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Economic and Environmental Feasibility of Constructing a Grid-Connected Sun-Tracking PV Power Plant in Iraq

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Abstract- Feasibility assessment of constructing a 10 MW sun-tracking PV power plant in Iraq from an economic and environmental perspective has been analysed. A type of PV panel having desirable specific properties according to the international standards has been selected and used. Three PV-panel installation systems, namely: fixed-tilt, single-axis, and dual-axis tracking systems have been tested. Al-Anbar city (33.26°N, 40.31°E) west of Iraq has been selected for constructing the proposed power plant. The study mainly concerns the assessment of the annual and cumulative revenues rising from the proposed PV power plant. Evaluation of other economic parameters including the levelized cost of energy (LCOE), cash flow over the power plant lifecycle, and net present value (NPV) also have been achieved and revealed. The analysis demonstrates that the selected region is very promising for solar PV investment in electric power production. Moreover, incorporation of a dual-axis tracking system substantially enhances the economic feasibility of the project. The environmental benefits relating to the reduction of greenhouse gas (GHG) emissions have been confirmed in all the PV-panel installation modes considered in this study.

Keywords Solar PV power, Economic feasibility, Environmental analysis, Sun-tracking systems, Iraq.

1. Introduction

The on-going depletion of fossil fuel due to the limited source availability in addition to the growing energy demand worldwide motivates the move to more sustainable and renewable alternatives such as solar, wind, geothermal, etc. Among these alternatives, solar comes at the top of the list as the most abundant source with more even distribution in the globe. Two technologies are available for solar-energy harnessing: photovoltaic and solar thermal. Photovoltaic systems (PV) are made from semiconductor materials being able to convert sunlight directly to electric power by the photoelectric effect. PV is increasingly recognized as the most popular technology of harnessing solar energy worldwide [1]. In Iraq, the use of solar PV to meet the national growing demand for electrical power is promising as the amounts of solar energy reaching the surface of the earth in the form of radiation are immense [2]. The benefits include no by-products such as the harmful carbon emissions in addition to the efficient and cost-effective electricity production. In the current scenario, Iraq is still in low electrification rate due to the massive damage of its electrical infrastructure because of the war in addition to the increasingly country's need to import fuel that is being used to produce electricity. Thus, the move to increase the share of electricity generated from fossil-fuel alternatives like solar and wind has started to receive growing attention from the researchers and policymakers in the energy field locally and worldwide as well.

A considerable amount of literature has been published to assess many aspects related to the use of PV technology for power generation. These aspects include the economic feasibility of utilizing solar power for heating demands [3], the technical and economic feasibility of using solar power for producing electricity [4-8], and the enhancement of PV power plant performance through incorporation of sun-tracking systems in two cases, single-axis and dual-axis tracking [9-12]. Jobair et al. [3] evaluated experimentally the economic feasibility of utilizing solar energy for heating proposes. The study had been achieved under Iraqi climate conditions in Baghdad city. The study revealed the benefits of utilizing flat-plate solar collector in reducing the amount of consumed national-grid electric power for heating purposes. Gomes et al. [10] estimated analytically the economic feasibility of utilizing PV systems for feeding the residential claims in Brazil. This study showed economic viability of connecting the PV systems to the national electric grid in many regions of Brazil. Pillai & Naser [13] evaluated the economic potential of constructing a 1MW grid-connected PV system for matching the daily peak load in Bahrain. Several economic parameters such as levelized cost of energy (LCOE), net present value (NPV), payback period, and energy payback time were analyzed. The results showed that utilizing solar energy specifically PV systems is a feasible option for meeting future electricity demand. Bhakta and Mukherjee [14] used Homer simulation software to predict the technical and economic feasibility of constructing a PV power plant in an Indian isolated island. The economic parameters including initial capital costs (ICC), total costs of investment with operating and maintenance were taken into consideration. The study revealed the economic feasibility of this project.

