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A Comprehensive Feasibility Study Incorporating Economic Metrics and Performance Dynamics for 100 MW Wind Farm in Al-Fajer Site, Iraq

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Abstract

Analyzing feasibility studies is essential for enhancing wind farms' availability, efficiency, and economy during construction and operation. Wind power and other renewable energy sources offer promising prospects for sustainable and cost-effective energy solutions. Considering technical and economic factors, this study evaluates the viability of establishing an onshore wind farm in the Al-Fajer location in southeastern Iraq. The RETScreen expert software is used to conduct financial analyses and assess the potential annual energy generation of the proposed project. The study includes analysis and evaluation using three distinct scenarios: economic factors such as investment costs, operation and maintenance costs, and the increasing debt rate. The second scenario produces the most favorable financial results, with a net present value of $236,505,368 and an internal rate of return of 18.2%.

Keywords: Wind farm, feasibility study, RETScreen, Iraq.

دراسة جدوى شاملة تتضمن المقاييس الاقتصادية وديناميكيات الأداء لمزرعة رياح بقدرة 100 ميجاوات في موقع الفجر، العراق

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الخلاصة

يعد تحليل دراسات الجدوى أمرًا ضروريًا لتعزيز توافر وكفاءة واقتصاد مزارع الرياح أثناء البناء والتشغيل. توفر طاقة الرياح ومصادر الطاقة المتجددة الأخرى آفاقًا واعدة لحلول الطاقة المستدامة والفعالة من حيث التكلفة. تقيم هذه الدراسة مدى جدوى إنشاء مزرعة رياح برية في موقع الفجر في جنوب شرق العراق، مع الأخذ في الاعتبار العوامل التقنية والاقتصادية. تم استخدام برنامج RETScreen لإجراء التحليلات المالية وتقييم توليد الطاقة السنوي المحتمل للمشروع المقترح. تتضمن الدراسة التحليل والتقييم باستخدام ثلاثة سيناريوهات متميزة، بما في ذلك العوامل الاقتصادية مثل تكاليف الاستثمار، وتكاليف التشغيل والصيانة،

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ومعدل الديون المتزايد. واظهر السيناريو الثاني النتائج المالية الأكثر ملاءمة، حيث تبلغ القيمة الحالية الصافية 236,505,368 دولارًا ومعدل عائد داخلي قدره 18.2%.

1. Introduction

Wind power possesses several similarities to other forms of renewable energy sources in terms of their advantages. Firstly, increasing wind power output reduces reliance on fossil fuels, thus mitigating global warming by lowering carbon dioxide emissions and other greenhouse gases (GHGs). Due to the widespread use of renewable energy sources, the Geographic Information System has become essential for identifying the most favorable locations for these energy generators, depending on geographical factors. Spatial analysis can utilize geographical and cultural landscape-based energy potential estimates to discover promising sites for generating renewable energy [1]. LIDAR is considered the most accurate and quantitative method for measuring wind power. It is an effective instrument for remote wind sensing as it can accurately detect the velocity, orientation, and turbulence of the wind and provide comprehensive information on the overall wind patterns and characteristics [2]. Wind turbines do not emit any dangerous pollutants into the atmosphere or water. Wind turbines can minimize the increasing electricity demand [3]. Wind turbines are continuously increasing in size and height [4]. IRENA reports a 56% decrease in the average cost of onshore wind energy production from 2010 to 2020, indicating a significant growth in global wind power capacity [5]. The government policies [6],[7], and [8], academic research [9],[10], and the energy sector are now primarily focused on investing in renewable energy resources [11].

The process of initiating a new wind farm project starts with exploring an appropriate site and the economic viability of the wind farm [12], [13]. Furthermore, to guarantee the efficiency of wind farm installations, it is essential to evaluate the feasibility of constructing them by analyzing financial metrics [6]. H. Yaqoob *et al*. [14] analyzed a 100MW wind farm in Gwadar, Pakistan, using on-site wind data, financial considerations, and optimal design configuration to assess its long-term economic viability. Ismail *et al*. conducted an economic analysis to determine the viability of establishing a wind farm in the coastal region of South Purworejo, which is considered strategically important for Indonesia. The methodologies employed encompassed analysis and assessment, which comprised precisely three types of analyses: economic analysis utilizing scenarios, risk analysis, and sensitivity analysis [15].

