

Multiattribute decision-making for site selection of wind-powered reverse osmosis desalination systems in Western Kazakhstan

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Abstract

This article aimed to apply a multi-attribute decision-making technique, technique for order preference by similarity to ideal solution (TOPSIS), to prioritize four locations, namely, Aktau, Fort Shevchenko, Zhanaozen, and Atyrau in Kazakhstan for the installation of wind-powered reverse osmosis desalination systems. In this regard, different criteria were considered for ranking the alternatives. Among the considered criteria, the need for desalinated water and land availability earned the highest scores from the experts, representing the highest importance. According to the implemented analysis based on the TOPSIS, Aktau ranked first among these alternatives, followed by Fort Shevchenko, Atyrau, and Zhanaozen.

Keywords: RO desalination; wind energy; TOPSIS; multiattribute decision-making; site selection

Nomenclature

Symbols	
c	Criteria
r_{ij}	Vector normalization
S^+	Separation from positive-ideal solution
S^-	Separation from negative-ideal solution
v_{ij}	Weighted normalized value
C^*	Similarity to positive-ideal solution
Abbreviations	
AHP	Analytic Hierarchy Process
ELECTRE	Elimination and Choice Translating Reality
GDP	Gross Domestic Product
MADM	Multi-attribute Decision-Making
MADM	Multi-objective Decision-Making
MCDM	Multi-criteria Decision-Making
NZE	Net Zero Emissions
RE	Renewable Energy
RO	Reverse Osmosis
SAW	Simple Additive Weighting
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
TES	Total Energy Supply

Alternative clean energy sources have attracted attention in recent decades to alleviate environmental pollution due to energy-consuming activities. Renewable energy (RE) sources are eco-friendly and can be used for various applications such as power generation, cooling, and heating. In addition to the applications mentioned above, RE systems are usable for desalination in different ways. For instance, solar technologies are relatively simple technologies that convert water with high salinity into potable water using solar radiation's thermal energy [1]. In addition to the thermal systems for desalination, reverse osmosis (RO) technologies are applied to this purpose. These technologies require electricity to drive the pump, which increases the pressure of saline water. REs can supply this electricity to reduce emissions and make these systems sustainable technologies. Various power generation systems based on REs, such as solar photovoltaic systems [2, 3] and wind turbines [4], can be integrated with RO desalination to power the plant. In recent years, researchers have broadly evaluated the use of clean energy sources for supplying electricity to RO systems to assess their feasibility and performance to optimize their operational characteristics [5–7].

The use of electricity produced by thermal power plants using fossil fuels leads to significant emissions of greenhouse gases such as CO₂. Employing cleaner energy sources to power RO desalination units is crucial in terms of sustainability and environmental protection [8]. Different clean energy

1 Introduction

Significant consumption of fossil fuels, including oil and coal, has led to emissions of greenhouse gases such as CO₂ that are harmful to the environment and cause climate change.

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sources, specifically REs, have been evaluated for supplying electrical energy to RO desalination. Alsheghri *et al.* [9] evaluated an RO desalination system powered by a solar photovoltaic (PV) system and the grid to supply the water requirement of Masdar Institute with a capacity of 200 m³/day. They reported that employment of the proposed system will result in a yearly reduction in the GHG emissions by 1035 tCO₂. Ghaithan *et al.* [10] assessed the feasibility of using solar energy to power a large-scale RO system by considering different cases, including full grid, PV-grid, PV-grid-battery storage, and PV-battery storage. They pinpointed that the final cost of a PV-grid system without a battery is cheaper than a full grid under fuel subsidies. In addition, it was noted that the PV-battery system is less competitive; however, it has the potential to be competitive and effective when considering environmental concerns. Concerning the inconsistent nature of RE sources, hybrid energy systems have attracted attention in recent years. These systems include multiple power production technologies with or without storage units [11–13]. Hybrid energy systems could be integrated with RO technologies to power them. In a study by Ghaithan *et al.* [14], multi-objective optimization was implemented on a PV-wind-grid system linked to an RO desalination plant. They reported that in the optimized case, it is possible to prevent a significant amount of GHG emissions and have energy costs lower than the corresponding cost of power purchased from the grid. Different studies have reported the advantages of hybrid energy systems for powering the RO plants in terms of the environment [15].

