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Toward Sustainable Wind Energy in Iraq: A Multi-Provincial Feasibility Study, Implementation, Challenges, and Strategic Outlook

Ali K. Resen*, Omar F. Ahmed, Khalid S. Heni, Ammar A. Fadhi, Wasan T. Musa

Scientific Research Commission, Baghdad 10071, Iraq

Corresponding Author Email: dr.aliresen@src.edu.iq

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ABSTRACT

This research analyzes the national potential of wind energy in Iraq by combining the resource assessment and thorough techno-economic analysis of it and, therefore, informs sustainable energy planning. The main aim is to evaluate the wind potential of eight central and southern governorates; Wasit, Karbala, Qadisiya, Najaf, Maysan, Thi-Qar, Basrah and Al-Muthanna and provide evidence-based recommendations on large-scale implementation. Financial modelling was achieved by extrapolating the high-resolution wind data, 10-minute and 50 m hub height, to 149 m turbine hub heights of Vestas 3.45 MW and including the data in the RETScreen software. The key performance indicators include Levelized Cost of Energy (LCOE), Net Present Value (NPV), capacity factor (CF), Internal rate of return (IRR) and payback period. Findings report capacity factor of between 34 -49.4% and wind power density of 131-387 W/m^2 with associated competitive LCOE values of 0.039 -0.05 $/kWh and NPV of 326,242-662,327 million. To assess the robustness of site rankings under varying techno-economic conditions, univariate analyses were conducted. This paper has concluded that under favorable regulatory frameworks and location choice, wind energy can form a foundation of the diversified and sustainable energy transition of Iraq.

1. INTRODUCTION

Much of the greenhouse gases that cover the earth and trap the heat of the sun are a result of energy production, with electricity and heating power generated using fossil fuels. This dependence on nonrenewable resources is a contributor to climate change and a threat to the health and biodiversity of the population. To reduce these effects and to secure a sustainable future, it is necessary to switch to renewable energy sources, including wind, solar, and hydroelectric energy [1]. In order to reduce the worst impact of climate change, it is necessary to cut down on emissions by approximately half by the year 2030 and to reach net zero by the year 2050 [2]. Wind energy was among the leading sources of production of renewable electricity in the European Union by the year 2022, with approximately one in three renewable electricity being produced by it. This came with hydropower, which supplied around 29% [3]. In 2022, wind energy all over the world contributed more than 7.8% of the total electricity production worldwide, and about 2,304 TWh of wind energy was generated [4]. The fossil fuel reserves of most countries in the region such as Iraq are blessed and others like Morocco, Tunisia and Jordan are largely dependent on imported energy. Moreover, the deregulated energy markets and subsidized energy prices are also practical challenges to the energy transition in the Middle East and North Africa (MENA) [5]. The Middle East region is experiencing an increase in energy demand. This will intensify demand for energy in the Middle East by 2% annually up to the year 2040 [6, 7] The other problem is that the losses incurred in the distribution of electricity in the stable MENA countries stand between 11% and 15% as compared to only 4% in Germany [8]. The energy system of Iraq is based mostly on the sources of fossil fuel, because of the abundance of fossil fuels in the country. Considering that Iraq is today the third largest oil exporter in the world, it is also probable that it will continue to be among the three oil exporting countries in the future [9]. Iraq, on the other hand, happens to be among the three foundational countries in the group of twelve countries called the Organization of the Petroleum Exporting Countries (OPEC) [10]. But at the moment, Iraq is also developing measures to shift to becoming a more sustainable economy, such as increasing investments in natural gas and allocating 12 gigawatts of renewable energy. By 2022, the power production in Iraq was still strongly dependent on fossil fuels, and the emissions per person were slightly higher than the global average. The electricity generation based on gas increased by 105% a year due to the building of a new gas-based power plant. Hydropower provided slightly more than 3% of electricity generation in the country and solar and wind almost 1% [11]. The Ministry of Electricity estimates that its peak electricity demand would be 41,000 megawatts by 2030. The ministry has already mentioned a plan to partially satisfy this requirement by using gas produced in the country, and raise the portion of solar power to 5% of the overall electricity production.