Cristian Mattar *et al*. conducted a study on the potential of offshore wind energy in Chile and assessed its technical and economic viability. The performance of the V164–8.0 MW wind generator was evaluated. The terms "Levelized Cost Of Energy (LCOE)," "Net Present Value (NPV)," "Internal Rate of Return (IRR)," and "Payback (PB)" refer to specific financial metrics used in evaluating the cost and profitability of energy projects [16]. Y. Himri *et al*. conducted a study on the economic feasibility of wind farms and the evaluation of wind power potential in the South-West area of Algeria using the RETScreen and WAsP tools, respectively [17]. This study examines the process of analyzing wind properties in producing an atlas. The RETScreen software assesses energy generation potential and determines a wind farm's economic viability. Several indicators are evaluated during the process, including Benefit-Cost ratio, Net Present Value, Annual Life Cycle Savings, Simple Payback Period, and Internal Rate of Return. Samuel Sarpong [18] comprehensively evaluated the technical, financial, and environmental effects of a 50-MW utility-scale wind farm in Ghana, covering four sites. The Net Present Value (NPV) was the primary economic indicator used to assess the feasibility of the projects. The study conducted by Youssef *et al.* [19] primarily aimed to examine the economic feasibility of different-sized wind farms and, for the first time, evaluate the wind power potential of 22 specific sites across Libya. In addition, the RETScreen program is employed to calculate the energy production and perform an economic viability assessment of the wind farm. The Sustainable Energy Program is the leading global tool for making informed decisions about sustainable energy. The application of advanced algorithms simplifies the decision-making process for energy projects, which includes renewable energy, energy efficiency, and cogeneration [20].

The Gulf Cooperation Council (GCC) has started prioritizing environmental sustainability. Despite the area's inexpensive fossil fuels, developers are putting more pressure on the GCC region to create renewable energy owing to falling technological prices and missed investment possibilities. [21]. Historically known for its plentiful fossil fuel supply, the Middle East and North Africa (MENA) region is significantly changing into a more environmentally conscious energy future focusing on renewable sources [22]. Regional governments progressively acknowledge the significance of diversifying their energy portfolios and diminishing their reliance on conventional fossil fuels. Egypt, Jordan, and Morocco have built significant renewable energy capacity [23]. There is already a long-term demand for wind turbine components in the Middle East and North Africa [24]. The wind energy development in Iraq is still in its early stages; however, there are promising signs of progress. Iraq aims to upgrade renewable energy production to 20-30% of the total power output by 2027. The country has targeted boosting renewable energy production to 10 gigawatts (GW) by 2030 [25].

In Iraq, the southeast region has considerable wind potential [26]. Several studies have assessed different sites in Iraq [27-29]. An extensive analysis was conducted by Resen and Ahmed [29] to determine which wind turbine model would be most suitable for the Al-Najaf location in Iraq. Determining the optimal wind turbine generator according to the capacity factor requires a site-matching study with nine different types. Bashaer et al. [30] conducted A novel program that was constructed and subsequently developed using MATLAB to conduct an in-depth analysis of wind energy in selected locations within Iraq. Ali K Resen et al. 2020 [31], conducted at three sites in Iraq (Al-Shehabi, Al-Najaf, and Al-Fajer), analyzes monthly wind speed and wind direction changes. Discusses temporal fluctuations in the low-frequency and high-frequency wind shear coefficient, emphasizing the common assumption of treating WSC as a constant in various cases.

This study focuses on the importance of considering debt rate, investment cost, and operation and maintenance (O&M) cost in feasibility studies as financial parameters considering the analysis of the sensitivity of the wind farm project. It discusses various factors, such as the impact of debt on a firm’s performance, the role of the debt-to-equity ratio in project investment, and the importance of precise evaluation of investment costs in the early planning phase for erecting wind farms in the Al-Fajer site in Iraq.

2.Study Area

Al-Fajr is a city far north of the Dhi Qar governorate. It is located at the intersection of four Iraqi governorates: Misan, Wasit, Dhi Qar, and AL-Muthana. Al-Fajr is approximately 110 km from the center of Dhi Qar governorate and is the center of Al Fajr district. The location of the wind power plant in this study was determined by considering the area's topographical evenness and wind energy potential (Figure 1). In addition, this site has accurate data on wind speed and direction through a metrological mast, which provides data for four years with a 10-minute time interval. The site's coordinates were 31 51.193 N and 45 51.355 E.

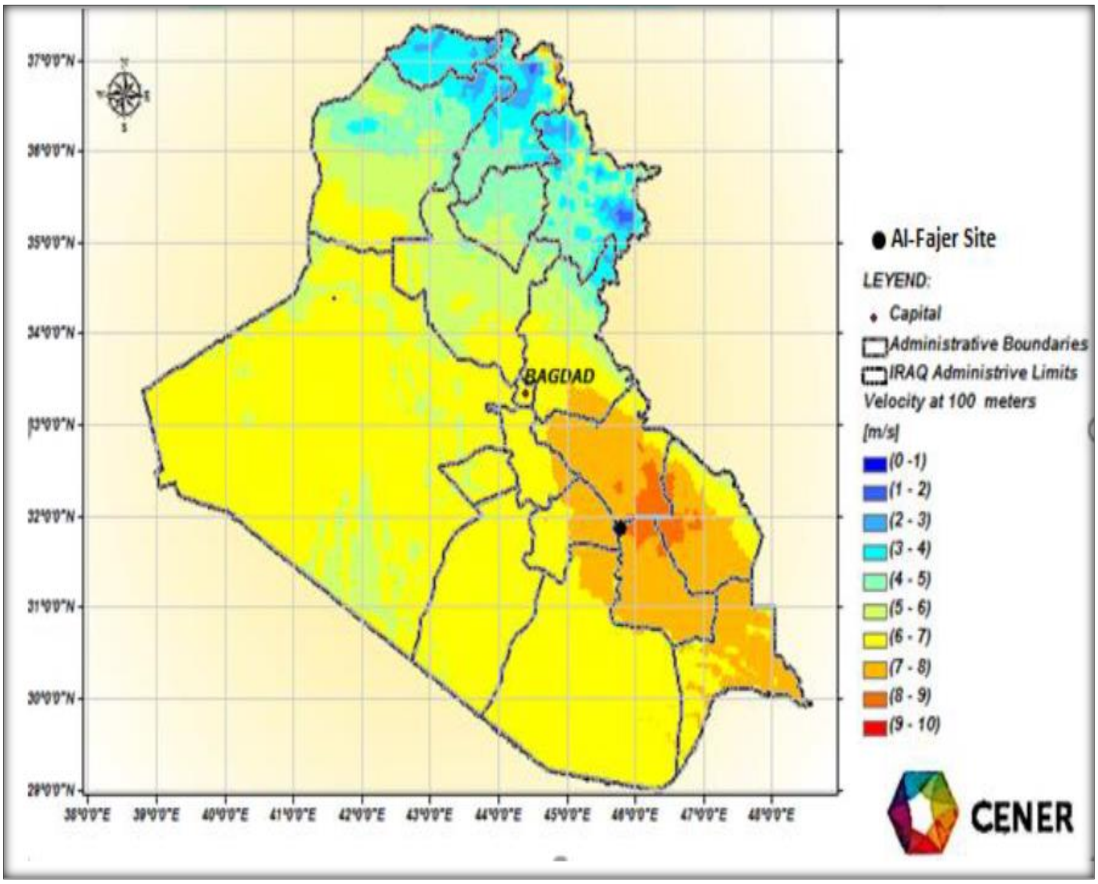

Figure 1: Iraq wind map and location of study area [19]

3.Materials and Methodology

The Al-Fajer location was suggested for a feasibility analysis of the construction of an onshore wind farm. This site was selected because it experiences high wind speeds and possesses other significant features for siting. Investment costs were evaluated using the RETScreen expert software and the empirical principles proposed by Samuel Sarpong Asamoah et al. [18]. The RETScreen approach consists of multiple sequential processes, which include the energy model, cost analysis, revenue summary, GHG emission reduction analysis, and sensitivity and risk analysis. This study considered three scenarios: Scenario 1, Scenario 2, and Scenario 3. In Scenario 1, the input values were adopted based on the values used in [18]. In Scenario 2, it was assumed that the initial cost would decrease by 10%, the cost of maintenance and operation by 10%, and the debt ratio would decrease by 5% compared with Scenario 1. In Scenario 3, the study was built as a bad or non-ideal case, assuming that the initial investment cost was considered to have increased by 10% over Scenario 1, as well as the maintenance and operation cost of 10%, and the debt ratio increased by 5%. A Vestas V90–2 MW wind turbine was proposed, and the technical-specific attributes are shown in Table 1. The study suggested that the wind farm consists of 50 turbines of this type, with a total capacity of 100 MW. Finally, the LCOE was estimated, and investment viability was analyzed using other financial metrics.

Table 1: Lists the specific attributes of the Vestas V-90 wind turbine

Turbine	Value
Manufacturer	Vestas
Model	VESTAS V90-2.0MW-105 m
Power Capacity per Turbine	2.0 MW
Cut-out-wind speed	25.0 m/s
Cut-in wind speed	4 m/s
Hub Height	105 m
Tower type	Tubular
Rotor Diameter	90 m
Swept area	6,362 m^2
No. of turbines	50

4.The Wind Farm's Economic Viability as Planned

This part will examine the wind farm's financial viability at the Al-Fajer location in Iraq. Several economic indicators are used to analyze the economic viability, including the payback duration, discount rate, debt rate, and (NPV). Costs for operation and maintenance (O&M) and the turbines' cost comprise the basic cost. Financial costs, the project's wind resources, the number of wind turbines (WTs) erected, the hub heights of the WTs, and O&M expenses all contribute to the total cost of the wind farm.

4.1 Modalities to the wind farm's economic evaluation criterion

Various methodologies and indicators exist for assessing the economic viability of new projects, such as wind farms. The subsequent part employs analytical techniques to examine the economic viability of a wind farm at the Al-Fajer location. Wind energy density and potential were evaluated to calculate the annual energy production (*AEP)*. This calculation involves using the Weibull wind speed probability distribution and the power curve of a wind turbine selected based on the distribution of wind energy [32].

$$AEP = \sum_{u=1}^{n} P_u * f(u) * 8760 \qquad kWhs \tag{1}$$

The turbine wind speed, denoted as u, ranges from 1 to the cut-out wind speed stated by the manufacturer in the power curve. The turbine's power at speed u is denoted as P. Typically, wind turbines have a cut-in speed of 2-3 m/s, below which no power is generated.

The function $f(u)$ represents the Weibull distribution and can be expressed with the equation [33].

$$f(u) = \frac{k}{c}(\frac{u}{c})^{k-1} exp\left[-(\frac{u}{c})^{k}\right] \tag{2}$$

Wind resource quality can be assessed based on scale parameter c and shape parameter k. Parameter c varies with the wind speed, while k describes the shape of the Weibull distribution.

Revenue generation *(R)* calculation depends on the price per kWh or the tariff rate *(TR)* of electricity provided in Iraq. If the energy produced is assumed to be wholly consumed in the location, the revenue generated can be calculated using the following expression:

$$R = AEP * TR \tag{3}$$

The anticipated project cost considers the going rate for turbines in the global market and other expenses such as installation and maintenance.

4.1.1 Net Present Value (NPV)

First, the NPV, which is the difference between the values of future cash inflows and outflows, was calculated to assess viability using the net present value (NPV) approach. For this purpose, all revenues and withdrawals were discounted and added up [34].

$$NPV = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t} \quad (4)$$

R_t is net cash inflow outflows during a single period t, i is the discount rate or return that could be earned in alternative investments (usually 8-12%), and n is the number of periods.

4.1.2.Simple Payback (SPB): which determines the time required for the sum of the cash flows to equal the initial investment [35].

4.1.3. The Internal Rate of Return (IRR) is a financial metric used to assess the effectiveness of project investments by calculating IRR. It refers to the discount rate at which the entire present value of capital inflow equals the total present value of capital outflow, resulting in zero NPV [36].

4.1.4. The benefit-to-cost ratio (BCR) is a valuable method for selecting project portfolios when assessed using various competing criteria [37].

4.1.5. Levelized energy cost (LCOE) is widely used to compare the costs of different electricity generation technologies [38].

$$LCOE = \frac{\sum \frac{(I_t + M_t + F_t)}{(1+r)^t}}{\frac{E_t}{(1+r)^t}} \quad (5)$$

The cost components are initial investment expenditures *(I)*, maintenance and operations costs *(M)*, and fuel expenditures (if required) *(F)*. The entire output of the power-generating asset encompasses the aggregate of all electricity generated *(E)*. The project's discount rate *(r)* and the system's lifetime *(n)*. The debt interest rate is the yearly interest rate paid to the debt holder after each loan year.

5.Results and Discussion

Figure 2 depicts the wind speed histogram in the study region. The average wind speed in the region was precisely 6.6 meters per second, measured at a height of 50 m. Table 2 lists the attributes of wind farms.

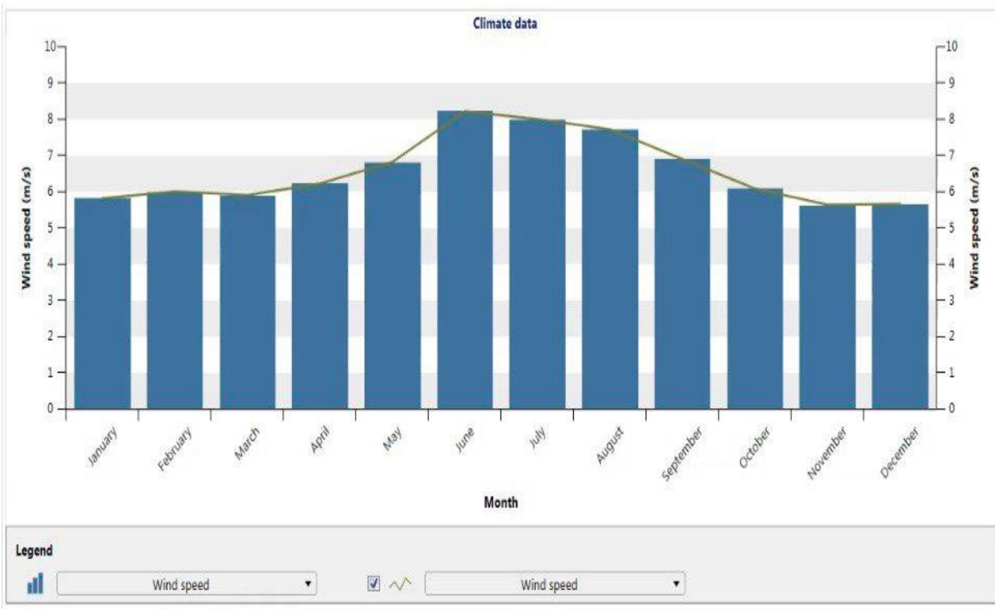

Figure 2: Wind speed histogram

Table 2: Wind farm characteristics

Turbine Manufacture	Vestas V-90 2MW
Hub height	105 m
Wind speed	6.587 m/s
Wind speed Measure at	50 m
Wind shear exponent	0.14
Capacity per turbine	2 MW
Total capacity	100 MW
No. of turbines	50
Swept area	6,362 m^2
Rotor diameter	90 m
Project lifespan	20 years

5.1 Wind Farm's Financial Results

The fundamental expenditures of a wind turbine, including installation and other associated expenditures for a wind farm, were considered in the economic analysis. This analysis is presented in Tables (3, 4, and 5) representing Scenarios 1, 2, and scenario 3, respectively.

Table 3: Input parameters and costs in RETScreen Model (Scenario 1)

Investment cost	100,350,000 $
O&M Cost	45 $ kw/h year
Debt ratio	70 %
Debt term	10 years
Electricity export escalation rate	2 %

Table 4: Input parameters and costs in RETScreen Model (Scenario 2)

Investment cost	90,315,000 $
O&M Cost	40,5 $ kw/h year
Debt ratio	66.5 %
Debt term	10 years
Electricity export escalation rate	2 %

Table 5: Input parameters and costs in RETScreen Model (Scenario 3)

Investment cost	110,385,000 $
O&M Cost	49.5 $ kw/h year
Debt ratio	73.5 %
Debt term	10 years
Electricity export escalation rate	2 %

The net revenue was determined using a price 0.10$/kWh for energy in Iraq. Tables 6, 7, and 8 list the outcomes of Scenarios 1, 2, and 3, respectively.

Table 6: Results of Scenario 1

Debt payment	13,105,000 $/year
Debt	70,245,000 $
Equity	30,105,000 $
Electricity export to the grid	279,432 MW
Income	27,943,246 $
Electricity export rate	0.10 $ kw/h
Per-tax IRR Equity	39.5 %
Pre-tax IRR Assets	14.7 %
Simple payback	4.3 year
Equity payback	2.8 year
NPV	214,550,873 $
Energy production cost (LCOE)	0.058 $/kWh
Benefit-cost rate	8.1

Table 7: Results of Scenario 2

Debt payment	11,739,750 $/year
Debt	60,059,475 $
Equity	30,255,525 $
Electricity export to the grid	279,432 MW
Income	27,943,246 $
Electricity export rate	0.10 $ kw/h
Pre-tax IRR Equity	46.2 %
Pre-tax IRR Assets	18.2 %
Simple payback	3.8 year
Equity payback	2.3 year
NPV	236,505,368 $
Energy production cost (LCOE)	0.052 $/kWh
Benefit-cost rate	8.8

Table 8: Results of Scenario 3

Debt payment	15,858,960 $/year
Debt	81,132,975 $
Equity	29,252,025 $
Electricity export to the grid	279,432 MW
Income	27,943,246 $
Electricity export rate	0.10 $ kw/h
Pre-tax IRR Equity	33.6 %
Pre-tax IRR Assets	11.8 %
Simple payback	4.8 year
Equity payback	3.6 year
NPV	192,238,578 $
Energy production cost (LCOE)	0.065 $/kWh
Benefit-cost rate	7.6

Based on the data provided in Tables 6, 7, and 8, the difference in IRR-tax equity percentage was roughly 16.96% for Scenario 1 compared to Scenario 2 and -14.94% for Scenario 1 compared to Scenario 3. An escalation in IRR-Tax Equity signifies a rise in the rate of return on investment, enhancing the venture's attractiveness. This suggests that the project or investment will yield a greater yearly growth rate. This may be attributed to causes such as improved profitability, reduced expenses, or other favorable financial indications.

A reduction in IRR-Tax Equity signifies a contraction in the return on investment; this might diminish the appeal of the investment. Possible causes include decreased profitability, heightened expenses, or other adverse financial indications. A project's equity IRR will be lower than the project IRR only if the cost of debt (or the interest on debt) exceeds the project IRR. The percentage differences for the three Scenarios, relative to Scenario 1, for IRR-tax assets are as follows: Scenario 2 shows an increase of 23.81%, while Scenario 3 shows a decrease of 19.73%. An augmentation in the IRR of tax assets indicates a rise in the return on investment, enhancing the attractiveness of the investment. This suggests that the investment's tax advantages will result in a greater yearly growth rate. This may be attributed to heightened tax deductions, credits, or other favorable financial indications.

A decline in the IRR of tax assets indicates a reduced return on investment. This might diminish the appeal of the investment. Possible causes include reduced tax advantages, alterations in tax legislation, or other unfavorable financial indications.

During the analysis of the NPV, the percentage differences between the three instances observed and those observed in Scenario 1 are roughly 10.23% for Scenario 2 and 10.39% for Scenario 3. A positive NPV signifies that the expected future revenues from a project or investment, after accounting for the time worth of money, surpass the predicted expenditures, adjusted for inflation. An investment with a positive NPV is lucrative, while an investment with a negative NPV will lead to a financial deficit.

Table 9: Comparison of financial parameters for three scenarios

Scenario	NPV (USD)	IRR %	Simple Payback (years)	LCOE (USD/kWh)
Scenario 1	214,550,873	14.7	4.3	0.058
Scenario 2	236,505,368	18.2	3.8	0.052
Scenario 3	192,238,578	11.8	4.8	0.065

Table 9 compares the financial and performance metrics for Scenario 1, Scenario 2, and Scenario 3. These scenarios are likely to be related to investments in wind farm projects. The table shows that Scenario 2 provides the most favorable financial outcomes, with the highest NPV and IRR, shortest Simple Payback period, and lowest LCOE. Conversely, scenario 3 showed the least favorable outcomes across all metrics. Scenario 1 fell between these two extremes.

6.Conclusions and recommendations

Increasing debt ratios can potentially raise the cost of capital, thus leading to a rise in LCOE. In contrast, reduced debt ratios can lead to a fall in the price of capital, which may result in a lower LCOE. The debt ratio can also influence a project's NPV. Excessive levels of debt ratios can lead to an escalation in the cost of capital, which is employed as the discount rate in calculations of NPV. This could reduce a project's NPV. It can be concluded that when the initial cost decreases by 10%, as well as the cost of O&M by 10%, and the debt ratio decreases by 5%, it provides the most favorable financial outcomes, with the highest NPV and IRR, shortest simple payback period, lowest LCOE. Therefore, it is necessary to continuously monitor and review debt ratios to enhance financial indicators and reduce capital costs. Efficient expenditure management may decrease LCOE, NPV, and IRR while increasing the return on investment (ROI).

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