Parrado et al. [15] conducted an analytical study to calculate the levelized cost for producing power in Chile using different supplied sources including PV, and PV-CSP (concentrated solar power) hybrid power plant, and other conventional power plants. The study demonstrated that PV-CSP hybrid power plant is more feasible than other tested systems. The study also concluded that a PV-CSP hybrid power plant better contributes to the electricity price stabilization. Rodrigues et al. [16] studied analytically the economic feasibility of small PV systems in different countries. The main purpose of this diversity in the selected locations is to clarify the best investment opportunities. The study concerned about the selection of which countries could provide opportunities for the makers, investors, and researchers for working and investment. The study demonstrated that Australia, Germany, and Italy could provide the most benefit in comparison with the other selected countries. Boukelia et al. [17] performed an integration for two power plants utilized a parabolic trough collector with thermal energy storage and fuel backup system. Each plant was assumed to run on a different heat transfer fluid (HTF). The study approved that the power plant with molten salt as HTF is more feasible than that utilized Therminol (VP-1) as HTF. Mohammadi et al. [9] evaluated analytically several financial, technical, and environmental standpoints for a 5MW PV power plant in eight locations in Iran. The PV panels were installed with different tracking systems; fixed-tilt, single-axis, and dual-axis tracking systems. The levelized cost of energy (LCOE) and feed-in-tariff parameters are computed as well as the percentage reduction in greenhouse gas emission. The results approved the advantage of constructing PV power plants in all tested locations. Ceron et al. [10] performed an analytical study to evaluate the influence of the operating expenditure (OPEX) of a photovoltaic tracking power plant. The study demonstrated that the high quality operating and maintenance of the PV tracking systems does not permanently improve the LCOE. Weida et al. [18] generalized a model based-analysis using RETscreen software to evaluate the financial viability of PV systems at three different regions in Germany. Six locations in each region were tested so that the effect arising from the difference in climate and geographical conditions can be well evaluated. The results showed a very promising reduction in the levelized cost of energy (LCOE) and green-house gasses (GHG) by 2030.

There is little work reported on the economic and environmental feasibility assessment of large-scale grid-connected PV systems in the Middle East and none specifically for Iraq. Thus, the major objective in this study is to evaluate the environmental and economic feasibility of constructing a 10MW PV solar power plant in Al-Anbar City, Iraq. Three different tracking modes have been tested, namely; fixed-tilt, single-axis tracking, and dual-axis tracking to optimize towards the best technical and economic benefits. The feasibility assessment is conducted in terms of the levelized cost of energy (LCOE), reduction of greenhouse gases (GHG) emission, and the accumulative power delivered from the installed PV power plant. The cash flow, payback period, and net present values (NPV) are also computed to confirm the economic benefits of constructing the proposed PV power plant.

2. Methodology

Iraq has a substantial potential for solar energy utilization due to the relatively long sunshine duration which is about 3250 h/year with average solar radiation of 5.4 kWh/m^2/day [19]. This makes solar-based electricity generation a viable option for reducing the national power bill along with decreasing the environment-polluting carbon emission as well. However, there has been little discussion about the economic and environmental feasibility of having large-scale PV power plants in Iraq. In this study, an attempt has been made to introduce a feasibility study for constructing a 10 MW sun-tracking PV power plant in Iraq. Data for this study was collected using the global solar atlas to select an appropriate site for installing the postulated PV power plant. Figure (1) demonstrates the solar map of Iraq with the values of global solar radiation for all locations in the country. The data from figure (1) indicates that the highest values of solar radiation in the country are in Al-Anbar city (33.26°N, 40.31°E). These values are 5.8 kWh/m^2/day and 2118 kWh/m^2/year. Geographically, Al-Anbar is the largest city in the western territory of Iraq around Euphrates River. It is characterized by a hot desert climate with summer temperatures rise up to 42 ºC [19]. The values of global solar radiation in Al-Anbar are considered very promising for successful solar-energy applications, especially in the field of solar electric power production. This kind of applications is docile in terms of the population-related electric power supply which is the most important challenge to the local governments and policymakers. This study concerns the feasibility of developing a grid-connected PV plant in Al-Anbar city/Iraq from technical, economic and environmental perspectives.

The commercially available, renewable energy technologies (RETs) viability decision support software (RETscreen) has been used to assess the technical, economic and environmental aspects of developing the proposed PV plant. This software is capable of assessing different RETs viability factors such as power production and saving at the project site, equipment performance, initial project costs, project environmental benefits by estimating the greenhouse gases emission reduction as well as life cycle analysis and cost-effectiveness analysis for both off-grid and grid-connected power plants. RETScreen software incorporates a series of databases that help to overcome difficulties associated with gathering meteorological data, equipment performance data, etc. [20]. The software has been widely used to study the feasibility of various renewable energies including hydropower [21-23], solar photovoltaic [24, 25], solar water heaters [26-28], and wind energy projects [29]. In this section, the methodology to conduct the economic analysis is presented and discussed.

