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An Analytical Study on the Potential of Installing Photovoltaic Stations in some Iraqi Cities

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Abstract

Due to the obvious rise in electrical energy demand, primary energy resources such as oil, gas, and coal, which are used to get the electrical energy, are depleting. Most primary energy sources available today come with environmental issues and high extraction costs. Therefore, increasing the utilization of renewable energy resources (RES) is considered one of the most effective solutions to address these challenges. Among the various RES options, photovoltaic power systems (PVPS) are commonly employed as they provide electrical energy without causing environmental issues. However, due to the relatively high costs of PVPS, conducting feasibility studies is crucial for implementing major RES-related systems. These studies involve various proposals that play a crucial role in the formation of PVPS. The methodology adopted in this study is based on a simulated software program called PVsyst incorporates features of the system being used and real-time meteorological variables from Visual Crossing Weather. Parameters such as tilt angles, solar radiations, power production, temperature, humidity, wind speed, and other factors are considered in investigating the selection of optimal locations for the proposed PVPS system. Western Iraq was the best in all respects, but southern Iraq was the worst compared to the east or north parts of the country. Findings are then reviewed for four major cities in Iraq to determine the best city for solar power plant installation, along with the characteristics of each city.

Keywords: renewable energy resources, photovoltaic power systems, PVsyst, visual crossing weather.

الخلاصة: نظرًا للزيادة الواضحة في الطلب على الطاقة الكهربائية، فإن مصادر الطاقة الأساسية مثل النفط والغاز والفحم، التي تُستخدم للحصول على الطاقة الكهربائية، تتناقص بشكل ملحوظ. كما أن معظم مصادر الطاقة الأساسية المتاحة اليوم تأتي مع مشكلات بيئية وتكاليف استخراج مرتفعة. لذلك، يُعتبر زيادة استخدام مصادر الطاقة المتجددة (RES) أحد الحلول الأكثر فعالية لمواجهة هذه التحديات. من بين خيارات الطاقة المتجددة المتعددة، تُعتبر أنظمة الطاقة الشمسية الكهروضوئية (PVPS) الأكثر شيوعًا، حيث توفر الطاقة الكهربائية دون التسبب في مشكلات بيئية. ومع ذلك، وبسبب التكاليف المرتفعة نسبيًا لهذه الأنظمة، فإن إجراء دراسات جدوى أمر بالغ الأهمية لتنفيذ الأنظمة المتعلقة بمصادر الطاقة المتجددة. تتضمن هذه الدراسات عدة مقترحات تلعب دورًا محوريًا في تشكيل أنظمة الطاقة الشمسية الكهروضوئية. المنهجية المعتمدة في هذه الدراسة تعتمد على برنامج محاكاة يُسمى "PVsyst" يتضمن ميزات النظام المستخدم ويستفيد من متغيرات الطقس الفعلية المقدمة من "Visual Crossing Weather". يتم أخذ معايير مثل زوايا الميلان، والإشعاع الشمسي، وإنتاج الطاقة، ودرجة الحرارة، والرطوبة، وسرعة الرياح، وعوامل أخرى في الاعتبار عند دراسة اختيار المواقع المثلى للنظام المقترح للطاقة الشمسية الكهروضوئية. كانت المنطقة الغربية من العراق هي الأفضل من جميع النواحي، بينما كانت المنطقة الجنوبية هي الأسوأ مقارنة بالمناطق الشرقية أو الشمالية من البلاد. بعد ذلك، يتم مراجعة النتائج لأربع مدن رئيسية في العراق لتحديد أفضل مدينة لإنشاء محطة طاقة شمسية، بالإضافة إلى تحديد خصائص كل مدينة.

1. INTRODUCTION

Solar energy, derived from the sun's light and heat, has been used by humans since ancient times through evolving technologies. Solar energy techniques include solar thermal for direct heating, mechanical conversion for movement or electricity, and photovoltaic panels for electricity generation. Solar energy is considered abundant, reliable, and environmentally-friendly, gaining global attention and investment for a sustainable future [1]. Optimal site selection is crucial for maximizing energy production while minimizing costs. Several studies have been conducted to identify suitable locations for solar power plants in the literature [2-6].

Iraq has recently emerged as a player in the solar energy industry due to its favorable geographic location with dry and sunny weather conditions in the western and southern regions, making it conducive for solar energy utilization [4]. The depletion of fossil fuels, concerns about frequent power outages, and the environmental impact of backup generators powered by petroleum compounds have prompted Iraq to shift towards renewable energy sources like solar energy [2-3]. Solar energy is seen as a compelling solution for meeting Iraq's energy demands, given its abundant availability, environmental benefits, and potential for cost-effective electricity generation. Careful site selection and strategic planning are essential for optimizing solar energy installations, and transitioning towards renewable energy sources is imperative for a sustainable and greener future [4].

Ongoing research focuses on developing new techniques and machinery to improve the performance of solar systems in various environmental conditions. In a study conducted in Duhok, Iraq, the tilt angle of a photovoltaic (PV) system was adjusted to maximize power generation from solar radiation [2]. The researchers used PVGIS, a photovoltaic geographical information system simulator, and a free online solar photovoltaic energy calculator to analyze the performance of three different PV system technologies: crystalline silicon, copper indium selenide (CIS), and cadmium telluride (CdTe). The findings revealed that the ideal monthly tilt angle for Duhok city in northern Iraq is 30° during summer and over 50° during winter. Similarly, in another study conducted in Basra city, southern Iraq, researchers investigated the ideal tilt angle for PV systems through theoretical calculations and practical investigations of PV cell performance [3]. After using an experimental test rig and manually adjusting the tilt angle within a range of 0° to 90°, the researchers concluded that the yearly ideal tilt angle for Basra city is 28°. Further research has also been conducted to analyze the effects of temperature, wind, humidity, and dust on solar energy applications in Iraq [4]. The authors recommended the use of photovoltaic thermal (PVT) cells or hybrid solar collectors to utilize the heat generated by solar panels in other applications and boost overall efficiency. In addition, studies have compared the performance of fixed-tilt and tracking solar systems. Drury et al. found that two-axis tracking systems can enhance PV generation by 30 to 45 percent compared to fixed tilt systems [5]. Another analysis conducted on a test rig demonstrated that the overall generated power of a two-axis tracking system was 35 percent higher than that of a fixed-angle system [6]. Furthermore, it has been elucidated in a study conducted in the Basra Governorate that fixed and tracking solar power systems exhibit differences in sun energy production [7]. The findings were obtained through theoretical calculations, online PVWatts, and worldwide solar atlas simulator system simulations, among other methods. These studies highlight the importance of optimizing solar energy systems through techniques such as adjusting tilt angles, utilizing PVT cells or hybrid solar collectors, and implementing tracking systems to maximize power generation efficiency in different regions of Iraq. Continued research and development in solar energy technology are crucial for further advancements in harnessing the potential of solar energy as a sustainable and environmentally friendly source of electricity.

In this study, the effectiveness of two different solar power generation systems—a fixed tilt system and a seasonal tilt adjustment system—is compared in four different Iraqi cities, representing the north, south, east, and west of the nation: Mosul, Basra, Diyala, and Anbar. The following goals are the focus of the study: Outlining the reasons Iraq should switch to renewable energy analyzing the solar path and choosing the four cities' ideal solar elongations comparing the differences in solar energy output between solar power systems with fixed tilt and those with seasonal tilt adjustments. examining the effects of weather on photovoltaic (PV) system performance and output, and comparing these effects between cities.

The research methodology for this study is described in the second section, followed by the presentation of results and comments in section 3. The findings of this investigation are summarized in section four. Additionally, this part provides a brief introduction to solar energy and a review of relevant literature.

2. METHODOLOGY

In this section, we designed and simulated a 1000-kilowatt solar power plant connected to the grid without a storage system in four different provinces in Iraq. This research was done using the PVsyst Program [8], which is intended for architects, engineers, and researchers to use. It's also a fantastic teaching resource. It comes with a comprehensive contextual help menu that describes the techniques and models utilized, as well as a user-friendly approach with a project development guide. PVsyst can import meteo data as well as personal information from a variety of sources.

2.1 The Geographical Locations and Weather Conditions of the Selected Cities

Al-Mosul is the first selected city in Upper Mesopotamia, located at a height of 223 meters above sea level. It experiences hot, dry summers, mild autumns and springs, and chilly winters [9]. The second city, Basra, located in southern Iraq, has hot, humid summers and cold, lightly raining winters due to its proximity to the Arabian Gulf. Temperatures can reach up to 50°C in the summer and as low as 2°C in the winter [10-11]. The third one is in Diyala Governorate, located in northeast Baghdad, and has a mean annual temperature of 36°C and covers an area of 17,685 square kilometers [12]. Anbar, the fourth city in the western desert region of Iraq, is one of the driest governorates, with steppe and desert topography. It receives minimal rainfall annually and experiences extreme temperatures, with summer maximums reaching 52°C and winter minimums dropping to 0°C [13]. Design a 1000-Kilowatt Solar Power System in Pvsyst.

2.2 Design a 1000-Kilowatt Solar Power System in PVsyst

The solar panel, composed of interlocked photovoltaic cells or solar cells, harnesses light to generate electricity. These panels are commonly used in residential and industrial settings to produce electricity. When selecting solar panels, it's important to choose reputable products that meet the system's requirements. For instance, Omnis Power USA offers the OP600M60-P4 solar module, which has a length of 2172 mm, a width of 1303 mm, and a thickness of 35 mm, with a weight of 30.9 kg. The module covers an area of 2.830 m² and contains 120 cells utilizing Si-mono technology. It has a short-circuit current (Isc) of 18.52 A and a maximum power point (Impp) of 17.44 A. The temperature coefficient (muIsc) is 9.3 mA/C, and the open circuit voltage (Voc) at -10°C is 45.8 V, while the voltage at the maximum power point (Vmpp) at 60°C is 29.7 V. To achieve a nominal AC power of 1000 KWAC, 1672 panels would be required, with each panel delivering 600 watts at 29 volts. The estimated area needed to accommodate these panels is around 4732 m², and the solar plant would comprise 76 strings, each consisting of 22 panels connected in series.

An inverter is a type of electrical equipment that transforms the direct current generated by solar panels into an alternating current, which may then be sent into the electrical grid or utilized locally to power a load not linked to the grid. Solar inverters are one of the most important components for the stability of solar electric systems because they allow the operation of alternating-current electrical loads. They also play an important role in anti-islanding in solar panel systems connected to the grid, as well as tracking the maximum power point. In this study, two inverters (500/4 mod-ID) from the Sepsa company have been chosen. 500/4 mod-ID has input and output sides designed for a DC PV field and an AC grid, respectively. The system has a height of 1700 mm, a width of 3200 mm, a depth of 600 mm, and a weight of 1650 kg. The output voltage is 400 V at 50/60 Hz, and the nominal AC power is 500 kW, with a maximum AC power of 550 kW. The nominal AC current is 722 A, while the maximum AC current is 793 A. The system has a maximum power point (MPP) voltage of 600 V and an absolute maximum PV voltage of 950 V. The power threshold of the system is 2475 W.

As seen in Fig. 1, these primary components are connected together. The use of a storage system in these systems has been overlooked since the goal of this study is to do an analytical study on the installation of fixed and seasonal tilt-adjusted solar power systems in various locations across Iraqi cities.

