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Impact of solar photovoltaic technology on GHGs reduction – a case study in Jordan

Wpływ technologii fotowoltaicznej na redukcję gazów cieplarnianych: studium przypadku w Jordanii

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ABSTRACT: The global warming phenomenon, primarily caused by the emissions from conventional energy sources, has become a pressing concern worldwide. Greenhouse gases (GHGs), particularly carbon dioxide (CO_2), emitted into the atmosphere contribute significantly to this issue. They have diverse impacts on climate, ecosystems, public health, and socio-economic systems, highlighting the need for comprehensive mitigation and adaptation strategies. To address this problem and minimize GHG emissions, renewable energy sources have emerged as the most promising alternative for power generation. These sources offer a sustainable and clean alternative to fossil fuels, mitigating climate change, reducing air pollution, and fostering energy independence. In the context of this study, a 100 kW solar photovoltaic (PV) station was proposed in Ma'an, Jordan, as a sustainable solution. The effectiveness of this PV station in mitigating GHG emissions was evaluated by comparing it to a base case involving an oil station. To perform this analysis, RETScreen software, a widely recognized tool for assessing renewable energy projects, was used to examine the environmental impact of switching from a conventional energy system to a renewable energy system. The results obtained from the analysis revealed a remarkable reduction in annual gross GHG emissions in the proposed case compared to the base case. Specifically, the emissions would be reduced by 89%, translating to an annual reduction of 49.9 tonnes of CO_2. These findings underscore the significant potential of the proposed solar PV station in curbing the emissions responsible for global warming. By significantly reducing GHG emissions, the solar PV station contributes to creating a more sustainable future, aligned with the principles of environmental preservation and climate change mitigation.

Key words: greenhouse gas emissions, renewable energy, CO_2 reduction, solar photovoltaic system, RETScreen.

STRESZCZENIE: Zjawisko globalnego ocieplenia, przede wszystkim spowodowane emisjami z konwencjonalnych źródeł energii, stało się palącym problemem na całym świecie. Emitowane do atmosfery gazy cieplarniane (GHG), w tym zwłaszcza dwutlenek węgla (CO_2), w istotny sposób przyczyniają się do tego problemu. Mają one różnorodny wpływ na klimat, ekosystemy, zdrowie publiczne oraz systemy społeczno-gospodarcze, co podkreśla potrzebę kompleksowych strategii zarówno w zakresie ich ograniczania, jak i adaptacji. Aby rozwiązać ten problem i zminimalizować emisje GHG, źródła energii odnawialnej pojawiły się jako najbardziej obiecująca alternatywa dla wytwarzania energii. Źródła te oferują zrównoważoną i czystą alternatywę dla paliw kopalnych, przyczyniając się do łagodzenia zmian klimatycznych, redukcji zanieczyszczeń powietrza oraz promowania niezależności energetycznej. Jako trwałe rozwiązanie w kontekście tych badań zaproponowano stację fotowoltaiczną o mocy 100 kW w miejscowości Ma'an w Jordanii. Skuteczność tej stacji fotowoltaicznej w ograniczaniu emisji GHG została oceniona poprzez porównanie jej z przypadkiem bazowym, obejmującym stację ropną. W celu przeprowadzenia tej analizy wykorzystano oprogramowanie RETScreen, powszechnie uznawane narzędzie do oceny projektów związanych z energią odnawialną. Celem było zbadanie wpływu środowiskowego przejścia od konwencjonalnego systemu energetycznego do systemu opartego na energii odnawialnej. Wyniki analizy wykazały znaczną redukcję rocznych emisji GHG w zaproponowanym przypadku w porównaniu z przypadkiem bazowym. Konkretnie, emisje zostałyby zredukowane o 89%, co przekłada się na roczną redukcję o 49,9 ton CO_2. Te wyniki podkreślają znaczący potencjał proponowanej stacji fotowoltaicznej w zwalczaniu emisji odpowiedzialnych za globalne ocieplenie. Mając na uwadze znaczne zmniejszenie emisji GHG, stacja fotowoltaiczna przyczynia się do stworzenia bardziej zrównoważonej przyszłości, zgodnej z zasadami ochrony środowiska i łagodzenia zmian klimatycznych.

