing harmful gaseous and heat emissions and their dangerous consequences; Reducing greenhouse gas emissions and harmful heat and their dangerous consequences [2]; Reduced numbers and risks of natural disasters resulting from global warming; Not to form acid rain that harms all crops, agricultural products, and all different life forms; offering a significant reduction in the formation and accumulation of harmful waste in all its forms (gaseous, liquid and solid); Protecting all living organisms, especially the endangered species; Protecting groundwater, seas, rivers, and fisheries from the risk of pollution; Contribute to ensuring food security; In addition to increasing the productivity of agricultural crops as a result of eliminating chemical and gaseous pollutants [3].

The sun is one of the largest sources of light and heat on the face of the earth, and this energy is distributed over the parts of the earth according to its proximity to the equator, and this line is the area that receives the largest share of that energy, and the thermal energy generated by the sun's rays is used by converting it into (energy Electricity) by panels (solar cells). There are also two methods of collecting solar energy. The first one is that the sun’s rays are focused on a collector employing convex mirrors. The collector usually consists of several tubes containing water or air [4]. The sun’s heat heats the air or turns water into steam. The second method, in which a level plate collector absorbs the sun's heat, uses the heat to produce hot air or steam.

The geographical location of the Arab Republic of Egypt is between latitudes 22 and 31.5 north, and as a result, Egypt is located in the depth and value of the global sunbelt. As a result, Egypt has been considered one of the world's richest countries with solar energy [4]. Where the Ministry of Electricity and Energy conducted a lot of research and studies to determine and clarify the characteristics of solar radiation in the Arab Republic of Egypt, which resulted in updating information, data, and statistics that were provided by meteorological stations and centers and adding many new stations and modern measuring devices. According to the various economic events and developments that Egypt has gone through during the modern era and their clear impact on the projects implemented in the field of renewable energy, and as a result of the flexibility of adequate strategies to keep pace with the changes and developments. Events, its renewable energy strategy has been implemented and adjusted to target 20% of the total production of energy during 2022 [2, 5, 6]. The energy sector in Egypt (electricity, renewable energy, and petroleum) has prepared a study for the optimal combination of technically and economically for energy production until 2035 in cooperation with the European Union through the Technical Support Program for the Restructuring of the Energy Sector in Egypt (TARES) [6]. The project included several parts, the most important of which was supporting the sustainable and integrated energy strategy in Egypt until 2035.

This study includes a set of scenarios for the energy mix with different assumptions to assess the impact of the introduction of renewable energies in different proportions to the electricity generation mix from a technical and economic perspective, to choose the optimal scenario. In October 2016, the Supreme Council of Energy approved the Egyptian Energy Strategy until 2035 and chose Scenario (4-B) as the reference for energy planning in Egypt during the coming period [7], which aims to reach the percentage of renewable energy contribution to 42% of the total amount of electricity production by 2035.

RETScreen simulation program is a clean energy management software that is used for energy efficiency studies and feasibility assessment of renewable energy cogeneration projects and performing the required analysis for energy performance [8]. This program empowers professionals and decision-makers to quickly point out, evaluate and optimize the viability of renewable clean energy projects from the technical and financial sides. RETScreen software also makes it easy for managers to estimate and verify the real performance of their projects and helps them to obtain supplementary energy savings/production opportunities. RETScreen program has been utilized in many research papers. In [9] the feasibility study of a 100MW photovoltaic power station at Bati, Ethiopia has been conducted and the results showed that 2365.3 tCO_2 will be reduced to be exhausted into the environment. In [10], the assessment of solar energy potential in Algeria has been evaluated. In this study, 61 different sites have been evaluated and the results showed that the southern regions of the country have a great solar energy potential. In [11], the pre-feasibility study of nine small-scale hydropower plants in Turkey has been evaluated, and the obtained results were compared with those reported in State Hydraulic Works of Turkey. It was observed that RETScreen is capable of performing pre-feasibility studies of these small hydropower plants within a relatively short period concerning the time taken by other classic methods. In [12] cost, financial, and risk analysis for a 100 kW wind power plant, containing two 50kW wind turbines, that is planned to be installed on Taşlıçiftlik Campus in Tokat has been accomplished using RETScreen software program. In [13] an environmental and economic assessment of a grid-connected PV system established in a public institution in Brazil using the RETScreen program, the results proved that the project is environmentally viable but still needs tax remuneration to attract investors in the country. In [14] RETScreen Expert software has been utilized to implement Measurement and Verification analysis to evaluate the energy effectiveness of an existing building in Korea based on the collected data of 12 years of gas consumption. In [15] an economic analysis based on RETScreen to evaluate the case of transition from grid electricity to PV power plants for a domestic building existing in Ado ekiti, Nigeria. The results showed that the PV system is more economic than depending on the grid electricity and the cost of energy is relatively cheap. The RETScreen software has been used in evaluating the technical potential and economic feasibility of different renewable generation projects in different countries [16-18]. Taking into consideration the great dependency on RETScreen simulation software in performing feasibility studies of renewable energy sources, the authors are motivated to evaluate the technical and economic performance of the planned PV power plants in Egypt.