Both technology and site play key roles in installing RE systems, whereby properly selecting these factors is essential for policymakers and designers. The multicriteria decision-making (MCDM) technique is a practical approach for assessing multiple conflicting criteria to select the most appropriate solution [16]. MCDM methods provide a solution for cases involving multiple and conflicting objectives [17]. MCDM models are either multiobjective decision-making (MODM) or multiattribute decision-making (MADM) [18]. Scholars in different energy-related problems have extensively used the MADM method to prioritize technologies and sites [19]. Various approaches, such as Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), analytic hierarchy process (AHP), etc., are applicable for MCDM analysis. Nazari *et al.* [20] employed the TOPSIS technique to rank the site locations in Iran for the installation of wind turbines. Alavi *et al.* [21] applied different techniques, namely TOPSIS, simple additive weighting (SAW), and elimination and choice translating reality (ELCTRE) for optimal site selection of wind turbine installation in the eastern region of Iran. In a study by Şengül *et al.* [22], the fuzzy TOPSIS method was applied to rank the RE supply systems in Turkey. The MCDM analysis revealed that the hydropower station is the case study's most renewable energy supply system. In another research, Bilgili *et al.* [23] used intuitionistic fuzzy-TOPSIS to assess RE options for the sustainable development of Turkey. They considered several criteria to prioritize different options and reported that the best choice for the sustainable growth of their case study is solar energy. Amiri *et al.* [24] utilized the AHP-TOPSIS method for the selection of RE sources in Saudi Arabia. Lee and Chang [25] applied MCDM methods for ranking RE sources in Taiwan. Furthermore, they applied a sensitivity analysis on the weight and reported that the best choice can be different depending on the focused criteria.

Ishfaq *et al.* [26] applied the MCDM method for the selection of the optimum RE source for the Pakistan energy sector. Aside from the site and technology or source selection and prioritization, MCDM methods are applicable for other RE-related subjects such as the strategies and plans associated with the development and growth of RE systems [27].

Various scholars have researched the relevant subjects in Kazakhstan regarding the importance of RE systems and the plans and policies for the evolution of these systems in this country. For instance, Karatayev and Clarke [28] in 2014 reviewed the energy resources in Kazakhstan and the future opportunities of REs. They reported that despite the remarkable potential of different REs, due to some barriers such as technical, economic, and social, these resources had not been sustainably captured and developed. In addition to analyzing REs and their potential in the country, decision-making tools have also been studied for some energy-related topics in Kazakhstan. Mukhamediev *et al.* applied a multicriteria spatial decision-making support system to develop RE in Kazakhstan. The developed MCDM and software tool to process spatial heterogeneous data that would be applicable for assessing the potential of RE sources [29]. Akhanova *et al.* [30] implemented a study on developing an MCDM framework for assessing building sustainability in Kazakhstan. The results of their study could produce helpful references to policymakers on green building in the country. Until now, there have been few studies on the applications of MCDM methods in the site selection of RE systems, particularly wind turbines. The ability of these methods to prioritize alternatives makes them an attractive option for policymakers in Kazakhstan, and it is beneficial to develop these techniques in the process of decision-making and policy design.

According to the literature review, MCDM methods are appropriate tools for prioritizing alternatives in RE projects. In Kazakhstan, several policies and plans support the development of RE systems for a variety of purposes, ranging from power generation to desalination. Applying these methods in the process of decision-making can assist designers, engineers, and policymakers. To date, MADM techniques have not been applied to prioritize site locations for the RE systems in Kazakhstan. This study aims to fill the gap by ranking different locations in the west of Kazakhstan for the installation of a wind-powered RO plant for the first time. In this context, applying a suitable tool and considering impactful factors, including the criteria relevant to both the wind power projects and desalination plants, is necessary. In the present work, TOPSIS—an attractive MADM method—is applied to prioritize four locations. The factors that impact the decision-making must be identified to perform this prioritization. After that, each factor must be assigned a weight according to its importance. Subsequently, the performance of each alternative with respect to each criterion must be evaluated. Finally, the alternatives are prioritized according to the computed scores using the TOPSIS approach. Since multiple, and sometimes conflicting, criteria are influential in the decision-making process, the use of the MADM approach would be helpful for policy and decision-makers. Prioritizing the alternatives using this technique facilitates the process of decision-making and helps identify the most suitable option among the available choices. The following sections provide an overview of Kazakhstan's energy system and wind potential. The third and fourth sections of the present article provide the importance of desalination for the country and the method explanation,