Słowa kluczowe: emisje gazów cieplarnianych, energia odnawialna, redukcja CO_2, system fotowoltaiczny, oprogramowanie RETScreen.

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Introduction

The world today is witnessing an increasing demand of fossil fuel energy sources for electricity generation due to the rapid growth of the economy and population worldwide. The massive use of oil and coal as the main fossil fuel sources has detrimental impacts on the environment and climate. They have long been relied upon for transportation, electricity generation, and industrial processes, but their combustion is linked to the global warming crisis that the world faces today. This warming is caused by the increasing emission of particular gases, called greenhouse gasses (GHGs), that comprise methane, carbon dioxide, nitrous oxide, ozone, water vapour, and various classes of halocarbons (Natural Resources Canada, 2009). Their abundance in the atmosphere does not prevent the delivery of the sun's rays to the earth, but it delays the escape of heat from the earth, leading to it being trapped and increasing the average temperatures (Natural Resources Canada, 2009). Anthropogenic emissions of carbon dioxide (CO_2) are believed to be the primary cause of the global climate change acceleration that can be seen in severe weather events such as extreme colds and storms in winter, as well as extreme heat and drought in summer that occur repeatedly (Natural Resources Canada, 2009). The urgency to address GHG emissions stems from the realization that the consequences of climate change extend far beyond environmental concerns. They permeate social and economic spheres, affecting human health, livelihoods, food security, and global stability. Two-thirds of the world's GHG emissions and 80% of CO_2 emissions are a result of the production and use of energy (Ahmed et al., 2021).

To diminish GHG emissions, there is an urgent need to transition away from high-emission fossil fuels towards cleaner and more sustainable energy sources which are the best environmentally friendly alternative for our non-sustainable conventional energy systems. The switch to clean energy depends in large part on the use of renewable energy, which has improved steadily over the past few decades (Momete, 2018). There are practically no GHG or CO_2 emissions from renewable energy sources (Adam and Apaydin, 2016). One example of these sources is the solar radiation energy system which is widely exploited throughout the world. Such a transition is vital not only to mitigate climate change but also to ensure a healthier and more secure future for generations to come.

Solar PV technology generates electricity by harnessing the sun's abundant energy, providing a clean and renewable energy source. Solar PV systems emit no direct emissions or pollutants during operation as they convert sunlight directly into electricity. Furthermore, in addition to GHG reduction, solar PV technology provides benefits such as improved energy security, job creation, and economic growth. According to theoretical calculations, the maximum energy efficiency that PV panels can achieve is just 29%, and for the commercial product, it is only 26% (Dewi et al., 2019).

Jordan has a huge potential for solar energy because it is located in the world's solar belt. The average direct solar radiation ranges from 5 to 7 kWh/m^2 with an average of 310 sunny days per year (MEMR, 2014). The average global solar irradiance on a horizontal surface is 5.6 kWh/m^2 per day on an annual basis, while the total yearly irradiance ranges from 1800 to 2700 kWh/m^2 (Abu-Rumman et al., 2020). Despite numerous attempts to develop alternative energy sources in Jordan, the contribution of clean energy is currently just about 7% of overall energy demand (Abu-Rumman et al., 2020). In this study, a solar PV energy plant with a capacity of 100 kW is assumed to be installed using RETScreen Clean Energy Project Analysis Software in order to investigate the environmental effect of replacing a conventional energy system with a renewable energy system by investigating the reduction in GHG emissions. However, the comparison is carried out assuming that the most common type of fossil fuel used in Jordan is oil (MEMR, 2014).

Case study

Developing solar power plants is very applicable in Jordan due to its location. Table 1 shows the average solar irradiance received annually at nine locations in Jordan for designing the proposed solar power project.

As noted from the given data, Ma'an has the highest annual value for solar irradiation. This makes it the candidate to be selected as a case study due to its significant solar energy potential of about 5.94 kWh/m^2 per day.

Table 1. The average annual solar radiation data for different areas in Jordan provided from RETScreen

Tabela 1. Dane dotyczące średniorocznego promieniowania słonecznego dla różnych obszarów w Jordanii dostarczone przez RETScreen

Location	Average annual solar irradiation [kwh/m^2/day]
Irbid	5.1945
Mafraq	5.1745
Amman	5.6419
Al-Badieh	5.3496
Irwaished	5.6774
Queen Alia airport	5.1617
Bāyir	5.6242
Ma'an	5.9382
Aqaba	5.8885

RETScreen software was used to conduct the analysis for this study, which has a beneficial effect on the global decision-supporting process. It is used, particularly in this study, to assess the energy production and emissions reduction of one type of renewable energy technology: the PV solar panel technique. Tables 2 and 3 show the technical parameters data from RETScreen software for the base and proposed cases, respectively.