The New Valley is the largest and least densely populated governorate in Egypt. Its capital is Kharga and includes the southern half of the Egyptian part of the Libyan Desert. It is bordered to the north by the governorates of Minya, Giza, Matrouh, and to the east by the governorates of Assiut, Sohag, Qena, and Aswan, and to the south by the borders with Sudan and to the west by the border with Libya. The New Valley Governorate is characterized by the presence of vast land areas that can be used in the establishment of various projects in all industrial, service, agricultural, and tourism fields. The New Valley Governorate is considered one of the best governorates in Egypt in terms of solar radiation intensity. The average annual number of hours of sunshine per day ranges from 9 hours to approximately 11 hours in the southern desert of Egypt, which means greater investment opportunities in the domain of different solar energy applications [4, 19]. Therefore, we find that there is a trend, whether personally by farmers, to operate many water wells with solar energy or by government agencies recently. Fig. 1 presents the Global Horizontal Irradiance (GHI) that appears in all regions of Egypt [20].

In this paper, a study of the potential of a PVPP installation in New Vally is carried out. In general, five sites for the construction of 50 kW power stations were assessed according to their technical potential. The selected locations represent the five administrative regions of the New Vally governorate. The analysis of the feasibility of the project is carried out using the RETScreen software, taking into account the peculiarities of electric power production at the proposed power plant, economic feasibility, and reduction of greenhouse gas emissions.

The Rest of the paper is organized in the following manner: Section II introduces the climatic conditions in the proposed sites; Section III provides the technical specifications of the PV module used in this study: Section IV presents the obtained results and discussion; and finally, Section V is conducted for the conclusion and future work.

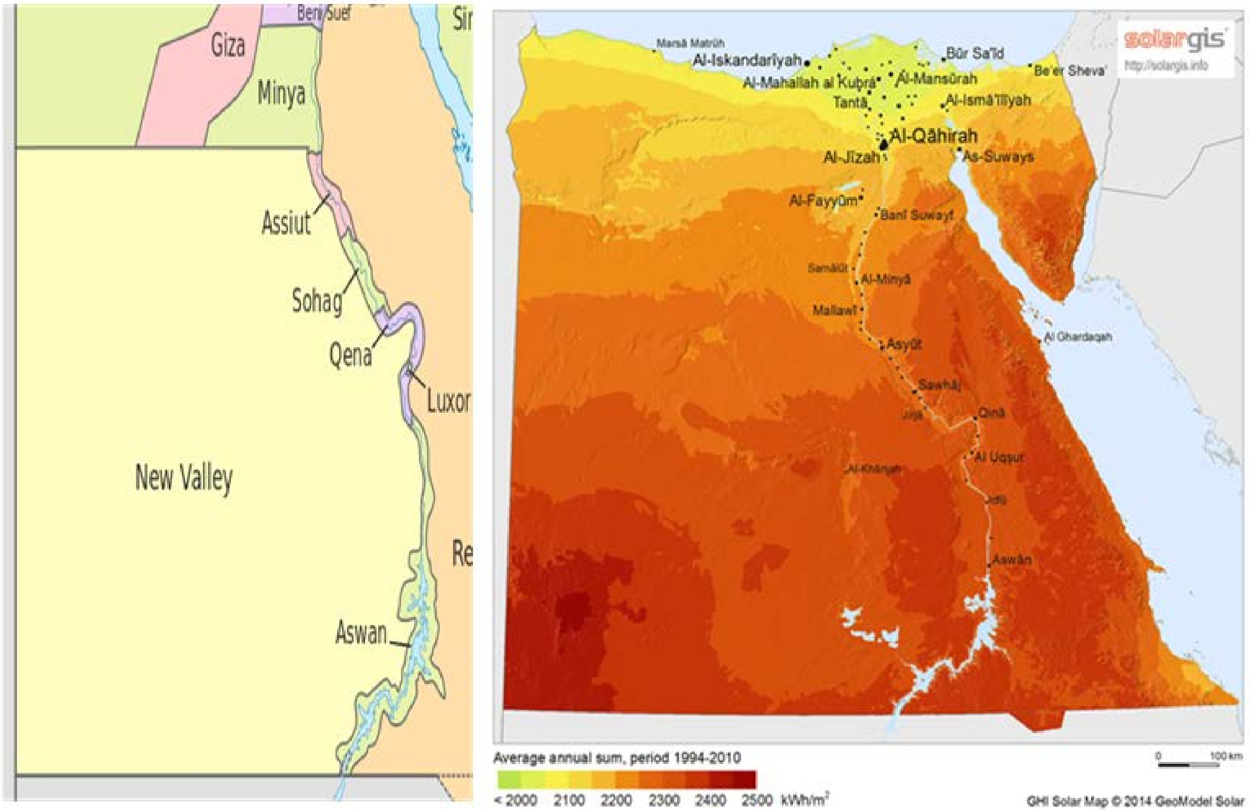


Fig. 1. Global Horizontal Radiation in Egypt.