GLOBAL WIND ATLAS
MEAN WIND SPEED AT 100m
KAZAKHSTAN

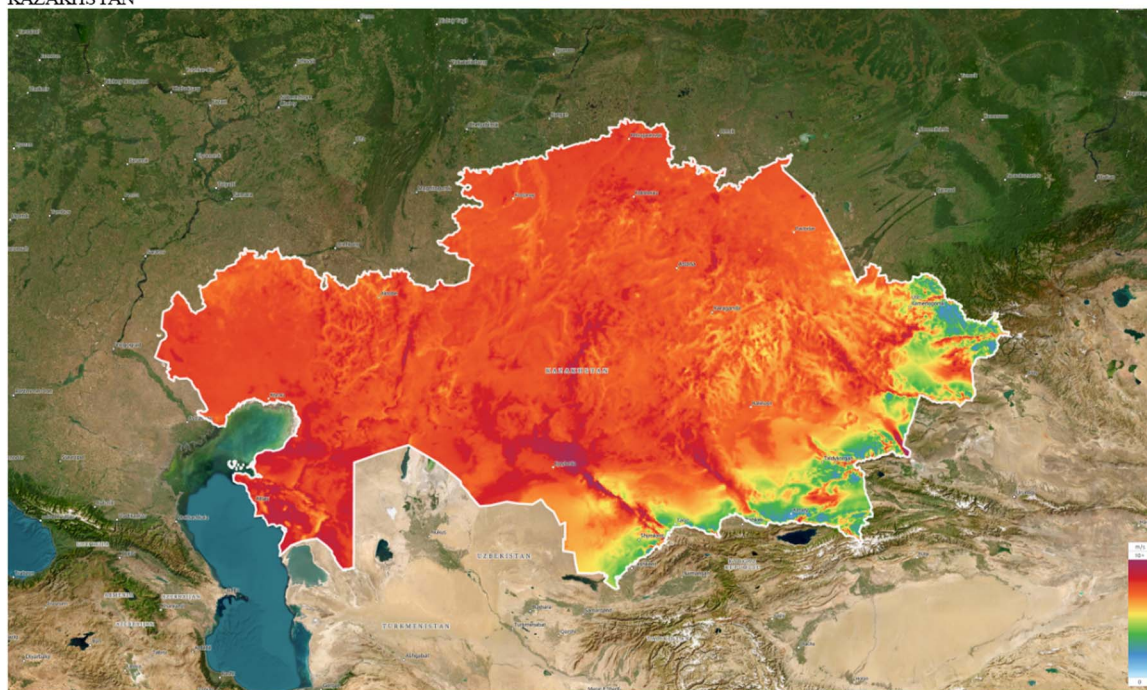


Figure 1. Mean speed of wind at a height of 100 m in Kazakhstan according to the simulation period of 2008–2017 (obtained from the Global Wind Atlas version 3.3, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas version 3.3 is released in partnership with the World Bank Group, utilizing data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: <https://globalwindatlas.info> [43, 44].

respectively. In the fifth section of the present work, results are presented. Finally, in the conclusion section, the most important findings are presented.

2 An overview of Kazakhstan's energy system

Kazakhstan is the ninth-largest country in the world, primarily located in Central Asia. In 2023, its population was around 20 330 000 [31]. This country's economy and energy systems are highly dependent on fossil fuels. Kazakhstan plays a vital role in the production of fossil fuels like coal, crude oil, and natural gas, and is an important exporter of energy carriers [32]. In 2022, coal had the highest share in the country's total energy supply (TES), followed by natural gas and oil [33]. Coal and natural gas have the highest shares in power generation in Kazakhstan. In 2022, Kazakhstan recorded a CO₂ emission intensity of 1 kgCO₂ per 2015 USD, substantially surpassing the global average and markedly exceeding the levels observed in most developed countries [33]. In July 2009, Kazakhstan enacted a law to support the use of renewable energy sources, followed by several amendments, with the most recent introduced in December 2021. According to this law, the feed-in tariff scheme aims to increase the share of REs in power generation, which aligns with the Green Energy Concept targets [34]. After that, some more policies and plans were developed to support the development of RE systems. The government aims to diversify the country's energy mix and increase the shares of REs. By 2050, the government expects that nonthermal sources will contribute to a minimum of 50% of the country's energy requirements. To reach

the goals of this plan, significant development of nonhydro REs and the initiation of a domestic nuclear program are required [35].