Table 2. Features of the base case plant as input variables to RETScreen software

Tabela 2. Charakterystyka elektrowni według przypadku bazowego jako zmienne wejściowe dla oprogramowania RETScreen

Parameter	Value	Unit
Fuel type	Diesel (#2 oil)	[$/liter]
Electricity type	Electricity export rate	[MWh/year]
Electricity export rate*	0.123	[$/kWh]
Initial costs	210.105	[$]
Operation & maintenance costs	2.501	[$]
* (Global petrol prices)		

Table 3. Parametric characteristics of the proposed PV plant as inputs to the RETScreen analysis

Tabela 3. Charakterystyka parametrów proponowanej elektrowni fotowoltaicznej jako dane wejściowe do analizy RETScreen

Parameter	Value	Unit
PV technology type	Photovoltaic mono-Si	
Power capacity	100	[kW]
PV model	Mono-Si – SP150	
Tracking mode	Fixed	
Capacity per unit	150	[W]
Number of units	667	
Slope	26	[degree]

Results and discussion

In this study, the base case of power generation source for the selected location was an oil power plant, while the proposed case was a solar PV plant with a non-tracking (fixed) mode. RETScreen software was used to evaluate the feasibility of setting up a 100 kW solar PV system in Ma'an city. The value of 100 kW is used to calculate the capacity factor, in per cent, to determine to what extent the energy-generating resource is productive. However, a 23.3% capacity factor is considered a good value for the 100 kW solar PV module.

The amount of electricity generated is influenced by the solar radiation at the location (Njoku and Omeke, 2020). Therefore, the solar system proposed in Ma'an provides 204 MWh of electricity exported to the grid annually and $ 25,076 of electricity earnings. Table 4 shows additional characteristics calculated by the software for the designed solar system. In addition, the average monthly solar radiation of the selected city was obtained, as illustrated in Figure 1.

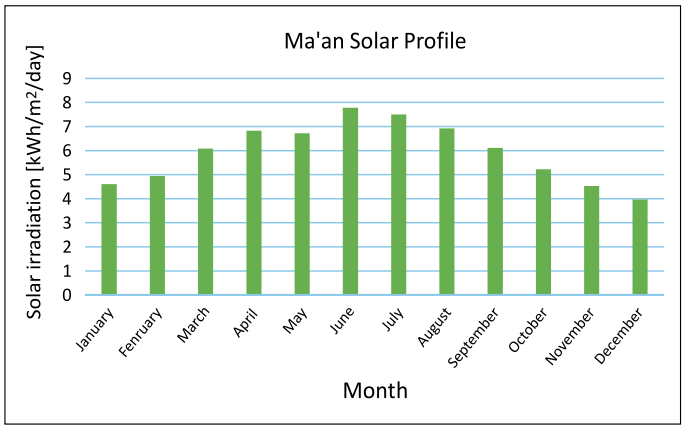

Figure 1. Monthly variation of the daily solar radiation of Ma'an city

Rysunek 1. Miesięczne wahania dziennego promieniowania słonecznego w mieście Ma'an

Table 4. Summary of solar PV energy system in Ma'an

Tabela 4. Podsumowanie systemu solarnej energii fotowoltaicznej w Ma'an

Parameter	Value	Unit
Electricity exported to the grid	204	[MWh/year]
Capacity factor	23.3	[%]
Efficiency	11.7	[%]
Frame area	1.28	[m^2]
Temperature coefficient	0.4	[% (°C)]
Inverter efficiency	95	[%]
Solar collector area	855	[m^2]

The emission analysis is used to determine the reduction in greenhouse gas emissions caused by the solar PV installation (Owolabi et al., 2019) compared to the base case. The transmission and distribution losses of 11% (Electric power transmission and distribution losses) and the GHG emission factor of 0.245 kg CO_2/kWh (Emissions from home energy use for Jordan) were treated as the base case electricity system in Ma'an. RETScreen software allows the user to know the CO_2 emission generated from the base case and the proposed case energy systems. It also calculates the gross annual GHG emission reduction, in terms of equivalent tonnes of CO_2 (tCO_2), for the renewable energy project relative to the conventional system as shown in Table 5.