II. Climatic Conditions of the Proposed Region

From Cairo to the far south, Egypt receives radiation exceeding 6 kWh/m2/day, and the days on which clouds appear for most hours of the day are less than 20 days a year, and the total radiation increases from north to south, reaching a value of 5 kWh/m2/day "near the northern coast and exceeding 7 kWh/m2/day at the farthest point in southern Egypt, while the number of hours of sunshine exceeds 4000 hours annually. These numbers are among the highest in the world. The New Valley Governorate is considered one of the best governorates in Egypt in terms of the intensity of solar radiation and the average number of hours of sunshine. In the next subsections, the meteorological data of the five administrative regions of the New Vally governorate are presented.

A. Solar Radiation Intensity

The mean value of the solar radiation on the selected region for all months of the year is displayed in Fig. 2. From the shown figure, it has become clear that during the summer months the greatest value of the solar radiation is observed in Frafra while during winter the greatest value of the solar radiation is obtained in Paris and Kharga regions. The average, greatest, and least values of the solar radiation in the five locations are presented in Fig. 3. From this figure, it is noticed that Frafra region is characterized by the greatest and least values of solar radiation in New Vally. The mean value of the solar radiation in Paris and Kharga is the best within the five locations. Fig. 4 shows the variation of the mean value of the solar radiation, calculated by the mean value of the solar radiation over the five regions, over the year. It is obvious from the figures that the least solar radiation value is 5.88 kWh/m^2/day, and it is found in Frafra and the greatest solar radiation value is 6.28 kWh/m^2/day, and it is found in both Kharga and Paris.

B. Air Temperature

The manners of air temperatures have been presented in Fig. 5, 6, and 7 for the different locations. The monthly values of the air temperature over the selected sites are shown in Fig. 5, while the greatest, least, and average values of the air temperature in the proposed regions are shown in Fig. 6. It is obvious from the figures that the greatest air temperature value is 33.4°C and it is found in both Kharga and Paris. The least air temperature value is 11.3°C and it is found in Frafra. The lower values of air temperature were detected during winter months while the greater values in winter as expected.

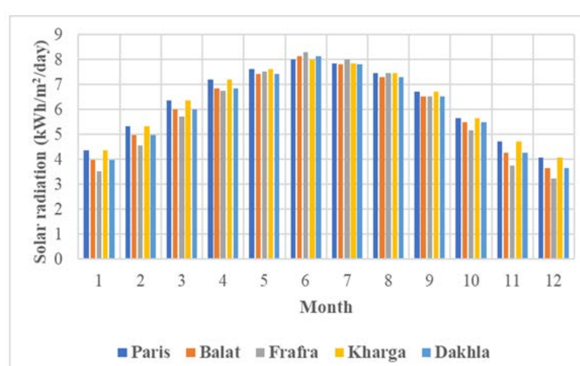


Fig. 2. The Monthly Values of Solar Radiation of Different Locations.

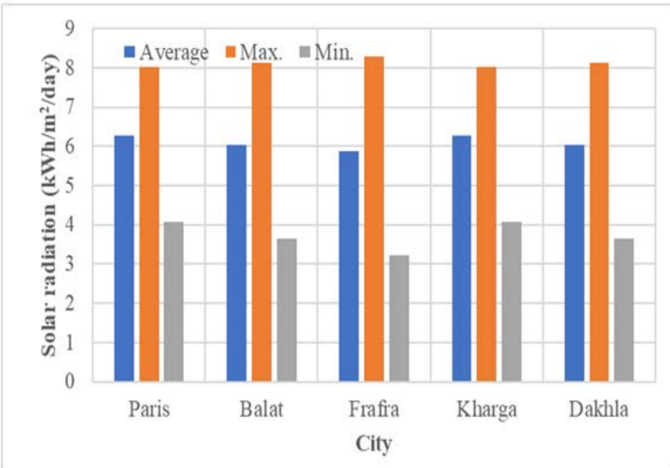


Fig. 3. Long-Term Average Solar Radiation.