In recent years, Iraq has been experiencing great difficulties in the energy sector. Demand of energy has always been higher than the capacity of generation thus leading to serious shortages of electricity [12]. This disparity has resulted in a massive supply demand gap where at peak summer, demand can be 50 times the average demand which the grid cannot supply. Although the production capacity has increased in the recent past, there is still a wide gap between peak demand and grid supply as shown in Figure 1.

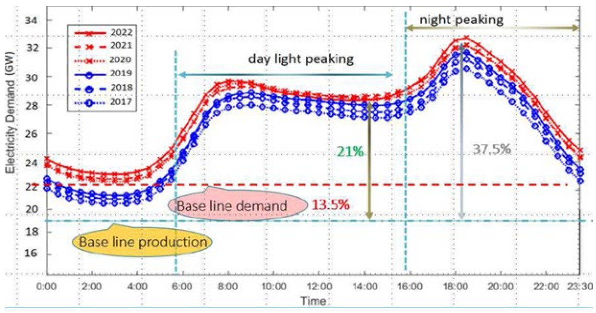

Figure 1. Daily power demand and supply [13]

The figure shows the continued disparity between power demand and supply in the past years, with clear daily trends and high deficits. The maximum daylight demand is 29 GW, and the maximum nighttime demand is 33 GW, compared to 19 GW and 23 GW maximum production and demand, respectively, and shortages of 21% and 37.5, respectively. The supply demand difference between the years 2013 and 2020 was constantly 5-7 GW, which indicated an increasing energy shortage. The trend in the daily demand of 2017-2022 shows that there is a steady increase in consumption, but the supply growth has not been sufficient. This highlights why there is an urgent requirement to increase the base load capacity, enhance grid efficiency, and incorporate renewable energy sources to generate peak demand. There is a need to bridge the gap and promote energy sustainability by making strategic investments in energy infrastructure, as well as demand side management and policy reforms.

Iraq was coming up with a broad scheme to be more productive because it could now produce up to 27,320 megawatts, which was 3,000 megawatts higher than the previous year [14]. It is expected that generation of electricity using renewable resources would occur within the short term, but the major application would be in the off-grid demand centres in remote locations in the future; however, the solar and wind energy would be fed into the grid in the medium to long term. The grid is faced by some challenges, among which are: degrading infrastructure, frequent power outages, and losses in transmission. Over the recent years, Iraq has recorded interconnections with the neighboring nations to increase the reliability of energy supply in the country and to satisfy the rising electricity demand. These connections will help it eliminate the shortages and incorporate renewable energy into the system, which will allow it to import and export electricity. The reinforcement of these interconnections and the modernization of the national grid will contribute to the solution of the problem of energy sustainability and the ability to accept wind and other projects using renewable sources.

This infrastructure should include the national electrical grid preparedness, the thoroughfares, the wind turbine structural foundations, and probably the maintenance and spare parts facilities [15]. The guarantee of massive investments into wind energy can have a positive effect on the diffusion of the wind energy industry, as well as the shift in Iraq to an energy mix that does not rely on fossil fuels as its key component.

Figure 2 indicates that the geographical spread of wind power potentials in Iraq varies between 3-4 m/s in northern Iraq and 8-9 m/s in southeastern Iraq. The wind map compiles high resolution meteorological data and focuses on the annual and hourly wind speed at an altitude of 100m. This map is used in our study as a national reference framework to contextualize and support the interpretation of our wind resource assessment results, but it is not the primary data source for our analysis.

The source of hourly wind speed data at 100 meters was the ERA5 reanalysis dataset to capture the temporal variability and to aid in more detailed energy production modelling. Air pressure and temperature are also the critical meteorological variables considered in this modelling. The combination of Denmark Technical University (DTU) annual mapping of wind with the time resolution of ERA5 provides a holistic and precise evaluation of the wind energy source in various locations. ERA5 is a composite product that utilizes the power of remote sensing and physical modelling.