2.1 Technical perspective

In this study, the technical perspective which concerns the evaluation of the output power from the proposed PV power plant has been revealed by comparing three different PV-panel installation systems. Employment of tracking systems is to control the position and orientation of the PV panels automatically in accordance with the sun's movement.

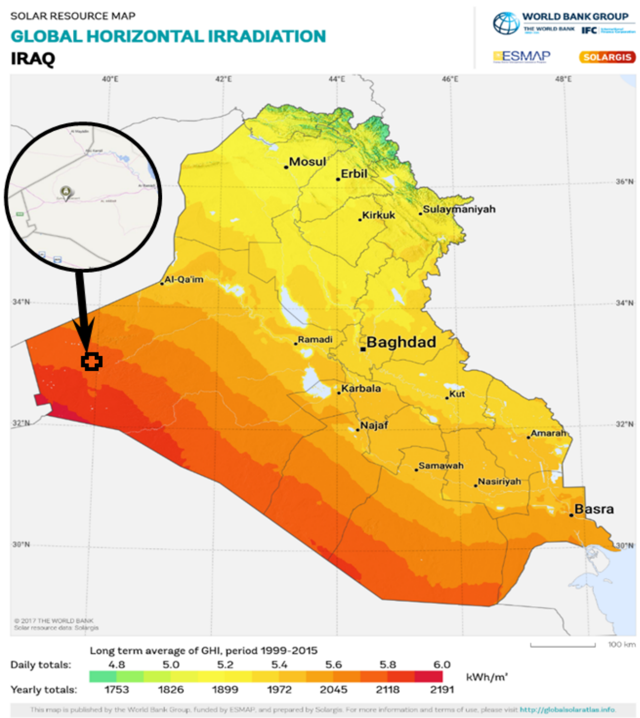

Fig. 1. Annual and daily totals of global solar radiation along with the location of Al-Anbar city in Iraq [19]

Thus, this study handles and compare between three different tracking systems to reach to the most suitable system. This system is the one that maximizes the electric power production thus gives the most astounding benefit from the technical perspective. The proposed solar 10MW PV power plant is assumed to have a specific type of PV panels. The general properties of this PV panel type are listed in table (1). The general properties of the selected PV panels in this study are conformed to the international standard and they all are certified by RETscreen software which is used in this study.

Table 1 The general properties of the selected PV panels [20]

Properties	Description
Type	Mono-Si
Manufacture	China sunergy
Model	Mono-Si-CSUN250-60M
Efficiency (%)	15.4
Number of units	40000
Area of PV (m^2)	64935
Efficiency of the inverter (%)	97
Miscellaneous loss (%)	4

2.2 Economical perspective

The second task in this study is to assess the financial aspects exemplified by determining the economic feasibility of installing the postulated PV solar power plant. Several economic parameters are evaluated including the levelized cost of energy (LCOE). This parameter represents the ratio of the present value of the total capital and operating costs of the plant to the net present value of the net generated electricity over the operating lifetime. The duration of lifetime operation is assumed 20 years in this study. LCOE is evaluated as:

$$\mathrm{LCOE} = \frac{\mathrm{LCC}}{\sum_1^N \mathrm{E_n}/(1+\mathrm{i})^{\mathrm{n}}} \tag{1}$$

Where LCC represents the life cycle cost which includes the costs of the installed power plant over the entire lifetime, E_n is the gained energy from the solar power plant for a particular year, N represents the year number (1,2,…, N), i is the percentage increase in the annual effective electricity rate. The life cycle cost (LCC) took into consideration the capital costs and the operational and maintenance (O-and-M) cost excluding the tax cost and supplementary costs. The reason for neglecting taxes in this research is due to the lack of a clear and explicit database of tax statistics in Iraq. The degradation of the PV system output power is very important to take into consideration in the case of installing a PV solar power plant. The importance of not neglecting the degradation comes from the decline in power output from solar panels as time advances. In this study, the degradation is assumed to be 25% per year. The mount of the degradation which is taken into account in this study is widely accepted and applied to the most types of PV solar panels in the case of building solar power projects of long lifetime. The initial cost for installing the power plant varies according to the selected tracking system. The O-and-M costs and maintenance costs of the proposed PV power plant according to the selected PV-panel installation system, as provided by the manufacturer, are listed in Table (2).