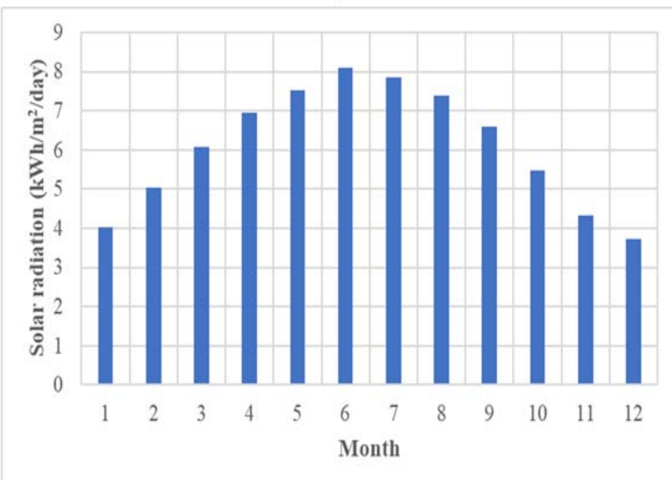


Fig. 4. The Total Variation in All Seasons of Global Solar Radiation in the New Valley.

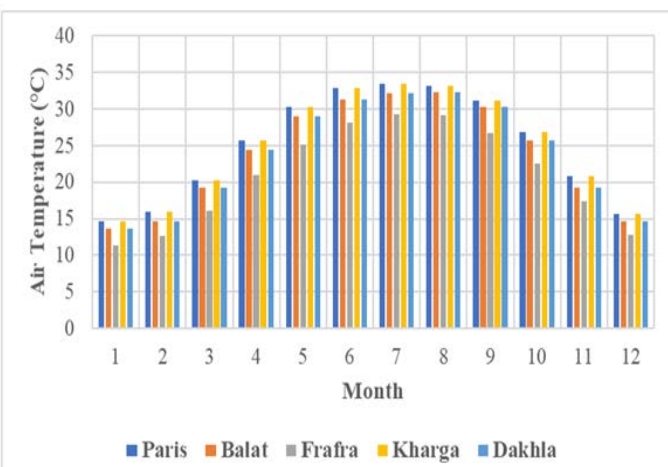


Fig. 5. The Total Monthly Variance of Air Temperature At Different Locations.

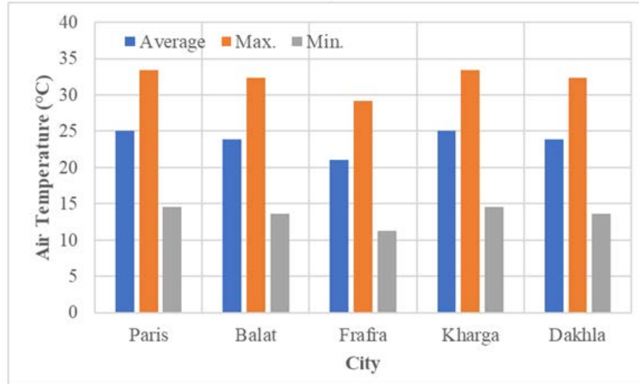


Fig. 6. Long-Term Averaged, Maximum and Minimum Air Temperature.

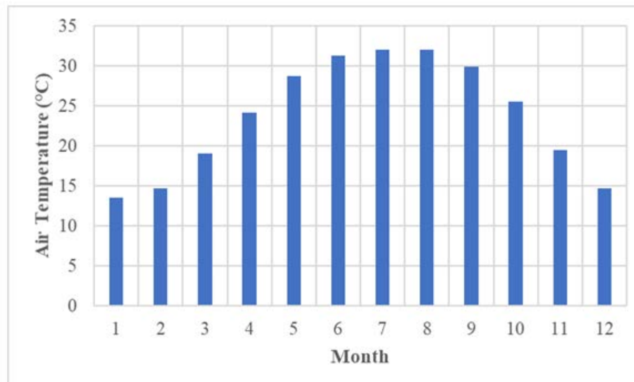


Fig. 7. The Total Variation in All Seasons of Air Temperature in New Vally.

C. *Relative Humidity*

The behavior of relative humidity can be discussed in Fig. 8, 9, and 10. It is obvious from the figures that for climatic conditions and relative humidity one can found that Frafra has the highest relative humidity 41.5%, the lowest relative humidity found in both Dakhla and Balat and equals 38.4%. The higher values of relative humidity were detected during winter months and lower in summer months as prospective.