Aside from environmental protection, the evolution of RE systems in this country would be beneficial in terms of other factors. For instance, the development of RE systems has high potential for job creation [36]. It is reported that value chains in sustainable and renewable technologies are more labour-intensive in comparison with extractive fossil fuels. Furthermore, investment in the REs would increase public spending and elevate residents' per capita income [37]. It is also important to note that, given the country's significant reliance on fossil fuel exports for income, transitioning to RE would allow it to conserve fossil fuel reserves for export, potentially increasing its gross domestic product, a trend observed in other energy-exporting countries [38]. Although the development of clean energy technologies offers economic, environmental, and social benefits for the country, several barriers remain. These include the need for substantial investment, limited public awareness of the advantages of clean and alternative energy sources, and a shortage of trained personnel. These barriers must be eliminated to accelerate the development of clean technologies, particularly RE systems.

The potential of various REs in Kazakhstan is relatively high. For instance, the estimated potential of geothermal energy in the country is 97 billion tons of oil equivalent (toe) [39]; however, the majority of the resources are competitive for heating purposes, due to their temperature, rather than electrification on a large scale [40]. The estimated yearly technical feasibility of hydropower is around 62 billion kWh [39], and this renewable source is already used for power

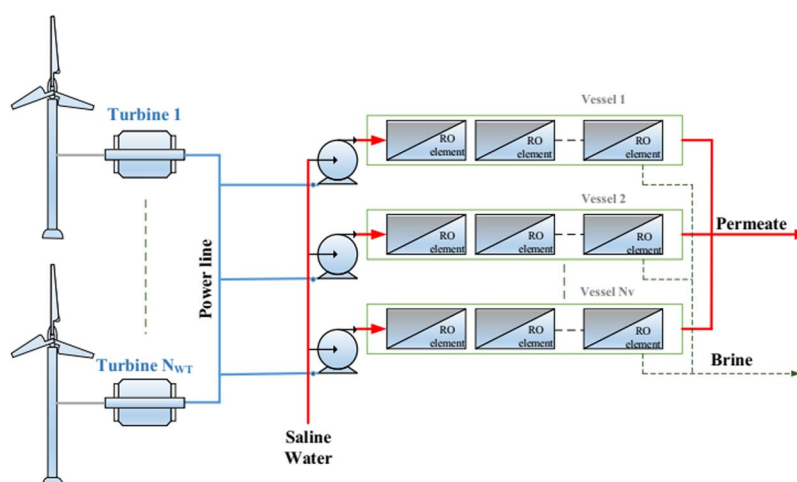


Figure 2. Schematic of wind-powered RO desalination systems (reprinted from reference [52]).

generation to a relatively large extent. In 2022, the generated power by this energy source was 9201 GWh, which ranked third in sources used for electricity production after coal and natural gas [33]. Solar energy has development potential in this country, particularly in some central and southern regions. The country's yearly solar energy potential ranges from 1000–1500 kWh/m² to 1300–1800 kWh/m² for the northern & western regions and central & southern regions, respectively [39]. Among different REs, wind energy is a very proper choice for the country due to its significant potential. Kazakhstan's Climate is ideal for the development of wind farms since wind speed above 5 m/s is available in wind corridors [41]. The highest reported potential of RE sources for electrification is wind, estimated at about 920 billion kWh annually [42]. In Fig. 1, the wind atlas of Kazakhstan is presented, which reveals considerable potential for power generation from this energy source. As represented in this figure, eastern regions, especially on the shore of the Caspian Sea and the surrounding regions, have considerable potential for installing wind turbines. As part of the planned development of REs in Kazakhstan to shift towards lower emissions in the country's energy sector, several projects are being financed and designed to install wind turbines in various regions of the country. Electricity generation from wind turbines in Kazakhstan increased from 3 GWh in 2012 to 2319 GWh in 2022 [45], and it is expected to further increase in the near future.

3 Importance of desalination systems in Kazakhstan

Kazakhstan has limited water resources, and the country faces significant water shortages to meet the requirements of the economic sector and provide drinking water for its population [46]. The challenge of providing drinking water to the populations of the West Kazakhstan and Mangystau regions is particularly critical, since these areas are located in a semidesert zone with restricted water resources. A sufficient supply of high-quality water is required to establish adequate conditions for intensive economic growth [47]. To resolve the issues related to freshwater supply, the government of Kazakhstan has planned to install several seawater desalination units and has invested significantly in this purpose. Since the western part of Kazakhstan is located on the southern shore of the Caspian Sea, these regions are focused on the installation of

seawater desalination systems. Although several technologies and configurations can be used for desalination purposes, RO systems remain the most attractive option due to their efficiency and currently hold the largest share of the market [48]. These technologies would be proper options for desalination purposes in the western regions of the country. The selection of an RE system to power RO desalination depends on multiple factors, including technical and economic feasibility, resource availability, and social acceptance.

Wind energy is one of the clean options for powering RO desalination. