Evaluation of the Environmental and Economic Performance of Wind Turbines in Regions with Different Climates

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The increasing utilization of limited energy resources, such as oil and gas, along with the depletion of their reserves, highlights the pressing need to shift towards sustainable and renewable sources of energy. Within this particular setting, wind energy presents itself as a notably dependable alternative for the production of power. This study examines the significant influence of climate change on the economic and environmental aspects of wind turbines using a complete numerical modeling approach implemented in MATLAB software. This study conducted a thorough analysis of four distinct places, each chosen to represent a significant meteorological climate, with the objective of evaluating the impact of climate change on wind turbine dynamics. The parameters under investigation were thoroughly analyzed through rigorous numerical modeling techniques. From an economic standpoint, the region characterized by a hot and humid environment has been identified as the most financially feasible in terms of energy production. This region has a levelized cost of $1.6 per kilowatt-hour of energy. In addition, the analysis considered the environmental aspect by utilizing the yard cycle evaluation approach, which took into account the carbon dioxide emissions during the whole lifecycle of the system. The pricing of these emissions was subsequently determined through the implementation of penalty regimes. The area characterized by a moderate and humid climate, with an annual carbon dioxide emission of only 169 kg (resulting in the lowest penalty loss of $3.02 per year), stood out as the most environmentally responsible option among the areas under investigation. This study highlights the urgent necessity of shifting towards renewable energy sources. Through a comprehensive analysis of various climates and their corresponding economic and environmental consequences, it becomes apparent that certain places, particularly those characterized by hot and humid conditions, provide highly favorable opportunities for the utilization of wind energy. The aforementioned findings highlight the significant significance of adopting renewable energy alternatives as a means to address the difficulties presented by climate change and the diminishing availability of fossil fuel supplies.

Keywords: Wind turbine, Environmental Impact Assessment, Economic Analysis, Climate, Modeling, Renewable Energy.

1. Introduction

Within the dynamic context of societal progress, there exists a growing need for energy across all sectors. This demand is driven by advancements in the social, economic, and industrial realms and, as a result, poses significant obstacles. The increasing energy usage has raised concerns about environmental degradation, widespread climate variations, and the rapid depletion of scarce energy resources. As a result, the necessity to shift towards environmentally friendly and sustainable energy sources has gained unprecedented importance. The implementation of this strategy adjustment not only guarantees long-lasting and continuous energy provision but also serves as a crucial factor in reducing the release of carbon dioxide, a significant contributor to the greenhouse effect and global climate change [1-3]. In the realm of renewable energy sources, which encompasses a variety of options such as solar, geothermal, and tidal energy, wind power has garnered significant attention due to its inherent sustainability and extensive availability [4]. Wind turbines are a pivotal technology in the utilization of wind energy since they have the distinct capability to directly transform the kinetic energy of the wind into electrical power[5-7]. Wind turbines can be classified into two main categories: vertical-axis turbines and horizontal-axis turbines. In recent years, there has been significant interest in horizontal-axis turbines due to their superior power coefficients and torque when compared to vertical-axis turbines. The performance of horizontal-axis wind turbines is closely tied to the wind intensity in the particular geographical region where the turbine is positioned[8, 9]. Consequently, the careful and thorough process of site selection assumes significant importance. In addition, it is important to note that different geographic regions display unique meteorological conditions, including variables such as wind speeds, humidity levels, and altitude above sea level. These factors significantly impact the operational effectiveness of wind turbines[5, 10-12].

On a global scale, climates can be classified into five main categories: tropical, desert, temperate, continental, and polar climates. In light of the wide range of climatic conditions and the resulting environmental fluctuations, it is crucial to carefully choose wind turbines that are suitable for the specific local climate and wind resources[13, 14]. Therefore, it is imperative to conduct thorough investigations that carefully examine the influence of climatic factors on the economic and environmental efficacy of wind turbines. These studies involve a comprehensive analysis that includes evaluating the levelized cost of energy (LCOE) per kilowatt-hour, taking into account complex economic factors. Additionally, there is a careful assessment of greenhouse gas emissions, with a specific emphasis on carbon dioxide, to conduct thorough environmental impact assessments. Extensive efforts have been devoted to the thorough examination and enhancement of wind turbine systems in research, taking into account many factors such as power generation, economic feasibility, and ecological preservation[15-18].

In this regard, Cheng et al. [19] conducted an investigation on the impact of climate conditions on the financial aspects of wind turbine projects, specifically focusing on costs and profitability. The study's results show that a 20% rise in extreme wind speed can cause the initial capital cost of installing the wind unit to go up by about 12%. This is after taking into account the 50-year return wind speed and changing the load safety factor from 1.35 to 1.7. The increased strength that tropical storms exhibit is to blame for this rise. During this time frame, the intensity of lightning strikes has been heightened as a result of the implementation of taller wind turbines and the increased angular velocity of their blades.

Garcia et al. [20] investigated the classification and analysis of related factors for optimal locations in onshore and offshore wind power plants and the results showed that among all factors, the wind speed coefficient is considered the most important parameter for onshore and offshore technologies. It includes more than 90% of the share.

Kumar et al. [21] conducted a comprehensive examination and evaluation of the energy, emissions, and environmental impacts associated with wind turbines, employing the life cycle assessment methodology. According to the study, the vertical axis wind turbine had higher levels of energy intensity and emissions per kilowatt hour/year of provided energy than the horizontal axis wind turbine when the base case system was used. The implementation of the material reuse approach has been shown to result in a reduction of embodied energy by over 60% and a decrease in environmental impact by more than 50%. Garcia et al. conducted a study on the categorization and examination of pertinent variables for the identification of optimal sites for onshore and offshore wind power installations. The findings indicated that, among the various factors considered, the wind speed coefficient emerged as the primary parameter for both onshore and offshore technologies. It encompasses a majority of the share, over 90%.

In this context, Bhandari et al. [22] conducted a study examining the greenhouse gas emissions throughout the life cycle of wind farms, with a specific focus on the influence of turbine size and capacity factors. The examination of uncertainty revealed that there is typically a minimal level of uncertainty encountered during the life cycle assessment (LCA) modeling stage of wind turbines. This finding suggests that the underlying mechanisms involved in the LCA of wind turbines are well understood and adequately documented. A sensitivity analysis was conducted on the capacity factor, revealing a non-linear relationship characterized by a hyperbolic progression in relation to the global warming potential (GWP).

One of the detrimental impacts associated with wind turbines is the issue of noise pollution. In this regard, Wang et al. conducted an investigation on the prevalent techniques employed for damage assessment and detection in the context of big wind turbine blades. Visual inspection and thermal imaging techniques have the capability to detect surface and internal damage to wind turbine blades without the need for physical contact. However, it is generally recommended to conduct these inspections when the wind turbine is not in operation in order to obtain more precise and reliable results. The utilization of voice recognition technology enables the non-contact detection of the operational condition of the blade in a running state, hence providing insights into its health status. The implementation of this approach necessitates solely the installation of a microphone, with the process being reasonably straightforward. The immediate installation of the device in its designated location is feasible; however, a more comprehensive investigation is necessary to accurately discern alterations in blade noise patterns resulting from blade impairment. The majority of wind farms are situated in geographically isolated regions, whereas offshore wind power is progressively expanding its presence in deep-sea locations[23]. In conclusion, the future of wind turbine blade damage detection will predominantly involve non-contact, real-time, online, remote, and precise methods for assessing blade health in operational settings.

1. Wind Energy Potential in Iraq: Scientific and Technical Assessment

Iraq, situated on the Asian continent, encompasses an area of around 4.38 square kilometers and sustains a population exceeding 40 million individuals. This nation exhibits a variety of climatic conditions. Iraq, being situated in the Middle East region, exhibits considerable prospects in the domain of wind energy which is given in Table 1. The utilization of wind energy in Iraq is seen as a viable renewable energy option due to the presence of expansive regions characterized by consistent and robust wind patterns[24, 25]. Wind speed and the frequency distribution of wind speeds observed on a monthly basis are two weather factors that affect the analysis of wind turbines. Additionally, the number of hours the turbine runs affects its operational efficiency, which depends on the specific turbine model. The amount of power produced depends on a certain range of speeds. After the type of turbine is described, relevant correlations and modeling techniques are given.

Table 1. The climate and geography of the studied cities.

City	Climate type	Above sea level (m)
Basra	Hot and humid	5
Baghdad	Semiarid	34
Erbil	Hot and arid	418
Ramadi	Subtropical	228

In order to investigate the impact of climate change on environmental and economic research, it is imperative to choose a wind turbine with specific dimensions as a reference for numerical modeling. The Siemens Gamesa SG 5.0-132 horizontal axis wind turbine is employed as a numerical modeling reference for the intended objective. Table 2 provides comprehensive information regarding the fundamental characteristics of the Siemens Gamesa SG 5.0-132 wind turbine. The properties encompassed in this category consist of geometric dimensions, the range of speeds at which the turbine operates effectively, the acceptable range of temperatures for the turbine, and additional needs for modeling.

Table 2. The climate and geography of the studied cities.

Unit	Amount	Parameter	Symbol
m/s	4	Cut-in Wind Speed	u_c
m/s	20	Rated Wind Speed	u_r
-	18	Furling Wind Speed	u_f
MW	5	Rated Power	P_e
^0C	-40,60	Temperature Range	T
m	24	Tower Height	H
Year	20	Lifetime	L
%	21	Discount Rate	I
m^2	40	Swept Area	A_x
m	132	Rotor Diameter	D

2. Examination of the pragmatic, financially viable, and ecologically elements

The power output of a wind turbine is highly dependent on the wind speed, to the extent that the turbine's power output is only equal to its nominal value within a specific range of wind speeds[26, 27]. Furthermore, in the event that the speed value exceeds the maximum allowable speed for the turbine or falls below the minimum speed necessary for power generation, the turbine is considered to be in an "out of circuit" state. The calculation of the power generated by a wind turbine can be determined by utilizing equation 1.

$$\begin{aligned} P_e &= 0 \qquad (u < u_c) \\ P_e &= a + bu^k (u_c \le u \le u_r) \qquad (1) \\ P_e &= P_{er} \qquad (u_r \le u \le u_f) \\ P_e &= 0 \qquad (u > u_f) \end{aligned}$$

In this context, P_e represents the rated power of the turbine, while u_c denotes the minimum speed necessary for power generation. The threshold speed required to achieve the rated power generation is denoted as u_r. The term u_f represents the upper limit of speed at which power can be generated by the turbine. The coefficients a and b are derived from equations 2 and 3, respectively.

$$a = \frac{P_{er} u_c^k}{u_c^k - u_r^k} \quad (2)$$

$$b = \frac{P_{er}}{u_r^k - u_c^k} \quad (3)$$

Additionally, the parameter k is the Weibull distribution and is determined through the computation of equation 4.

$$k = \left(\frac{\sigma}{\bar{u}}\right)^{-1.086} \quad (4)$$

Equations 5 and 6 are utilized to compute σ and average speed $\bar{u}$.

$$\sigma^2 = \frac{1}{n-1}\left[\sum_{t=1}^{n} m_i u_t^2 - \frac{1}{n}\left(\sum_{t=1}^{n} m_i u_i\right)^2\right] \quad (5)$$

$$\bar{u} = \frac{1}{n}\sum_{i=1}^{n} m_i u_i \quad (6)$$

The computed speed u_i frequency among all measured times n is represented by m_i in the relationships above. Finally, by calculating the output useful power for each speed using the above formula, the useful power of each city is determined as the monthly average of the powers.

The primary objective in the economic evaluation of wind turbines is to determine the financial expenditure associated with generating each kilowatt hour of electricity through the utilization of wind turbine technology. The aforementioned cost is derived from equation 7. Equation 8 is additionally employed for the computation of the initial equipment cost.

$$C_E = C_I + C_O + C_{Ins} \quad (7)$$

$$C_I = \frac{CI}{8760 P_{e,\,ave}} \quad (8)$$

In the aforementioned equations, the symbol C_I represents the initial cost of the equipment, while C_o and C_{Ins} denote the maintenance cost and insurance cost, respectively, measured in euros $/kWh Additionally, C represents the initial cost associated with the installation of the equipment, expressed in terms of $/kWh.

The coefficient pertaining to the lifespan of the equipment L and the interest rate i can be derived from equation 9. The specific numbers associated with the lifespan of the wind turbine and the interest rate are provided in Table 2, which presents the characteristics of the turbine under investigation. Additionally, it should be noted that the combined expenses associated with maintenance, repairs, and insurance are equivalent to 6% of the initial investment.

$$I = \frac{i(i+1)^L}{(i+1)^L - 1} \qquad (9)$$

The environmental analysis of energy systems is presented in accordance with equation 10. In this context, the variable x_{co2} represents the quantity of carbon dioxide emissions released during the specified time period, whereas the variable y_{co2} denotes the quantity of carbon dioxide associated with the reference energy system as determined using the life cycle assessment methodology. The symbol $\dot{p}_u$ represents the production power rate of the reference system, whereas $t_{working}$ denotes the operational time of said system.

$$x_{co2} = y_{co2} \times \dot{p}_u \times t_{working} \qquad (10)$$

Life cycle assessment (LCA) is a prevalent and established environmental assessment methodology employed for evaluating processes and products. It is widely recognized as a standard approach in the field of environmental assessment. Life cycle assessment (LCA) is considered a crucial method of environmental evaluation, complementing technical and economic assessments[28, 29]. It serves as the third dimension of a comprehensive sustainable assessment, enabling informed decision-making in relation to environmental concerns alongside technical and economic considerations. This methodology entails doing a comprehensive evaluation of the environmental impacts associated with the product, encompassing the entire lifecycle from extraction to disposal and recycling, culminating in the determination of an aggregate pollution index[29-31]. Figure 1 displays a schematic representation of the method under consideration.

Fig.1. Schematic of life cycle assessment method.

Table 3 presents a comparative analysis of varying y values across different systems. It is important to acknowledge that the numbers shown in Table 3 were derived through the use of the life cycle assessment methodology. In the realm of environmental analysis pertaining to energy systems, there are alternative methodologies. Among the emerging approaches in this domain, one notable method is economic environmental analysis, as denoted by equation 11.

$$C_{co2} = x_{co2} \times c_{co2} \qquad (11)$$

The economic environmental parameter, denoted as C_{co2}, and the carbon dioxide emission price, represented by c_{co2}, are the variables under consideration. The parameter acquired represents the monetary value associated with the carbon dioxide emissions generated within the specific system under consideration[32]. It serves as a means of assessing energy systems from an environmental standpoint. In order to mitigate climate change and associated phenomena such as global warming, various strategies and policies have been suggested with the aim of minimizing carbon dioxide emissions.

Table 3. The amount of carbon dioxide released.

System type	Wind	Solar panel	Natural gas	Fuel cell	Solar	coal
Carbon dioxide is released (kg)	0.0-98	0.0-541.2	0.443	0.670	0.0072	0.1-965.06

The utilization of an economic-based carbon pricing methodology aims to enhance the tangibility of environmental impacts, facilitating a more comprehensive investigation of the matter. Through the establishment of incentive or punitive policies, such as financial fines, this strategy effectively mitigates the environmental consequences associated with energy systems. Figure 2 depicts a schematic representation of the utilization of environmental-economic analysis and its interaction with environmental analysis. The cost of carbon emissions in various countries exhibits variability based on their respective policies, ranging from 13 to 16 dollars per metric ton of carbon dioxide emitted. This study considers the average value of $13.5 per ton, which is equivalent to $0.01350 per kilogram of carbon dioxide, based on the range of price fluctuations.