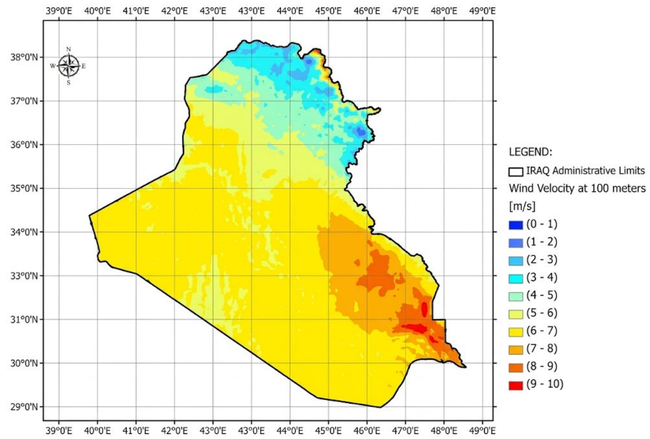

Figure 2. Iraq wind map [16]

To make sure that data in the map production process is reliable and the simulation is possible, measured data from 24 meteorological stations was utilized. An atmospheric mesoscale model (SKIRON) was used to make the wind map, and the map was visualized using a GIS. With the GIS as a powerful spatial evaluation and data presentation tool, specific wind power maps can be created at the national and geographically separated areas.

The southeast part of Iraq has good wind energy potential. Based on the wind map that has its resolution as 1km with an altitude of 100 meters, the speeds of the winds in the regions are between 8 and 9 m/s. The winds indicate high possibilities of wind power developments in the area. According to the power law, the mean speed of wind in such locations, at an altitude of 150 meters, is likely to be between 9 and 11 m/s.

Despite the usefulness of studies in terms of localized understanding, it is common to observe that they do not take an all inclusive look at the subject and regulate wind resource assessment with financial and environmental outcomes in their analysis. This research paper fills this gap by assessing the potential of wind energy in eight provinces of Iraq, which carries out a financial study in central and southern Iraq. The study takes a holistic approach to provide national level plans on the development of wind energy in the country, where the current position, future opportunities, and plans on the development of wind energy in Iraq are assessed. Moreover, it also examines different aspects of implementation, such as technological, legislative, financial, and logistical aspects, to test the effectiveness of wind energy projects.

2. RELATED WORK

Many studies have investigated wind energy in Iraq, most of them focus on targeted issues, parts of the wind turbines, such as designing and analyzing the blades that are specifically made to suit the wind conditions in Iraq to improve their performance [17]. Other studies have been done on feasibility studies on individual sites, evaluation of the technical and economic feasibility of wind energy at individual regions [18].

In the existing literature, wind energy research in Iraq has been approached from multiple methodological perspectives. A series of studies have focused mainly on the characterization of wind resources, using statistical modelling, most often using the Weibull distributions, to evaluate wind potential, and in the context of a preparation of location conditions with appropriate wind turbine generators in Najaf, central Iraq [19]. On a larger spatial level, Multi-Criteria Evaluation (MCE) based on geographic information system paired with the Analytical Hierarchy Process (AHP) has widely been implemented on the assessment of national and regional suitability as seen in works carried out in Erbil, northern Iraq, that used long-term climatic averages (20002024) and such important variables as wind speed, topography, and distance to electricity infrastructure [20]. At the same time, in rural areas with long distances to the power photovoltaic, like in Al-Faw city in the southern part of the Iraq, the use of advanced optimisation methods, such as Particle Swarm Optimization (PSO), has been implemented to plan hybrid photovoltaic-wind systems with the primary aim of minimizing the Cost of Energy (COE) and maximising the reliability of the system [21]. Additionally, there has been growing scholarly interest in atmospheric dynamics, new studies have been conducted to examine the stability of atmospheric conditions in southern Iraq, specifically in the Ali Al-Gharbi region, using the Monin-Obukhov length methodology. This was analysed based on field measurements of horizontal and vertical wind speeds and air temperature at the three heights (10, 30, and 50 m) on a meteorological tower in 2017 [22]. Together, these studies highlight the plurality of the analytical scales and methods used in the study of wind energy in Iraq, and, at the same time, hint at the need to introduce more integrative models that will combine resource appraisal, atmospheric dynamics, and techno-economic optimisation. There have been many research efforts investigating the technical and economic potential of wind energy across MENA countries with a focus on high variability regionally. The Shagaya onshore wind farms in Kuwait had high capacity factors, and the yearly energy generation had a value much higher than the expected values causing a low Levelised Cost of Energy (LCOE) [23]. Even though the Fayoum Governorate in Egypt is described as having low wind velocities, with an average wind speed of 6.02 m/s at a 50 m hub height, it was shown to support small to medium-sized turbines at an economically viable location with the Endurance E3120 50 kW turbine achieved the lowest LCOE compared to those tested there [24]. In Turkey, Selcuk University, Konya area recorded moderate wind speeds of 5.36-6.05 m/s and power densities of between 260 and 308 W/m^2, which enabled a 6 MW wind farm to attain a minimum payback period of 6.44 years [25]. Located in a wind-rich band, Iran has a huge technical potentialnot only can Iran reduce its dependence on fossil fuel as a source of energy in the long run, it can also take steps, albeit small, in making dents in other challenges facing the country [26]. The population of Iraq is estimated to grow by around 5.6 million individuals by the year 2024-2029 to a population of 50.06 million by the year 2029 and this is after a decade of the population growth. This huge growth will necessitate a great growth in energy output within the next few years especially with the high reliance on fossil energy to generate electricity in Iraq [27]. This is a fundamental issue that needs to be tackled by effective planning and incorporation of renewable sources of energy into the energy mix, which is mainly composed of fossil fuels [28].