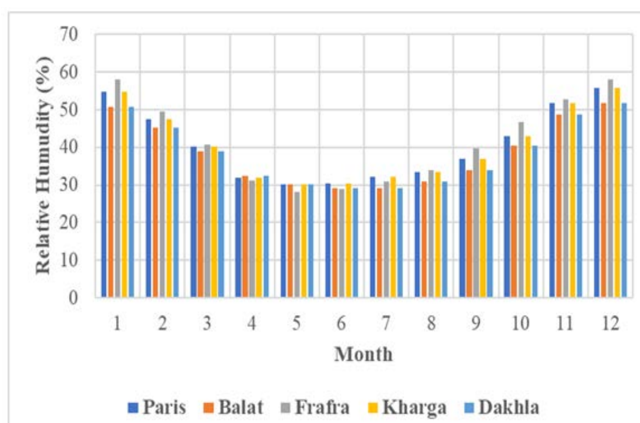


Fig. 8. The Monthly Values of Relative Humidity (%) in Different Locations.

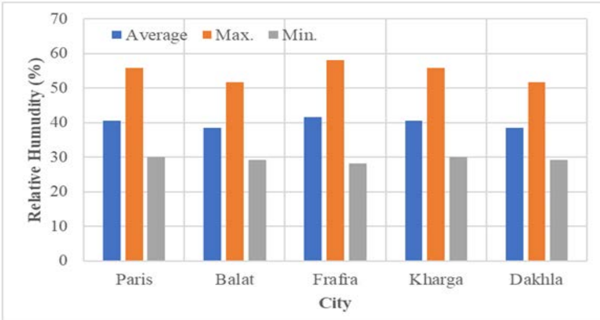


Fig. 9. Long-Term Averaged, Maximum, and Minimum Values of Relative Humidity (%).

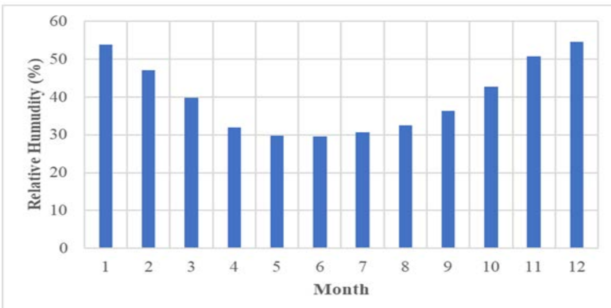


Fig. 10. The Total Variation in All Seasons of Relative Humidity (%) in New Vally.

III. PV Module Selection

The appropriate type of the photovoltaic module was chosen according to the proportion of the energy generated to the unit and its surface area (power/surface area 350w mono si-solaria power spandrel with a number of units equal 143 unit). The required PV module specifications are provided in Table I [21]. 143 units needed to establish the required 50 kW station. In our work, the fixed axis position of the modules will be chosen to reduce the initial cost 60kW inverters are selected with 95% efficiency.

TABLE I. Specifications of the Chosen PV Module

Model:	**350w mono si-solaria power spandrel**
Electrical Specifications	
Power P_{max}	350 W
Efficiency	17.3%
Open Circuit Voltage (V_{oc})	47.0V
Short Circuit Current (Isc)	9.6A
Max Power Voltage (V_{mp})	39.0V
Max Power Current (I_{mp})	9.0A
Temperature Performance	
Coefficient of P_{max}	-0.40% /C
Coefficient of V_{oc} -0.30% /C	-0.30% /C
Coefficient of I_{sc}	+0.05% /C
Mechanical Specifications	
length	1495 mm [58.8in]
Width	1350 mm [53.1in]
thickness	11.5 mm [0.45in]
Weight	52 Kg [114lbs] approx

IV. Results and Discussion

In this study, a 50kW PV power plant is proposed in the five locations and feasibility analysis of installing such a power plant in the New Vally region is assessed. The feasibility study is accomplished using RETScreen software. RETScreen Which means Clean Energy Management Software (usually abbreviated to RETScreen) is a package of programs for clean energy, improved and developed by the Canadian government that is an Excel-based software tool for making analyzes of clean energy projects, which helps decision-makers know both financial and technical feasibility in the field of energy efficiency, renewable energy and cogeneration (integrating heat and power generation) [8]. Conventional energy projects can also be designed and compared to more conservative alternatives. The program has the access to database of NASA and the values of the solar radiation on the horizontal surface, air temperature, relative humidity, and other meteorological data are applied to the RETScreen software [8, 22]. The program output is the annual total of energy produced from the proposed plant, the annual reduction of the GHG emissions thanks to the installed power plant in the selected locations.

A. Renewable Energy Production

The total annual power produced (MWh) is obtained from the RETScreen program as an output. Fig.11 shows the amount of energy produced in the five stations. The maximum energy amount is 100 MWh produced at Paris station. The minimum energy amount is 95 MWh produced at Balat station.

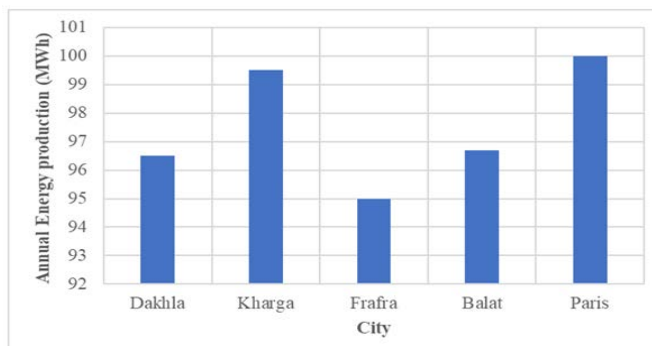


Fig. 11. Annual Energy Production of Different Stations.

B. Greenhouse Gases Reduction

One of the essential issues for validating the best-case study location is the Greenhouse Gases (GHG) Reduction. So, the model estimates the overall percentage and annual reduction in the amount of greenhouse gas emissions that would be incurred if the proposed case were implemented. The calculation is dependent on emissions of both the base case and the state systems selected on yearly basis. The units are given in CO2 equivalent annually per year (tCO2/yr). The annual GHG emission reduction thanks to the installation of the proposed 50kW PVPP in the five sites is presented in Fig. 12. According to this figure, it is noted that Kharga station has the highest rate of preventing greenhouse gases by 45 tons of CO2 can be prevented to reach the atmosphere. On the other hand, the Frafra station has the lowest rate of preventing greenhouse gases by 43.3 tons of CO2 can be prevented to reach the atmosphere.

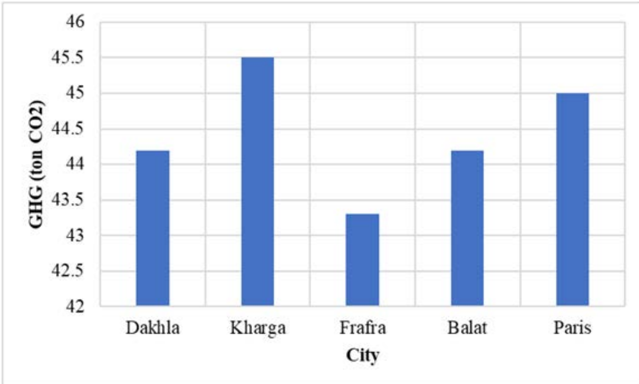


Fig. 12. Annual Reduction of GHG in the Selected Locations.

C. Economic Feasibility Analysis

RETScreen has been utilized to determine a series of economic indicators such as simple payback period (SPP), internal rate of return (IRR), benefit to cost ratio (BCR)), net present value (NPV), annual life cycle saving (ALCS), years of positive cash flow (YPCF), and energy production cost (EPC) for each project (50kW PV power plant). These indicators are explained in detail in the following subsections. The initial economic parameters, like the growth rate of energy cost, the rate of inflation, plus the cost of the main components of the PV power plant, are taken following the data given in Table II [13, 14].

TABLE II. FINANCIAL PARAMETERS THAT ARE USED IN THE STUDY [22, 23]

Parameter	Value
Project life	25 years
Inflation rate	2.5%
Discount rate	5%
Reinvestment rate	9%
Fuel cost escalation rate	0.0%
Debt interest rate	7%
Debt term	20 years
Electricity export rate	0.1$/kWh

a) Internal Rate of Return (IRR): Through IRR, companies can learn the feasibility of investment of the projects in the long term as it is one of the methods of capital budgeting. It is the discount rate at which the present value result is equal to zero, and it is usually explained by the expected profits that an investment decision generates [5]. In general, If the rate exceeds the capital value for the project, this will represent an added value for the project. IRR is calculated as given in equation (1):

$$InitialInvestement = \sum_{t=1}^{N} \frac{C_t}{(1+IRR)^t} \tag{1}$$

where C_t denotes the Net of cash inflow during the period called t, IRR is defined as the internal rate of return, N represents the lifetime of the project, and t represents the number of time intervals.

b) Simple Payback Period (SPP): A measure of the project's liquidity. It refers to the period of time during which the initial cost is recovered from the cash receipts, and this method is based on the fact that the more investment value is recovered in a shorter time, the more acceptable the investment or the paid-back capital period, which is one of the capital budgeting tools that the investor or financial manager relies on to implement an investment project. The higher the recovery period of the invested money in a shorter time, the better the investment in this project and vice versa.

c) Years of Positive Cash Flow (YPCF): It refers to the movement of money in or out of a business, enterprise, or financial product. It is usually measured over a specific, limited period of time. It indicates that the company's core business activities are thriving. It provides an additional measure of an indication of the company's profitability potential.

d) Annual Lifecycle Saving (ALCS): It is a nominal annual saving with an equation, with the exact value of the NPV discount rate and the project life, the value of ALCS is calculated.

e) Net Present Value (NPV): It is defined as the present equivalent value of future payments. One of the tools that companies use to evaluate investment projects (long-term projects); The method of working the net present value depends on ensuring that the project being evaluated generates cash flows above the value invested in the project [5, 23]. The financial flows of the coming years can be transformed to the net present value by the next equation:

$$NPV = \sum_{t=0}^{N} \frac{C_t}{(1+r)^t} \tag{2}$$

where C_t is annual cash flow, r represents the annual interest rate of annual interest, and t represents the current year.

f) Benefit-Cost Ratio (BCR): An indicator used in the field of cost-benefit analysis that attempts to arrive at the total value of money needed by the project. The higher the ratio is more than 1, the better the project, and the safer investment in it:

$$BCR = \frac{Discounted\ value\ of\ fringe\ benefits}{The\ value\ of\ the\ additional\ costs} \tag{3}$$

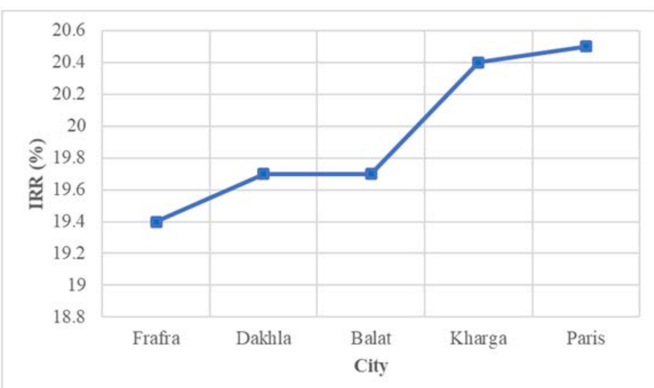
g) Energy Production Cost (EPC): Energy production cost per kilowatt-hour for generated electricity. This value is equivalent to the electricity export rate required to make a net present value (NPV) equal to zero.

The variation of the aforementioned economic factors concerning the location of the PVPP is presented in Fig. 13. If the value of IRR equals to or greater than the required return rate value, the study will be passed. The IRR values of all sites are shown in Fig. 13(a). The greatest value of the internal rate of return (IRR) is 20.5% found at Paris station while the minimum IRR value is 19.4% found at Frafra station. For SPP which equal to the period of time during which the initial cost is recovered from the cash receipts. The values of SPP and

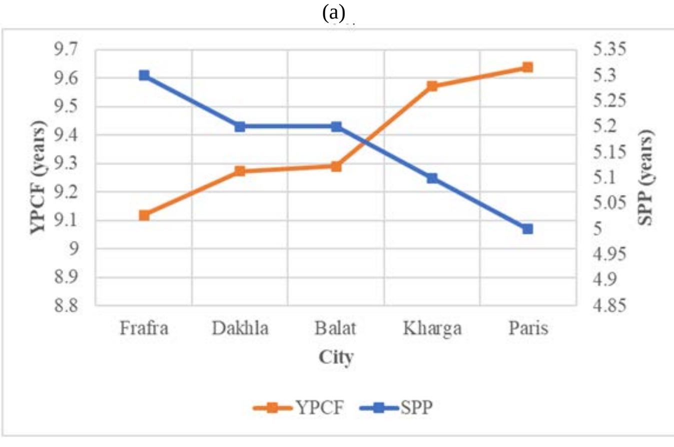
YPCF for all locations are shown in Fig. 13(b). The greatest value of the simple payback period is 5.3 years found at Frafra station while the minimum value is 5 years found at Paris station. For YPCF which indicates how long the project will take to recoup its initial investment. The maximum value of YPCF is 9.638 years found at Paris station. The minimum value of YPCF is 9.119 years found at Frafra station.

The values of NPV and ALCS of all sites are shown in Fig. 13(c). ALCS can be calculated using the discount rate, the NPV, and the life of the project. ALCS has a maximum value equal is 6.358 years found at Paris station. The minimum value of ALCS is 5.83 years found at Frafra station. The maximum value of net present value is 89.605 million USA$ found at Paris station while the minimum value of NPV is 82.28 million USA$ found at Frafra station. Positive NPV values ensure project feasibility. From the shown values in the figure, we can see that all the values are positive which ensures that all five stations are potentially feasible.

All the available values of BCR are greater than one so that it is an indicator for profitable and better projects. The values BCR for all locations are illustrated in Fig. 13(d). The greatest value of BCR is 2.9 at Kharga and Paris stations while the minimum value of BCR is 2.8 at Dakhla, Balat, and Frafra stations. The generating unit's production cost known as Energy Production Cost (EPC) is one of the outputs of the RETScreen program. The value EPC of all sites is shown in Fig. 13(e). The minimum value of EPC equals 3.7 cents/ kilowatt hour in Kharga and Paris stations while the maximum value EPC equals 3.9 cents/ kilowatt hour in Frafra station.



(a)



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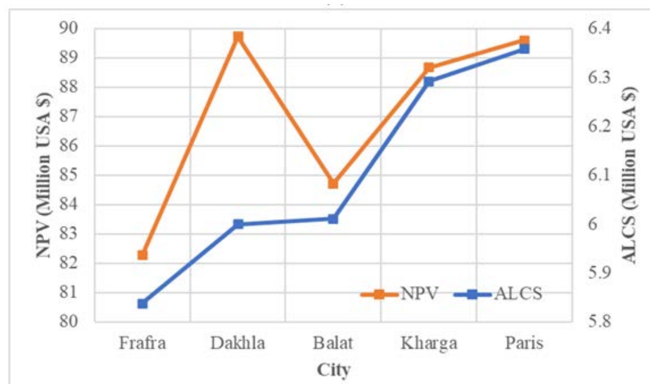
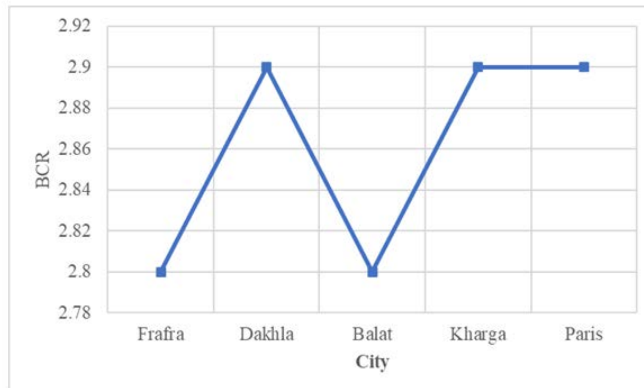
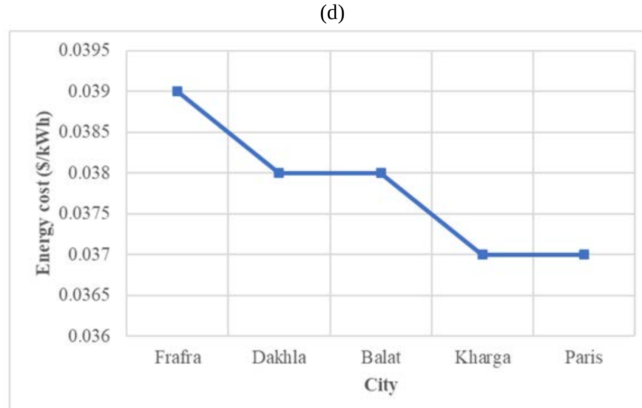


(c)



(d)



(e)

Fig. 13. Economic Indicators Varied According to the Location of the Photovoltaic Power Plants.

V. Conclusion

This paper presented a comprehensive study of the potential of a PVPPs installation in New Vally governorate, Egypt. For completing this study, five sites have been assessed for installing the same power plant with a capacity of 50 kW. This study has been accomplished to have a map for solar energy projects that will increase the international investment in the underutilized and superabundant environmentally friendly energy source in southwestern Egypt. After analyzing the meteorological conditions in the region it was obtained that the minimum solar radiation in the studied area is 5.8 kW/m^2/day and obtained in Frafra station, while the maximum solar radiation is 6.04 kW/m^2/day in the Kharga and Paris stations. The amount of annual energy produced from the proposed PV power plants in the suggested locations ranges from 95 MWh at Frafra station to 100 MWh at Paris station, which ensures the small variation in the output of the PV power plant regarding the location in the New Valley governorate. From the environmental side, it has been found that the 50kW PV power plant located in Kharga oasis has the highest rate of reduction in the greenhouse gases emissions with 45 tons of CO2 that can be prevented to reach the atmosphere annually, in addition, it has been found that the PV power plant located in Frafra oasis has the lowest annual greenhouse gases reduction by 43.3 tons of CO2. From the financial point of view, it was concluded that the installation of a solar PV power plant in any of the proposed places is economically feasible, and the cost of energy produced by solar power plants ranges from 3.7 to 3.9 cents per kWh. All the proposed sites are fully recommended for the installation of PV projects from all the accessible indices, but the proposed PV power plant located in Paris is considered to be the best choice because of the high energy exported to the grid utility. The payback period of the PV project in Paris is also the shortest compared to other sites.

It is recommended that solar photovoltaic power plants may be installed in Paris to acquire new experiences and endorse the PV technology in the regional environment. Based on the results obtained in this study, the authors in their future work are looking forward to studying the impact of the integration of such PV power plants into the distribution network in Paris on the power quality indicators in the distribution network.

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