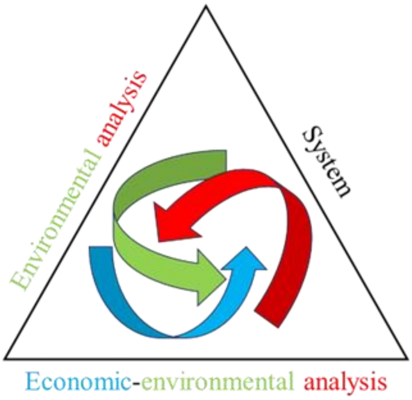

Fig.2. The relationship between environmental analysis and environmental-economic analysis.

3. Modeling and Validation

The primary objective of the numerical model constructed in the MATLAB software is to assess the influence of climate change on economic and environmental factors in relation to a horizontal-axis turbine system. The present software application, specifically developed for the purpose of analyzing environmental and climatic data acquired from meteorological sources, performs computations to determine the occurrence rate of wind speeds within specific ranges on a monthly temporal scale. This study provides a comprehensive analysis of the turbine's operational schedule in relation to power generation.

The model evaluates the turbine's effective power output and calculates the equilibrium between energy expenses, environmental factors, and economic-environmental indicators on a monthly basis for various cities.

The model consists of four primary components. The meteorological data is initially entered into the software from the appropriate source and subsequently classified as monthly averages using modeling techniques. In the subsequent phase, the generated power is assessed by considering the parameters of the turbine. The subsequent portions of this study delve into economic and environmental principles, utilizing the findings obtained from the examination. The modeling framework is designed to obtain outcomes on both a monthly and annual basis. In the present research framework, it is believed that all factors pertaining to the examined turbine, such as durability and capacity to withstand diverse weather conditions, are held constant in order to facilitate comparison analysis. Furthermore, within the context of the data classification process, it is assumed that there are no instances of human errors, and all presented values are cited with the utmost accuracy.

Before presenting the outcomes of numerical modeling, it is imperative to verify the precision and reliability of the model's performance. In this case, a validation procedure was used to check how accurate the numerical model was by comparing its outcomes with the information in the company's data sheet. The validation process was conducted with the average wind speed data for each respective city. In order to verify the accuracy of the numerical model, the power output of the turbine was assessed by referencing Figure 3, which was obtained from the official catalog of the company. This figure illustrates the correlation between wind speed and power production. The mean wind speed for each municipality was computed during a 12-month period. Subsequently, the power output value for each city was derived by employing the power curve depicted in Table 4.

Concurrently, the numerical model was utilized to compute the power output of the turbine by taking into account wind speed and meteorological parameters. The computations of the model were performed taking into account various weather conditions and employing the identical assumptions that were utilized during the validation procedure. The differences seen between the results of the numerical modeling and the data from the power curve can be caused by a number of different factors. Some of the things that can make wind speed data analysis uncertain are the fact that measurements of wind speed vary around their mean values, the assumptions that were made during the modeling process, the fact that data can be wrongly categorized, and the fact that a standard modeling approach is used that doesn't take into account different weather conditions.

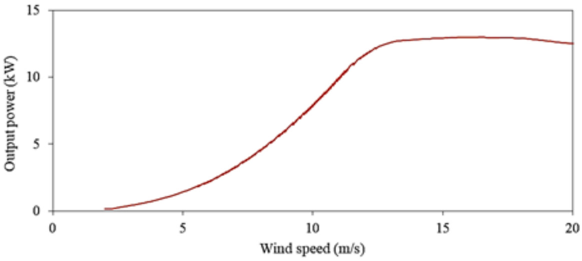

Fig.3. Turbine power curve.

It is very important to understand that the current differences and errors seen in the results of numerical modeling are due to these things. Attempts were undertaken to alleviate these concerns, and the process of validation yielded significant insights into the precision and constraints of the model.

Table 4. Comparison of turbine output power with power curve.

City	Power curve results	Modeling results	Error
Basra	0.550	0.594	5.4
Baghdad	0.830	0.890	5
Erbil	0.915	0.950	3.3
Ramadi	0.620	0.650	4.7

4. Results and examination of generated power, economic factors, and environmental aspects

The primary objective of this study is to investigate the impact of various climatic conditions on wind turbines. To achieve this goal, a research project was designed with a specific focus on the key economic and environmental aspects. During the development of a numerical model centered on horizontal-axis turbines, the fundamental parameters were computed. The user's text lacks sufficient information to be rewritten in an academic manner. Prior to presenting the findings pertaining to the analyses conducted in the realms of economics and the environment, it is deemed suitable. Firstly, it is imperative to examine the climatic component that has the greatest impact on wind turbine power generation. This parameter encompasses wind intensity and speed, together with the operational duration of the turbine. In order to assess the velocity and stability of the four primary regions in Iraq, namely Basra, Baghdad, Erbil, and Ramadi, it is imperative to analyze the variations observed in different months throughout the year. Table 5 presents the wind speed and frequency of each speed range during monthly measurements (Month), as well as the number of working hours of the turbine. These factors contribute to power generation, which is determined by the kind of turbine within a specific speed range.

Table 5. Frequency and average monthly hours of turbine operation.

	Basra (Hour)	Speed range	Abundance	Baghdad (Hour)	Speed range	Abundance	Erbil (Hour)	Speed range	Abundance	Ramadi (Hour)	Speed range	Abundance
January	4.4	0-12	36	7.9	0-12	49	4.9	0-12	42	4.1	0-12	70
February	5.6	0-12	36	9	0-12	48	10.1	0-12	49	8.6	0-12	51
March	4	0-12	42	10.7	0-12	39	8.8	0-12	51	6.9	0-12	58
April	5.2	0-12	40	10.4	0-12	36	8.8	0-12	53	8	0-12	57
May	6.6	0-12	51	10.7	0-12	37	10.2	0-12	55	6.8	0-12	58
June	6.9	0-12	53	14.4	0-12	36	10.6	0-12	63	5.8	0-12	63

December	November	October	September	August	July
4.1	2.7	2.2	3	4.2	3.1
0-12	0-12	0-12	0-12	0-12	0-12
47	29	20	31	35	35
6.5	8.3	2.2	5.1	11.8	9.1
0-12	0-12	0-12	0-12	0-12	0-12
53	52	77	58	31	44
2.5	4	2.3	6	9.8	8.9
0-12	0-12	0-12	0-12	0-12	0-12
32	36	34	57	70	60
1.3	1.6	1.7	2.9	6.6	4.9
0-12	0-12	0-12	0-12	0-12	0-12
88	89	85	77	54	64

Subsequently, the computation of the monthly mean velocity is performed for every urban area, as depicted in Figure 5. Given the research's focus on a yearlong timeframe, the data presented has been computed as the mean daily quantity for each month.

The data depicted in Figure 4 illustrates a discernible pattern wherein the city of Ramadi exhibits the lowest average speed, while the city of Baghdad has the highest average speed. Furthermore, it is evident that the highest average speed occurs in the cities of Basra and Baghdad during the month of June, whereas in the cities of Erbil and Ramadi, it is observed in February.

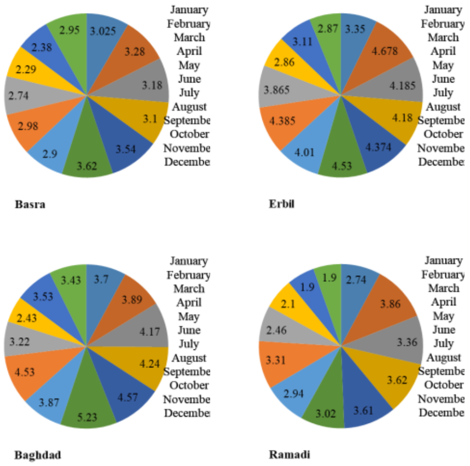

Fig.4. Average monthly wind speed.

As previously elucidated, the energy distribution within the system follows a specific pattern. Wind energy is introduced into the system as an input, and a portion of it is dissipated through heat transfer processes. Ultimately, the residual quantity is transformed into electrical power, serving as valuable and usable energy. Figure 5 presents the quantitative data pertaining to the usable power production derived from the turbine.

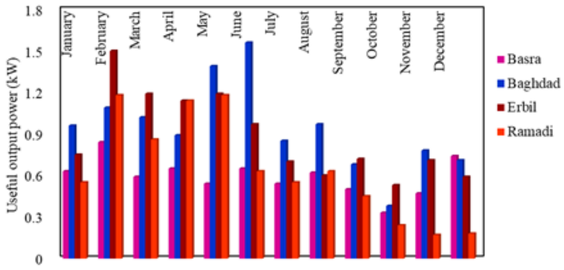

Fig.5. The power produced as a monthly average.

The hot and semi-arid climate of the city of Baghdad can be observed in Figure 6, which is attributed to the higher average speed depicted in Figure 5. Moreover, it should be noted that the aforementioned city exhibits the highest level of production power in comparison to other cities.

Within the scope of the economic analysis of the wind turbine system, a detailed examination of the energy production cost per unit has been done. This exploration goes into several elements, including the system's lifespan, interest rates given in Table 2, and auxiliary considerations such as repair and maintenance fees, along with equipment and staff insurance costs. By subtracting the overall expenditure from the aggregate energy output of the turbine, the per-kilowatt-hour cost of energy generation is precisely computed. Figure 6 effectively depicts the comprehensive breakdown of monthly energy costs for each city, offering significant insights into the economic dynamics of the wind energy initiative.

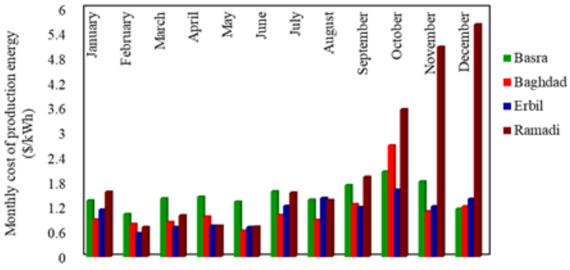

Fig.6. Average monthly energy unit cost.

Upon analyzing Figure 6, it can be inferred that cities that have a higher power output while maintaining the same total cost experience a lower cost per unit of energy. Hence, based on the analysis of Figure 6, it can be observed that Baghdad regularly exhibits the highest levels of usable power. As a result, the energy unit cost in this particular city is correspondingly at its lowest. In order to enhance the accuracy of comparing cities and their climates, Figure 7 has been compiled to depict the annual average energy unit cost for each urban area. The presented graphic depiction offers a comprehensive viewpoint, augmenting our comprehension of energy economics in various urban landscapes and environmental settings.

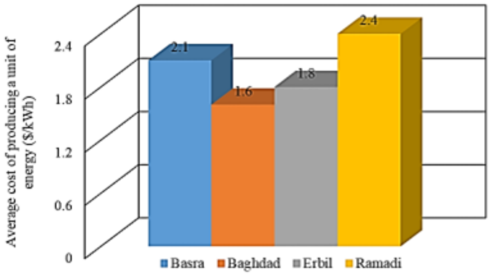

Fig. 7. Average annual energy unit cost.

Figure 7 illustrates that Ramadi, characterized by a continental climate, exhibits the highest cost per unit of energy. Conversely, Baghdad, with a hot and dry climate, demonstrates the lowest cost. Consequently, considering the economic aspect, Abadan city, with a hot and dry climate and an elevated cost of energy as of 1.03 $/kWh, emerges as the most favorable choice.

In accordance with the environmental assessment of the wind turbine system, the quantification of carbon dioxide emissions can be regarded as a fundamental metric. It is important to acknowledge that renewable energy sources generate significantly lower levels of carbon dioxide compared to fossil fuels. Consequently, the adoption of renewable energy sources plays a crucial role in mitigating greenhouse gas emissions. The quantity of carbon dioxide emitted throughout the life cycle of the system, encompassing production, utilization, and disposal, is contingent upon the effective power output. Table 6 provides a comparative representation of the average daily carbon dioxide emissions and the annual penalty cost of carbon dioxide emissions across different months.

Table 6. The average daily amount of carbon dioxide emitted per month and the annual penalty cost of carbon dioxide emissions.

City / Month	Basra (kg)	Baghdad (kg)	Erbil (kg)	Ramadi (kg)
January	0.443	0.787	0.493	0.414
February	0.564	0.895	1.013	0.862
March	0.410	1.076	0.880	0.687

April	0.531	1.04	0.883	0.793
May	0.659	1.072	1.020	0.683
June	0.687	1.436	1.058	0.578
July	0.313	0.913	0.893	0.485
August	0.435	1.182	0.976	0.659
September	0.298	0.510	0.593	0.289
October	0.232	0.218	0.233	0.173
November	0.269	0.832	0.403	0.168
December	0.414	0.653	0.261	0.141
Annual penalty cost of carbon dioxide emissions ($)	3.02	4.72	3.9	3.4

As evident from the data presented in Table 6, there exists a positive correlation between the quantity of carbon dioxide generated and the power output derived from the turbine. Consequently, it is noticed that the city of Baghdad, which exhibits the highest power generation, also experiences the highest emission rate.

In order to assess and contrast various cities, Figure 8 provides data on the annual carbon dioxide emissions per capita, based on electricity generated by wind turbines.

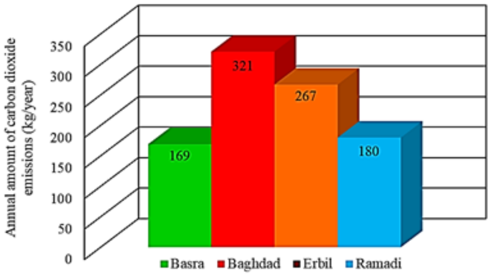

Fig.8. The annual amount of carbon dioxide emissions.

The data presented in Figure 8 and Table 6 indicate that, as hypothesized, the urban center of Baghdad exerts the most pronounced impact on the environment. This can be attributed to its superior production capacity in comparison to other cities, resulting in a higher emission rate. From an environmental perspective, it can be asserted that the city of Basra releases a total of 169 kg of carbon emissions. The city of dioxide has the lowest level of environmental degradation compared to other urban areas on an annual basis.

2. Conclusion

The present investigation involved a comprehensive examination of a horizontal-axis wind turbine, encompassing the consideration of economic and environmental indicators while also taking into account the ramifications of climate change. A range of climatic conditions, reflecting the diverse nature of Iraq, were recreated, each presenting distinct difficulties and opportunities.

Within the field of economic analysis, a comprehensive assessment was conducted to determine the cost associated with the generation of wind energy. This assessment took into account many factors, including initial setup expenditures, costs related to repairs, and prices associated with insurance coverage. This facilitated a comparative evaluation of energy unit prices in varying climatic conditions. Concurrently, within the realm of the environment, calculations were performed to determine characteristics such as carbon dioxide emissions and the corresponding costs of penalties.

The importance of wind speed and stability in turbine analysis cannot be overemphasized. Regions characterized by higher average wind speeds and decreased variability in data exhibit a greater capacity for harnessing wind energy. Baghdad, known for its hot and dry climate, has the highest production capacity, which can be attributed to its average wind speed of 6 meters per second and low variability in wind speed data.

From an economic standpoint, Baghdad presents itself as the most advantageous selection, particularly when considering a hot and arid climatic scenario, taking into account an interest rate of 23%, a 20-year operational duration, and a heightened energy cost of $1.6 per kilowatt-hour. This discovery highlights the feasibility of considering it as the most economically sensible choice. From an environmental standpoint, Basra emerged as the more ecologically conscious option among the cities examined, despite its comparatively smaller industrial capacity and annual carbon dioxide emissions of 169 kg.

It is imperative to acknowledge that the findings of this study are derived from data acquired in the year 2022 AD. Potential alterations to these results may occur due to fluctuations in weather conditions and other parameters. Therefore, it is not practical to designate a single location as the indisputable best choice. However, this study provides decision-makers with significant insights. In order to make educated decisions regarding the feasibility of establishing wind turbine power plants, it is necessary to evaluate the individual characteristics and priorities of each area.

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