Comparing the quantity of electricity produced using oil as the energy source with that generated using PV technology results in a net reduction potential of 49.9 tonnes of greenhouse

Table 5. Annual GHG emission for the base case system and 100 kW solar PV system

Tabela 5. Roczne emisje gazów cieplarnianych dla systemu według przypadku bazowego i systemu fotowoltaicznego o mocy 100 kW

GHG emissions	
Based case (tCO_2)	56.1
Proposed case (tCO_2)	6.20
Gross annual reduction (tCO_2)	49.9

gas emissions to the environment annually that, on a per kW basis, equals 0.5 tCO_2/kW. That means the atmosphere will be free of 89% of the CO_2 released.

to evaluate the net annual GHG or CO_2 emission reduction capacity of installing a 100 kW solar photovoltaic system using RETScreen software. This tool used the climatic data from NASA and some other technical parameters as input for the analysis.

Based on the selected area, the results indicated that the gross annual GHG emission would be diminished by 89% which translates into yearly savings of 49.9 tCO_2. The environmental assessments performed for the current paper showed that renewable energy sources would be used to create a more sustainable future by reducing the effect of global warming created by the consumption of conventional energy sources such as fossil fuel.

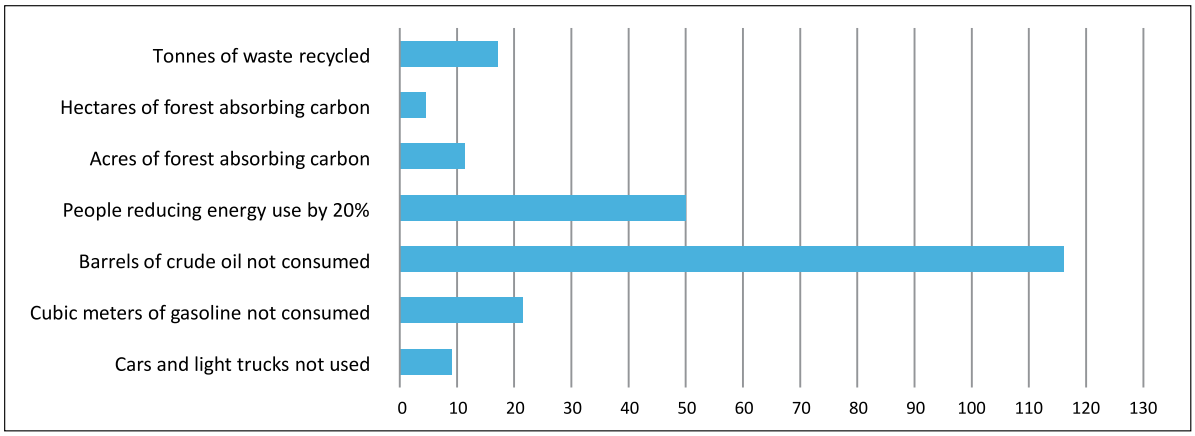

Figure 2. GHG equivalence for 49.9 tCO_2 reduction

Rysunek 2. Ekwiwalent gazów cieplarnianych dla redukcji wynoszącej 49,9 tCO_2

Figure 2 shows the GHG equivalence for the previous reduced value.

Based on the finding of this study, it compares well with the results of other studies that used RETScreen such as a 91% reduction in dairy farm in Iran (Gholami et al., 2019). The RETScreen GHG emission analysis indicated that Ma'an city has a considerable potential to prevent the GHGs that can be released into the environment by the use of fossil fuel energy sources. This demonstrates that Ma'an's reliance on solar PV farms for electricity generation will significantly reduce GHG emissions caused by energy-related activities that, in turn, may encourage the government to incentivize and subsidize it, and do further research on other cities in Jordan. Therefore, the project can be put into action since it is environmentally beneficial.

Conclusion

This study was conducted to assess the feasibility of a renewable energy project in Ma'an city in Jordan using a grid-connected solar photovoltaic system. Also, it was carried out

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