3. METHODS

3.1 Data acquisition and study area

The eight administrative regions that were included in the study area are in central and southern Iraq; Wasit, Karbala, Qadisiya, Najaf, Maysan, Thi Qar, Basrah and Al-Muthana as shown in Table 1. Ground based wind masts measured wind speed at a level of 50m and a temporal resolution of 10min; they are the main set of data that forms the basis of the current analysis. All the subsequent statistical analysis, wind resource descriptions, and evaluations of energy potentials that will be presented in the present paper are based on these observations. The methodology of the proposed research is based on a logical workflow, the starting point of which is the receiving of 10-minute wind-mast measurements of a height of 50 m at eight representative locations. Quality-control processes of the raw data were done in a manner that includes the removal of abnormal records, detection of data gaps and evaluation of the overall completeness of the data to achieve reliability. Lastly ,these wind projects were then measured in terms of the techno-economic performance using RETScreen software as an elaborate financial modelling, which included the important performance measurements like Net Present Value (NPV), LCOE and payback period.

Table 1. Locations and coordinates of the wind masts in the study area

No.	Wind Mast	Longitude	Latitude
1	Wasit (Shihabi)	E:46 24.551	N:32 46.389
2	Karbala (Lake Razzaza)	E:43 54.469	N:32 41.346
3	Qadisiyah (Dewaneia)	E:44 46.611	N:31 57.249
4	Najaf (Ishbija)	E:44 18.330	N:31 40.921
5	Maysan (Ali Al-Gharbi)	E:46 48.470	N:32 34.981
6	ThiQar (Al-Fajer)	E:45 51.355	N:31 51.193
7	Basrah (Hor Salal)	E:47 40.100	N:30 37.410
8	Al-Muthana (Al-Salman)	E:44 34.382	N:30 34.248

3.2 Wind profile extrapolation and power density calculation

Wind speed measurements at 50 m were extrapolated to the turbine hub height of 149 m using the power-law approach [29]:

$$V_{hub} = V_{50m} \times \left(\frac{149}{50}\right)^{\alpha} \quad (1)$$

where, α is the wind shear exponent. We employed a uniform shear exponent of α = 0.14, which is representative of flat-to-moderate terrain conditions typical of the study region.

Wind power density was calculated using:

$$P = \frac{1}{2}\rho A V^3 \quad (2)$$

where, ρ is air density (kg/m³) and V is wind speed (m/s). Site-specific air density was calculated from temperature and atmospheric pressure data recorded at wind masts across the eight governorates using the ideal gas law:

$$\rho = \frac{P}{R \times T} \quad (3)$$

where, P is atmospheric pressure (Pa), T is absolute temperature (K), and R is the specific gas constant.

3.3 Financial criteria

The process of identifying the best and worst conditions for wind farm installation begins with the entry of data, which is followed by a list of financial criteria. It is necessary to employ a number of financial metrics to explore the economic viability of new projects, such as the construction of new wind farms, and to ensure that each metric is adequately addressed in the overall evaluation. Five economic analysis metrics are utilized in this study in order to assess the economic feasibility of the proposed wind farms that are meant to be located at eight different locations throughout Iraq.

3.3.1 Simple payback (SPB)

It is the period required to recover the initial capital cost of the project, after which all subsequent cash flows are considered profit [2].

$$\text{Payback period} = \frac{\text{initial investment}}{\text{annual cash inflow } (B_t)} \quad (4)$$

3.3.2 Net Present Value (NPV)

It is the difference between the cash flows generated from the sale of electricity and the total project costs, including initial investment, operation and maintenance, and other expenses. It is also calculated using a specified discount rate and is expressed in Eq. (5) [18].

$$NPV = \sum \frac{(B - C)}{(1 + r)^n} \quad (5)$$

where, n is the time period of the project, r discount rate, C cost, and B interest rate.

3.3.3 Internal rate of return

It is the discount rate that makes NPV of a series of cash flows over the project's lifetime equal to zero [18].

$$0 = \sum_{t=0}^{n} \frac{C_t}{(1 + IRR)^t} \quad (6)$$

where, C_t is the cash flow at time t, n is the number of periods.

3.3.4 Benefit-to-cost ratio (BCR)

A financial measure used in analyzing the cost of the project to interest is used to indicate the profitability of the project takes into account the amount of cash gains achieved from the project against the cost resulting from the implementation of the project, where the higher the value of BCR, the greater the benefit derived from the investment [18].

$$BCR = \frac{\sum_{t=0}^{n} \frac{B_t}{(1 + r)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1 + r)^t}} \quad (7)$$

where,

If BCR < 1, it is not applicable.

B_t is the benefit (cash inflow) at time t, r is the discount rate.

If BCR > 1, project applicability.

3.3.5 Levelized Cost of Energy (LCOE)

It is the average cost per unit of energy, typically expressed in cents per kWh or dollars per MWh [18].

$$LCOE = \frac{\sum_{t=0}^{n} \frac{I_t + O_t + F_t}{(1 + r)^t}}{\sum_{t=0}^{n} \frac{E_t}{(1 + r)^t}} \quad (8)$$

where,

I_t: Investment costs (capital expenditures) in year t

O_t: Operation and maintenance costs in year t

F_t: Fuel cost in year t (if applicable)

E_t: Energy generated in year t

A lower LCOE indicates a more cost-effective energy project. Using software such as RETScreen, a comprehensive financial analysis was conducted by integrating the turbine's technical parameters with site specific wind resource data. This approach enabled the evaluation of key economic indicators, including LCOE, NPV, and payback period. The results provided valuable insights into the feasibility and profitability of wind energy projects at each location.

3.4 Wind turbine characteristic

In this study, the Vestas 3.45 MW wind turbine was used to perform a financial analysis for eight selected sites across central and southern Iraq. The characteristics of the wind turbine are presented in Table 2.

Table 2. Wind turbine characteristics

Power Capacity per Turbine	3.45 MW
manufacture	Vestas
Model	V-136
Power capacity	100.05 MW
Hub height	149 m
Rotor diameter per turbine	136 m
Swept area per turbine	14527 m^2
Cut-in speed	3 m/s
Cut-out speed	22.5 m/s
Rated wind speed	10.5 m/s

3.5 Input cost parameters in RETScreen model

This study presents a financial model for the establishment of a 100.2 MW wind farm at each designated location, assessing its economic viability through essential financial indicators as shown in Table 3.

Table 3. Proposed finance in this study [18]

Total Initial Costs	130,000,000 $
Debt ratio	60%
Debt	78,039,000 $
Equity	52,026,000 $
Debt interest rate	8%
Debt term	10 year
Debt payments	11,630,112 $/year
Electricity export rate	0.10 $/kWh
Electricity export escalation rate	5%
Discount rate	4.85%
O&M costs (savings)	45 $/kW-year
Life time	20 year

The current tariff is still fully subsidized and has not changed, as the price (kilowatt-hour is only 10 Iraqi dinars) for household items, while the state bears more than 65% of production costs to ensure that energy reaches citizens at the best possible cost. All finances are given in dollar. The volatility of the Iraqi Dinar (IQD) is high which means that relying purely on the local currency may cause high uncertainty in the project cash flows. As a measure to curb this risk, Power Purchase Agreements (PPAs) of renewable energy projects in Iraq are normally denominated in, or indexed to USD, as it has been customary practice in emerging markets. The projected 5 % increase in the prices of electricity is a combination of the projected inflation, as well as the actual increase in the electricity prices, to make sure that the financial analysis is realistic in terms of the economic conditions.

Table 4 is a brief overview of the loss assumptions that were included in the RETScreen model, thus forming an essential input to the following financial and energy yield processes.

Table 4. Detailing the specific loss assumptions applied in the RETScreen

Array losses	4%
Airfoil losses	5%
Miscellaneous losses	2%
Availability	98%

4. RESULTS

Table 5 illustrates that Wasit (Shihabi) and Mayasan (Ali Al-Gharbi) have the largest potential wind energy with the highest mean wind speed and make the site viable to utility-scale wind farms. The Dhi Qar (Al-Fajer), Al-Muthana (Al-Salman), and Najaf (Ishbija) have a good to excellent potential in terms of projects. Favourable conditions of the southern part of Iraq are due to the majorly flat land and the flow of wind that occurs in the area, which is caused by the Arabian Gulf. Moderate wind resources characterize Basra which suit medium scale projects. Conversely, the lowest power densities are to be found in Karbala (Lake Razzaza) thus limiting its use to small-scale or distributed generation. Table 6 explains the relationship between power exported to the grid, reduction in greenhouse gas (GHG) emission, and capacity factor (CF%) in the various proposed wind farm sites in Iraq. There is a conclusive positive correlation between electricity exports and the reduction of greenhouse gases because wind energy replaces fossil fuel-based generating, therefore reducing carbon emissions. The carbon dioxide factor in Iraq ranges between 0.6 and 0.7 kg/kWh and is considered 0.7 kg/kWh [30]. Besides, the capacity factor, which reflects the efficiency of the wind farms, has a slight growth as the power output goes up. Other sites like Maysan and Wasit, where the CF values of 49.4% and 41.7 are high, respectively, exhibit increases in energy production and emission reduction. To the contrary, sites having lower capacity factors, such as Karbala (34%), generate less power, hence the need to site wind farms in areas with high wind potentials to maximize the economic and environmental benefits. The wind speed distribution is expected to be smoother and more favorable in Maysan, and this would lead to an increase in the overall power generated and an increase in the capacity factor.

Table 5. Data analysis for the study area at 50 m height

No.	Site	Mean Wind Speed(m/s)	Power Density(W/m^2)
1	Wasit	6.94	387
2	Maysan	6.62	360
3	Thi Qar	6.47	309
4	Al-Muthana	6.31	281
5	Najaf	6.29	281
6	Basra	5.95	240
7	Qadisiyah	5.28	188
8	Karbala	4.72	131

Table 7 shows the most important parameters of the economic feasibility and attractiveness of wind energy projects in eight sites. The most financially viable site will be Maysan with the shortest simple payback period, the greatest NPV, excellent Benefit Cost (B-C) ratio, and the lowest LCOE. These and the greatest pre-tax Internal Rate of Return (IRR) on both assets and equity portray good profitability and rapid returns, making Maysan the most preferable investment opportunity. Karbala, on the other hand, provides the least appeal in terms of investment with the longest payback period, the highest LCOE, and the lowest IRRs, depicting a poor performance to capital and a lack of interest among investors. There are other sites, including Al-Muthanna and Basra, which show good financial results, with high NPVs and good B-C ratios; still, they have a slightly higher LCOE and longer payback time than Maysan. This comparative analysis indicates that although all the evaluated sites have a great potential in terms of investment opportunity, Maysan has the most favorable return-risk presentation in terms of money. To assess the robustness of site rankings under varying techno-economic conditions, a variant analyses was conducted. Five key parameters were examined: electricity price (±20%, $0.08-0.12/kWh), Capital expenditures (CAPEX) (±15%, $110.5M-$149.5M), discount rate (4.365%-5.335%), availability factor (90-100%), and curtailment rate (0-20%). Three comprehensive scenarios were developed: optimistic (CAPEX -15%, discount rate 4.365%, availability 100%, price +20%, curtailment 0%), base case (current assumptions), and pessimistic (CAPEX +15%, discount rate 5.335%, availability 95%, price -20%, curtailment 10%). The variant sensitive financial analysis demonstrates that the relative ranking of the proposed wind sites is highly robust to changes in key economic assumptions. Across the baseline, optimistic, and pessimistic scenarios Maysan consistently emerges as the most financially attractive location, followed by Al-Muthana and Basra, which together form a clear top tier in terms of investment priority. Najaf and Qadisiyah constitute a stable second tier, showing solid but comparatively lower financial performance, while Karbala, Wasit, and Thi Qar remain in the lower tier across all scenarios. Importantly, although absolute NPV values vary significantly between scenarios, the ordering of sites remains largely unchanged, indicating that the ranking is not driven by favorable assumptions but reflects structurally stronger techno-economic conditions at the leading locations. This stability confirms that the proposed site prioritization is resilient to financial uncertainty and provides a reliable basis for strategic wind energy planning in Iraq.

Table 6. Net electricity generation, revenue, and environmental benefits of wind energy across selected governorates in southern Iraq

No.	Site	Electricity Exported to Grid (MWh)	Electricity Export Revenue ($)	GHG Emission Reduction (tCO_2)	CF (%)
1	Wasit	365,280	36,528,028	124,05	41.7
2	Maysan	433,347	43,334,728	147,16	49.4
3	Thi Qar	358,609	35,860,873	76,02	40.9
4	Al-Muthana	338,384	33,838,360	71,73	38.6
5	Najaf	324,610	32,461,039	68,82	37
6	Basra	323,824	32,382,391	70,16	37.8
7	Qadisiyah	315,395	31,539,510	66,86	36
8	Karbala	298,320	29,832,016	63,24	34

Table 7. Economic feasibility metrics of wind energy projects across selected governorates in southern Iraq

No.	Site	Simple Pay Back (Year)	NPV (Million)	Benefit Cost (B-C) Ratio	LCOE $/MWh	Pre-tax IRR -Equity (%)	Pre-tax IRR Assets (%)
1	Wasit	4.1	336,359,185	7.5	47.19	43.7	19.2
2	Maysan	3.3	662,327,584	13.7	39.76	63.4	29.4
3	Thi Qar	4.1	326,242,008	7.3	48	42.4	18.7
4	Al-Muthana	4.4	469,450,026	10	50.94	45.3	21.9
5	Najaf	4.7	441,486,044	9.5	53.10	42.7	20.8
6	Basra	4.5	454,354,442	9.7	52.09	43.9	21.3
7	Qadisiyah	4.8	422,776,084	9.1	54.65	41.1	20.1
8	Karbala	5.1	388,108,538	8.5	57.78	37.9	18.7

5. DISCUSSION

From the results above, Iraq has an average potential of exploiting wind energy as compared with other energy sources in MENA countries. Hub height wind turbines have recorded a wind speed of between 4.72 and 6.94 m/s and power densities of between 131 and 387 W/m^2 with a capacity factor of 34-49.4 and LCOE of 0.0398 -0.0578 $/kWh. These metrics are lower than those which Kuwait experienced, with onshore and offshore plants attaining higher capacity factors and lower LCOEs (0.0460.091 $/kWh, and slightly underperform the ones in Egypt at the Fayoum region which contribute to economically viable small-to-medium-scale turbines (0.0485 $/kWh. The wind regime in the Konya region of Turkey exhibits similar velocities (5.36 6.05m/s), but it is linked with slightly higher power densities (260-308 W/m^2 and offers adequate economic returns. On the other hand, Iran is a country with a great technical potential, although the growth of such potential is constrained by the low feed-in tariffs, which highlights the importance of the policies that will be more likely to incentivize the investment into the same potential. As a result, Iraq has wind resources of medium size that could be economically feasible by means of introducing the favorable regulatory frameworks and selecting the locations with the strategic advantage. Table 8 depicts the summarizing the key wind energy metrics for the MENA countries. Some challenges can be described according to wind energy development in Iraq.

Table 8. Comparison of wind energy metrics for Middle East and North Africa (MENA) countries

Country	Hub Height (m)	Average Wind Speed (m/s)	Power Density (W/m²)	Capacity Factor (%)	LCOE ($/kWh)
Kuwait (Shagaya, Onshore) [23]	50	High (not specified)	–	High	0.046
Egypt (Fayoum) [24]	50	6.02	–	–	0.0485
Turkey (Konya, Selcuk University) [25]	10–40	5.36–6.05	260–308	–	–
Iran [26]	–	–	–	–	0.03–0.12
Iraq	50	4.72–6.94	131–387	34–49.4	0.0398–0.0578

First, the exploitation of renewable energy resources, particularly wind energy, needs more funding, both by the government and the people. It also requires incentive actions and promotion to minimize risks and make investment in this field more profitable because the government, due to other engagements like rebuilding of infrastructure, cannot allocate adequate funds towards renewable energy projects. Also, the government should offer sufficient financial incentives to attract investors, including tax exemptions or guarantees of return.

Second, the Iraqi economy is often associated with rates of high inflation and devaluation of the currency. These cause a rise in the prices of imported parts of wind turbines and other infrastructures and, therefore, impose more financial risks on investors and developers.

Third, most of the energy sector in the country is highly subsidized and this makes the energy generated using fossil fuels to be extremely cheap compared to the energy generated using renewable sources like wind. This will reduce the economic returns of wind power and even affect the interest of investors and government subsidies to transit to renewable sources negatively. Probably, the transition to wind power in Iraq will not go without a fight either to the policy maker or even at the individual level, as long as fossil fuels are a cheaper alternative, which will hinder the process of the transition to more sustainable energy mix.

As a roadmap for the implementation of wind power in Iraq should be provided in a step-by-step manner that involves the introduction of pilot projects, capacity building and the infrastructure.

- The roadmap of the Iraqi energy sector states that a third of the total electricity production power in the country is to be reached by the year 2040, with the proportion of the renewable energy sources, including wind energy.
- It is important to focus on the south eastern regions, which are regarded as the most efficient regions to harness wind power, which contains high wind speed (over 6.2 m/s), provision of infrastructure, and topography.
- Funding policies: come up with targeted subsidies and flexible electricity rates to entice the involvement of the large scale sector.
- Create funding principles which involve certain subsidies and flexible electricity rates so as to encourage the participation of the private sector in the wind energy plans.
- Adherence to international standards, including the provisions of the international energy agency IEA in the context of the diversification of energy sources and the decrease in the presence of fossil fuels.
- Multi criteria GIS analysis, which uses wind speed, terrain, and land use, is one of the ways of enhancing the site suitability and reduce conflicts.
- Focus on areas around the power grids and the road networks to minimize the construction and maintenance expenses.
- Minimize logistical challenges, e.g., grid connectivity, road accessibility, by upgrading infrastructure periodically. The limitations inherent in our present methodology of assessing wind resource is the discrete nature of the lattice of meteorological measurement stations that precludes the spatial representativeness of the data, and that observes the characteristics of wind at discrete points, although consistency of observed patterns of the wind to regional climatology and the application of rigorously validated methods of mesoscale modelling give the confidence that the data is adequately representative of conditions at the site.

6. CONCLUSIONS

The current study has estimated the potential of wind energy in eight governorates in the center and south of Iraq namely Wasit, Karbala, Qadisiya, Najaf, Maysan, Dhi-Qar, Basrah and Al-Muthanna as evidence-based suggestions to the large scale deployment of wind energy. The overall wind resource survey and financial viability demonstrate that there is a strong spatial heterogeneity in the development potential within the study area. Wasit (Shihabi) and Maysan (Ali Al-Gharbi) have the largest average wind speed, thus becoming the most promising options in terms of utility-scale wind farm construction, and Dhi-Qar (Al-Fajer), Al-Muthanna (Al-Salman) and Najaf (Ishbija) are good to excellent in terms of commercial-scale projects. The financial analysis recognizes Maysan as the best investment opportunity, which has a good NPV, IRR, and levelized cost of electricity. On the other hand, Karbala has the least appealing investment profile with the longest payback period, LCOE, and IRR, which implies poor returns on capital and low investor appeal. The optimism and pessimism scenarios of sensitivity analysis used to verify these rankings show the strength of the rankings as Maysan has always performed better in terms of financial performance regardless of the changes in the main economic assumptions. These results place Iraq in the moderate category of wind energy potential when compared to the other countries of the MENA, which implies that a wind energy development could be achieved economically due to the effective selection of the sites and a series of supportive regulatory measures. The outcomes offer practical recommendations to policymakers and investors who want to diversify the energy mix in Iraq and boost energy security through renewable resources. Although this research may have some shortcomings with regard to the representativeness of discrete meteorological measurement points on a spatial scale, the congruence of results with different methods of analysis supports the validity of our results. The future studies must focus on long-term measurement campaigns to decrease the level of uncertainty and carry out correlated studies that examine grid integration challenges and effects of wind energy on the environment to allow the shift to the resources evaluation to the functioning process of the wind energy potential in Iraq.

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