Table 2 The capital, operational and maintenance costs for different installation systems [20]

Installation system	Capital costs ($)	(O&M) costs ($)
Fixed-tilt	28000000	380000
Single-axis tracking	34000000	440000
Dual-axis tracking	34000000	440000

The second parameter for evaluating the economic feasibility of the PV power plant is net present value (NPV) which is an important parameter that should be computed in any investment project. NPV denotes to the difference between the present value of positive cash flow and the present value of negative cash flow. In other words, it denotes to the difference between the capital costs of the project and the cumulative revenues. This parameter is the one that can judge whether the project is economically feasible or not. Thus, the feasible project is the one that has revenues from the sale of the PV-generated electrical power which cover and appropriately exceed the construction costs of the PV power plant. The negative cash flow represents the total costs of the constructed power plant including the operational and maintenance costs. The positive cash flow comprises the annual and cumulative revenues acquired from the sale of the electrical power. In this study, the cash flow and cumulative cash flow for the PV power plant lifetime associated with the payback period is computed to fulfill the feasibility requirements for the postulated PV power plant. NPV can be computed from equation (2):

$$\mathrm{NPV} = -\text{Capital costs} + \sum_0^N \frac{R_N}{(1+i)^n} \tag{2}$$

Where R_N represents the annual revenue, i represents discount rate, $n = (0,1,2,\ldots,N)$. In this study, the discount rate is taken as 6%. Discount rate can be varied according to the circumstances related to the project or investment. In this study, the discount rate is considered as a constant value (6%). It would be better to take this factor as a variable value to find out the impact of it on the future interest rates, opportunity costs, future consumption and social wellbeing.

3.3 Environmental feasibility

The last task in this study is to determine the environmental feasibility thru identifying the amount of percentage reduction of greenhouse gasses (GHG) emission due to constructing the PV solar power plant. This can be done by comparing the results of GHG emission from the PV power plant to that of the conventional power plant. The annual percentage reduction in GHG emission in case of a PV solar power plant compared to a conventional power plant can be evaluated from the equation (3) [13] as:

$$\text{annual reduction } (\%) = \frac{\text{Base case} - \text{proposed case}}{\text{base case}} \% \tag{3}$$

Reference case here represents the emission of CO_2 in tons per year for a conventional power plant, and the proposed case represents the emission of CO_2 in tons per year for a PV solar power plant. The discussion of GHG emission is a vital aspect in the construction of a PV solar power plant. The vitality of this problem comes from the impact of global warming that mainly occurs due to the GHG emission arising from the fossil-fuel usage in conventional power plants.

3. Results and Discussion

As mentioned earlier in the previous section, the selected site for the construction of the proposed PV plant is Al-Anbar city (33.26°N, 40.31°E). The values of daily solar radiation as obtained from RETscreen software for dual-axis, single-axis, and fixed-tilt sun-tracking systems in Al-Anbar are shown in figure (2). The data from figure (2) indicate that the dual-axis tracking system receives the maximum amount of solar radiation compared to other systems. Figure (3) shows the results of monthly-generated electricity exported to the national grid using the three tracking systems: single-axis, dual-axis, and fixed-tilt. As expected, the maximum electric power exported to the national grid is by using a dual-axis tracker. The reason is that, the use of dual-axis tracker efficiently minimizes the angle between the incident solar radiation and the PV panels thus the amount of solar radiation absorbed by PV panels substantially increases. The maximum values of exported electricity, which occur in June, are 1800, 2600, and 2800 MWh for fixed-tilt, single-axis, and dual-axis trackers, respectively.

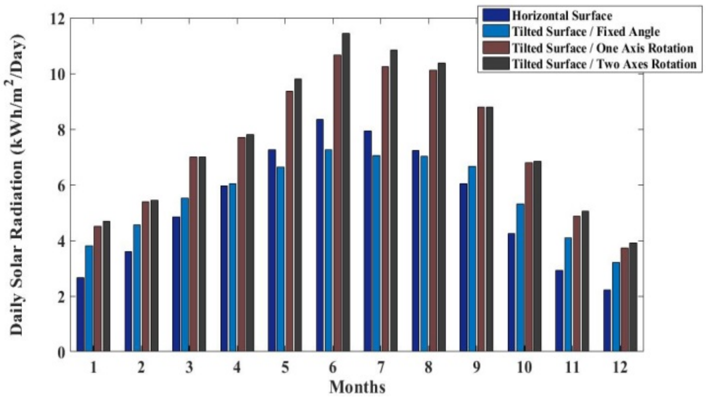

Fig. 2. The daily solar radiation for three systems for the selected location

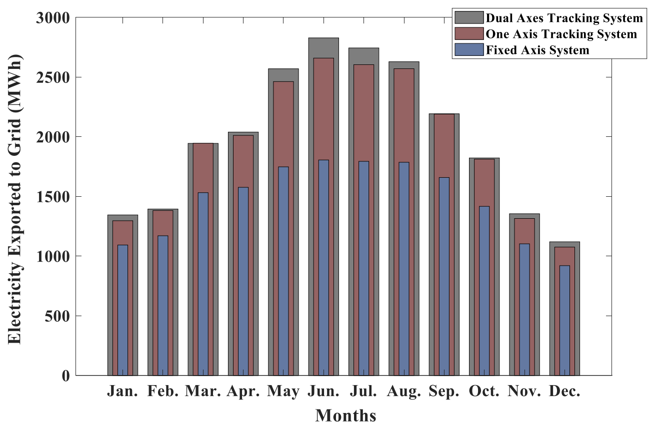

Fig. 3. The exported electricity for three systems for the selected location

The values of exported electricity over the entire lifetime of the installed power plant are illustrated in figure (4). Again, the effect of using tracking systems is obvious as the amounts of the generated power in the case of using trackers exceed those in the case of using the fixed-tilt system. The dual-axis tracking system gives the maximum amount of the electric power to the national grid compared to the other systems. Also, figure (4) elucidates a decrease in the amount of the exported electricity year by year due to the degradation in the performance of the PV panels with time. The decrease in the values of generated electricity for fixed-tilt, single-axis tracking and dual-axis tracking over 20 years of operation are: 3000, 4000, and 5000 MWh, respectively.

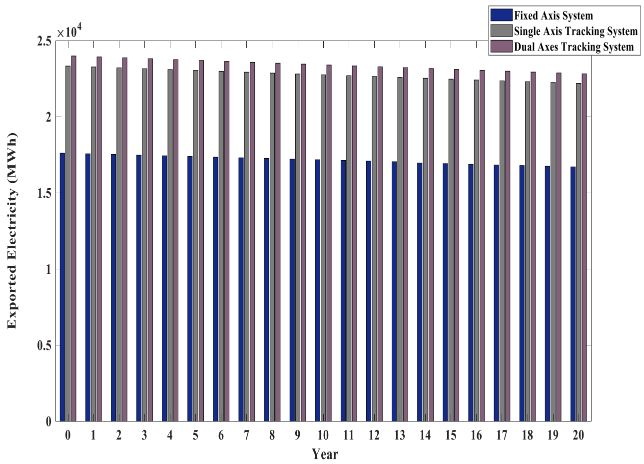

Fig. 4. The exported electricity along the lifetime of PV solar power plant for the three tracking systems

Figure (5) shows the cumulative cash flow for 20 years which represents the lifetime of the proposed PV power plant for all three tracking systems. For a fixed-tilt system, the cumulative cash flow takes a negative value for the first seven years, which is called the payback period. This period represents the amount of time that the power plant takes it to recover the initial investment. After that, the cumulative cash flow becomes a positive value which indicates the start of obtaining the benefit from the development of the proposed PV power plant. Regarding the other systems, i.e. single-axis and dual-axis trackers, the payback period is almost six years. This means the project recovers the initial investment within six years. After this six-years-period, the revenues of the constructed PV power plant start to appear.

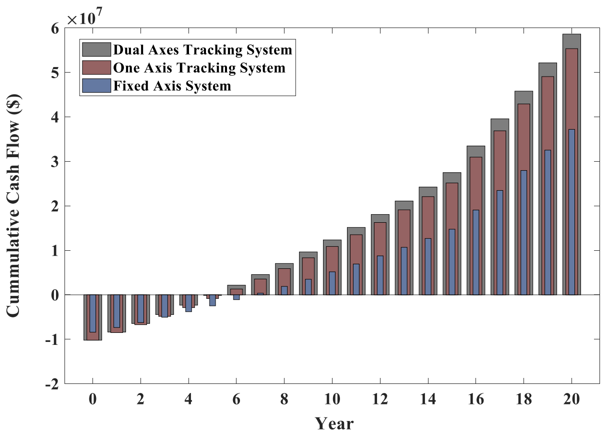

Fig. 5. The cumulative cash flow for three systems for the installed PV power plant

The annual and cumulative revenues resulting from the developed PV power plant with three different systems of sun-tracking are shown in figure (6). In the case of annual revenue, the obtained values decrease with time. The reason for this decrease is the degradation in the performance of the PV panels while the installed PV power plant is in progress. The cumulative revenues in the case of dual axes tracking system present a maximum amount of revenues throughout the entire lifetime of the installed PV power plant in comparison with the other two systems (fixed-tilt and single-axis tracking systems).

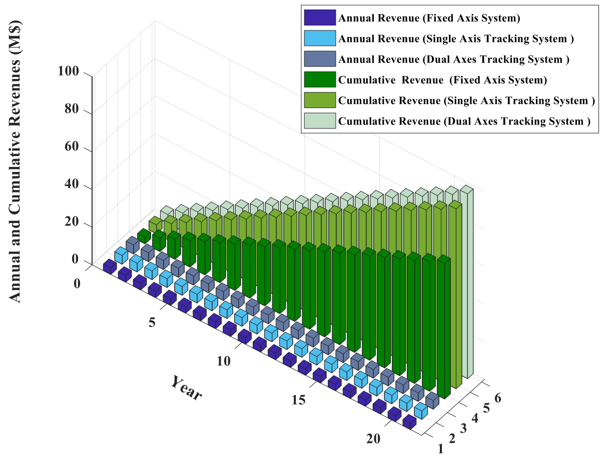

Fig. 6a. The annual and cumulative revenues for the postulated PV power plant for three installation systems (3D view)

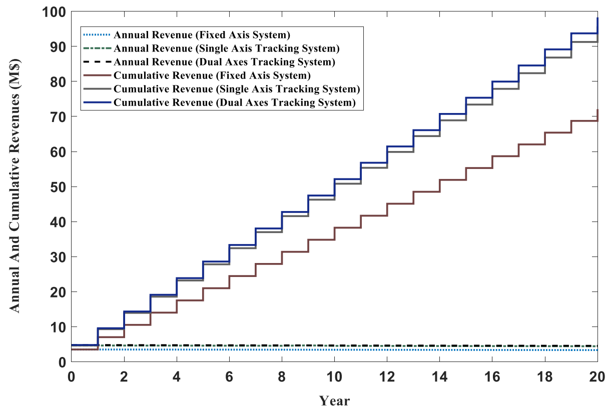

Fig. 6b. The annual and cumulative revenues for the postulated PV power plant for three installation systems (2D Stairs Chart)

Figure (7) elucidate the LCOE values for all three tracking systems used in the postulated PV power plant. Value of LCOE in the case of using a fixed-tilt tracking system is higher than those of other tracking systems throughout the power plant life cycle. However, the single-axis and dual-axis tracking systems show a slight difference in the value of LCOE with a larger value of LCOE tends to be by the single-axis tracking system. Based on the definition of LCOE in equation (1), the results demonstrate that the installed PV power plant with a dual-axis tracking system gives more benefit than the other two systems of the fixed-tilt and single-axis tracking.

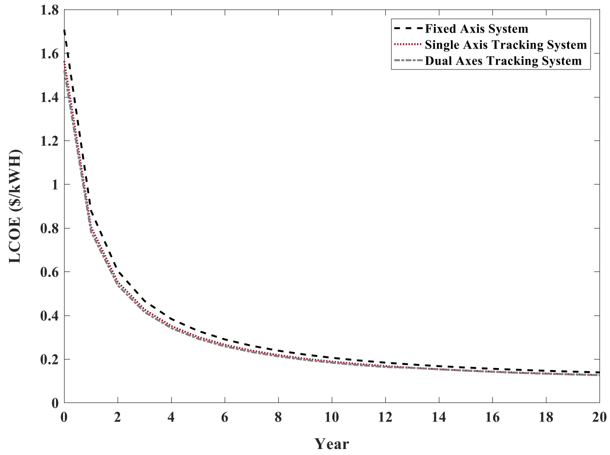

Fig. 7. LCOE for the selected systems ($/kWh)

Table (3) lists values of NPV for three tracking systems used in this study. These values represent the maximum benefit from the development of the proposed PV solar power plant. It would be worth mentioning that this present study has taken into consideration the capital costs, operational and maintenance costs excluding other initial costs such as the costs of investors and taxes.

Table 3 NPV for the selected systems of installing PV panels

Installation system	NPV (M$)
Fixed-tilt	43.71
Single-axis tracking	61.27
Dual-axis Tracking	63.95

The annual net GHG reductions in terms of tons of CO_2 per year due to the development of the proposed PV plant instead of the reference case of a fossil-fuel conventional power plant are shown in Figure (8). The data from this figure clearly identified that the reduction in GHG emission is confirmed for all three tracking systems used. The percentage reduction for all three systems compared to the reference case of a conventional power plant is the same which is around 93%.

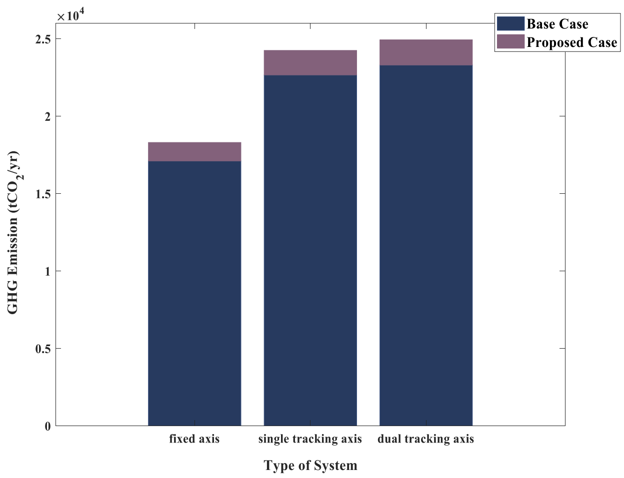

Fig. 8. GHG emission for the used systems in comparison with a conventional power plan

4. Conclusion

This study presents an economic and environmental feasibility assessment of constructing a 10 MW sun-tracking PV power plant in Al-Anbar city (33.26°N, 40.31°E) west of Iraq. Three different PV-panel installation systems have been considered. The affirmative aspects that this study has been approved are:

1. The supplied electrical power to the national grid in the case of using a dual-axis tracking system for installing PV panels is the maximum compared to the other systems i.e. fixed-tilt and single-axis tracking.

2. The cumulative electrical power acquired by using a dual-axis tracking system throughout the lifetime of the PV power plant is (491432 MW). This value is higher than that obtained using fixed-tilt and single-axis tracking systems by 27% and 3%, respectively.

3. The reduction in GHG emission is almost the same for all PV-panel installation systems considered in this study compared to a conventional power plant with the same power capacity. The percentage reduction in GHG emission is 93%.

4. The cumulative revenues in the case of constructing a PV power plant with a dual-axis tracking system are (98.2864 M$). This amount is of revenues is higher than that using fixed-tilt and single-axis tracking systems by 27% and 3%, respectively.

5. The average value of LCOE in the case of installing a PV power plant with a dual-axis tracking system is (0.31 $/kWh), while the average values of LCOE for fixed-tilt and single-axis tracking are 0.34 $/kWh and 0.31 $/kWh, respectively. Thus, the dual-axis tracking is preferred over the other systems due to the lower value of LCOE.

6. NPV is positive for all PV-panel installation systems considered in this study. The maximum NPV is obtained using dual-axis tracking about (63.95 M$). This value is higher than the value of NPV in the case of fixed-tilt and single-axis tracking by 32% and 4%, respectively.

Based on outcomes of the present work, several suggestions for further progress on the current topic would be recommended. Further work is needed take into account the effect of discount rate variation (i) on the net present value (NPV). This allows having a more realistic picture on the actual cost of operation and maintenance during the lifecycle of the plant. Also, it might be possible to use a set of PV panels having different efficiencies to find out how the PV panel performance affects the amount of the electrical output for the postulated PV solar power plant.

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