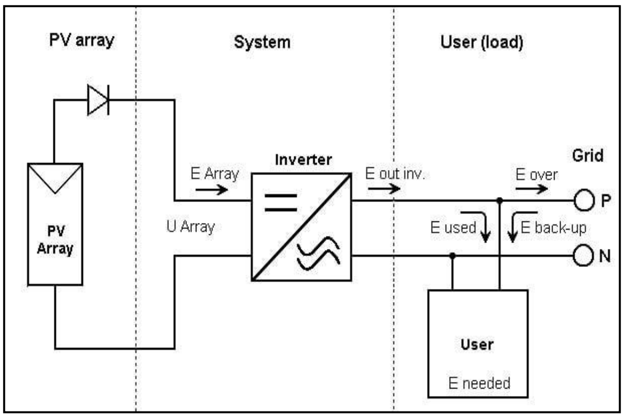


Fig. 1. The designed solar plant.

2.3 Sun Path and Solar Angle

We can infer that different tilt angles must be used when installing solar panels because the sun's path from sunrise to sunset varies throughout the year. The zenith angle (θz) is the angle formed by the sun and a vertical line. In the summer, the sun is nearly vertical, which means that θz is low and therefore the tilt angle (β) must be minimal. Winter time causes the θz reading to be greater, indicating that the β has risen as shown in Fig. 2. The sun has distinct zenith angles, or varying tilt angles, in the other months in between the summer and winter seasons. Mathematically, the tilt angle can be determined by (1) [13]. Where the latitude angle between a given point and the equator's plane is ∅. Also, δ, which is calculated by using (2), is the declination angle between the equatorial plane and the plane of solar radiation, where d is the targeted day of the year [14].

$$\beta = |\emptyset - \delta| \quad (1)$$

$$\delta = 23\ 45 \times sin\ [360 \times (284+d)\ /\ 365\ ] \quad (2)$$

Using (1) and (2), an ideal fixed tilt angle for a year was determined by averaging the tilt angles. Table I displays the slight variations in the sun's fixed tilt angle across the chosen cities. Also, calculating the seasonal tilt angles for the same locations is shown. After optimization, an ideal tilt angle is selected to serve as the fixed tilt angle for the entire year as well as two tilt angles for the summer and winter. To maximize the PV system's output power, these angles were chosen.

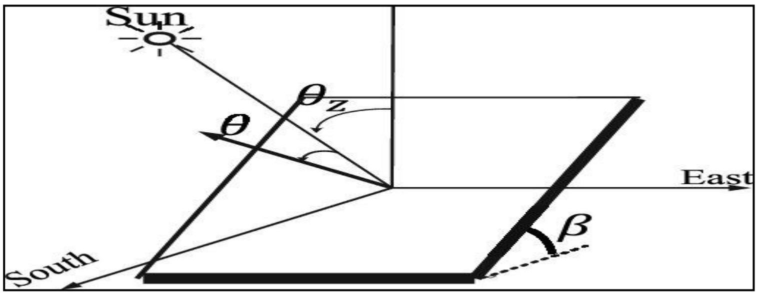


Fig. 2. The clarification of the sky and the sun's angles [1].

Table 1. The calculated tilt angles

Cites	**The fixed tilt angle**		**The seasonal tilt angles**	
	Summer	***Winter***	***Summer***	***Winter***
Mosul (36.409, 43.158)	33°		15°	53°
Basra (30.481, 47.762)	29°		13°	48°
Diyala (34.032, 45.075)	32°		15°	52°
Anbar (32.985, 40.297)	32°		15°	52°

3. RESULTS AND DISCUSSION

3.1 Power Production

The solar system has been installed in four different cities, with each city hosting an identical plant. Mosul, Basra, Diyala, and Anbar cities are the respective locations of the first, second, third, and fourth solar plants. Subsequently, calculations are carried out for system production, specific production, performance ratio, normalized production, array losses, and system losses using the equations provided in [8].

$$\text{System Production} = E/1000 \quad (3)$$

$$\text{Specific Production (SP)} = E/(A*Ppeak*T) \quad (4)$$

$$\text{Performance Ratio (PR)} = E/(A*G) \quad (5)$$

$$\text{Normalized Production (NP)} = E/(A*Ppeak) \quad (6)$$

$$\text{Array Losses (AL)} = (1-PR/100)*(G/1000) \quad (7)$$

$$\text{System Losses (SL)} = \text{AL} + \text{TL} \tag{8}$$

Where *E* is the total energy (in kWh) that a PV system has produced over a given period of time. *A* is the system's total PV module area (measured in square meters). Ppeak is the DC peak power (measured in kWp) of the PV system. *T* is the length of time (in years) used to measure the amount of energy produced. *G* is the PV system's cumulative solar radiation over the same time period (measured in kWh/m2). The PV system's performance ratio, or PR, is expressed as a percentage. *TL* is the total losses (expressed in kWh/kWp/day) resulting from all other factors affecting the system's performance, including inverter efficiency, wiring losses, and other system losses. As demonstrated in Table II, it shows the characteristics of the PVPS system in the four different cities in Iraq. Diyala has the greatest system performance ratio of 85.1 percent and is less affected by the array losses. On the other hand, Anbar city has the highest system production of 1990 MWh/yr due to the high value of global horizontal irradiation there. However, Anbar's location was the worst affected by large array losses. Basra was the worst site due to lower system production and high array losses.

Table 2. The general performance of the designed system using a fixed tilt angle

The system's characteristic	**Mosul**	**Basra**	**Diyala**	**Anbar**
System Production MWh/yr	1763	1689	1710	1990
Specific Production kWh/KWp/yr	1757	1683	1705	1984
Performance Ratio %	84.8	83.3	85.1	84.5
Normalized Production kWh/kWp/day	4.81	4.61	4.67	5.43
Array Losses kWh/kWp/day	0.77	0.84	0.73	0.90
System Losses kWh/kWp/day	0.09	0.09	0.09	0.1

Table III, shows the performance of the same plant when seasonal tilt angles are used on the same sites. A comparison was made between Table II and Table III in terms of percentage increase or decrease for various system characteristics. In terms of System Production (MWh/yr), all regions showed an increase: Mosul with a 7.35% increase, Basra with a 3.49% increase, Diyala with a 3.63% increase, and Anbar with a 4.72% increase. For Specific Production (kWh/KWp/yr), all regions also showed an increase: Mosul with a 3.75% increase, Basra with a 3.56% increase, Diyala with a 3.58% increase, and Anbar with a 4.73% increase. Regarding Performance Ratio (%), Mosul showed a slight increase of 0.12%, while Diyala had no change (0%), and Anbar showed a decrease of -0.12%. Basra had no change (0%). Normalized Production (kWh/kWp/day) increased in all regions: Mosul with a 3.95% increase, Basra with a 3.47% increase, Diyala with a 3.64% increase, and Anbar with a 4.79% increase. Array Losses (kWh/kWp/day) also increased in all regions: Mosul with a 3.90% increase, Basra with a 3.57% increase, Diyala with a 2.74% increase, and Anbar with a 5.56% increase. System Losses (kWh/kWp/day) remained unchanged in Mosul and Basra, while Diyala showed no change (0%) and Anbar had a 10% increase. Overall, the comparison indicates increases in most of the system characteristics, indicating improvements in system performance and production for the regions mentioned.

Table 3. The general performance of the designed system is determined by using seasonal tilt angles

The system's characteristic	**Mosul**	**Basra**	**Diyala**	**Anbar**
System Production MWh/yr	1892	1748	1772	2084
Specific Production kWh/KWp/yr	1823	1743	1766	2078
Performance Ratio %	84.9	83.3	85.1	84.4
Normalized Production kWh/kWp/day	5.0	4.77	4.84	5.69
Array Losses kWh/kWp/day	0.8	0.87	0.75	0.95
System Losses kWh/kWp/day	0.09	0.09	0.09	0.1

3.2 Weather Variables and the Effectiveness of the Solar System

Solar energy production is significantly influenced by climatic factors such as temperature, relative humidity, dust, and wind. This paper has relied on weather data and enterprise analysis tools to study the weather conditions in the four locations for one year, from January 1, 2021, to January 1, 2022. Data scientists, business analysts, professionals, and academics can access meteorological data and corporate analysis tools from Visual Crossing [15]. Since its inception in 2003, its goal has been to enable data users and analysts to make better decisions based on reliable, easy-to-access data. Climate summaries, historical weather forecasts, historical weather data, and specialist weather metrics like sun radiation, degree days, and weather alerts are all available via Visual Crossing. The temperature has a negative impact on the voltage we get from the solar panel; that is, when the temperature rises, the panel voltage drops dramatically, but the temperature-current relationship only rises somewhat. The efficiency of the solar cells in the solar panel is reduced as a result of this. 10–25% of output efficiency can be lost due to heat. The output voltage declines linearly while the output current rises exponentially as the solar panel's temperature increases. As a result, heat can significantly lower the output of the solar panel [11] and [16]. According to Fig. 3 (a), the highest annual maximum temperatures were reported in Basra and Diyala, whereas the highest annual maximum temperatures in Anbar were lower. Since relative humidity directly influences solar irradiation, it has an effect on how well solar panels operate. This is how the impact of humidity can be explained: when solar energy hits the ground, it will be absorbed by both the ground and the surrounding air. As a result, the surrounding temperature will increase. The air absorbs more heat than the ground does when the humidity reading is high. It's important to note that solar panel output energy is only proportional to ground absorption. So, if the ground absorption is low, the output power is also likely to be low [17], [18], and [19]. Fig. 3 (b) demonstrates the recorded relative humidity in all the locations over a year. Both Anbar and Basra have the highest relative humidity during the summer. However, Mosul has higher relative humidity during the winter.

The amount of solar radiation hitting the solar panel's surface as well as the current leaving the solar panel change from hour to hour and from day to day. Because of clouds and other things that obstruct the sun's rays from reaching the panel. In Fig. 3 (c), there is a comparison among the solar radiation that hits the four locations.

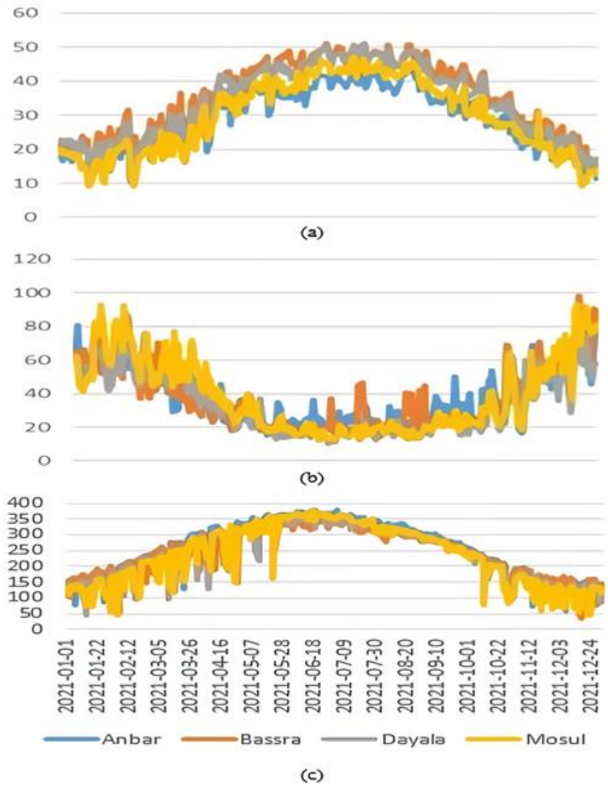
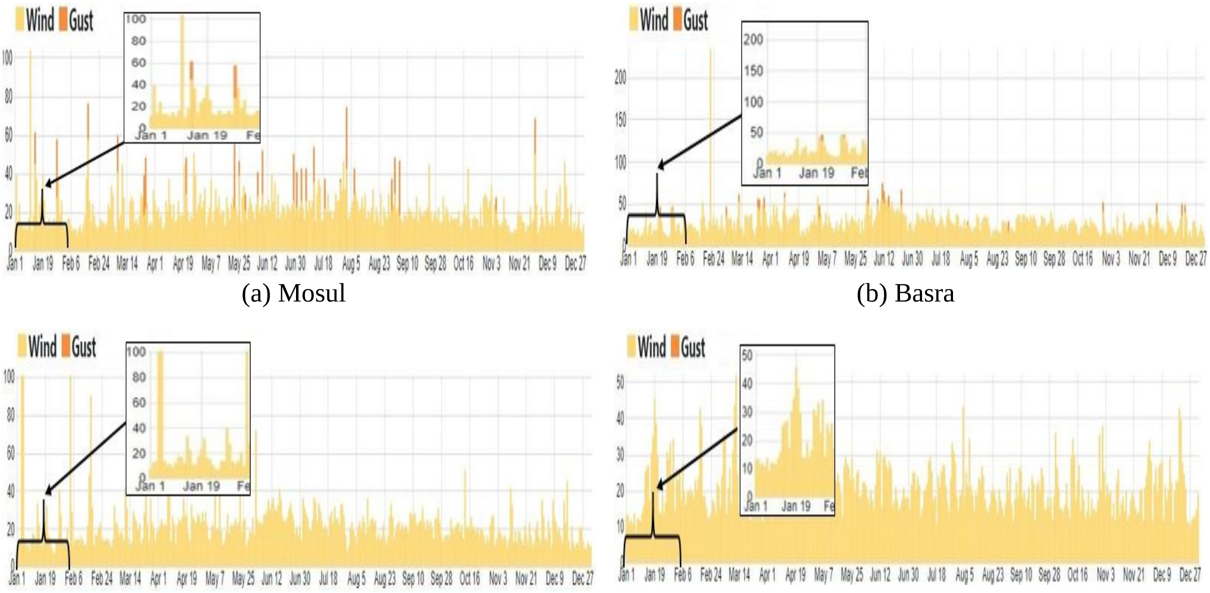


Fig. 3. (a) The maximum temperatures in C° in the four cities over a year. (b) The relative humidity in the four cities over a year. (c) The daily solar radiation over a year in four cities.

Another element that affects the effectiveness of solar panels is dust [18]. Solar panels cannot receive solar radiation because of dust particles. The dust screen that forms over the surface of solar panels, which stops solar energy from directly striking the solar cells, is made up of two different types of dust. There is yet another form of dust floating in the air, particularly in arid regions. By deflecting, reflecting, or absorbing the sun radiations, these particles cause distortion. On the other hand, the wind is regarded as nature's reaction to the aforementioned weather issues. Temperatures can be significantly lowered by the wind [18]. Additionally, it lowers relative humidity and cleans the solar panels' surface of dust. However, because different solar photovoltaic modules have varied strengths and stress norms, the high wind speed may potentially cause the modules to bend [20]. Fig. 4 shows the recorded wind and gust speed in the cities. It is very clear that we had some gust in Mosul and Basra when we had high speed wind. However, the wind speed exceeded 50 kph in one day only in the last year in Anbar, and there are not any gusts have been recorded in both of Diyala and Anbar



(a) Mosul (b) Basra

(c) Diyala (d) Anbar

Fig. 4. Wind and gust speed in kph in Mosul, Basra, Diyala, and Anbar

4. CONCLUSION

In this study, deciding on the most suitable location for a solar power plant installation is investigated. An identical simulated PV system was installed in four cities in Iraq based on real weather data. The results that have been reached give a clear idea of the pros and cons accompanying the installation of the solar system in the proposed areas. The results show that the high performance ratio was in Diyala and in Mosul, while the high system production was in Anbar and Mousl. On the other hand, the use of the angle of inclination according to the season has a significant positive impact in the provinces of Mosul and Anbar, while it has a lower effect in the provinces of Basra and Diyala. It was also found that Anbar Governorate represents the most appropriate place to install these units according to the weather conditions, such as the daily solar radiation, the maximum temperatures, and the wind and gust speeds available to the above areas, and the worst place was in Basra. Finally, the outcome of this paper provides preliminary data analysis on the types of constraints that accompany the use of these systems in those areas that could be further addressed in the future.

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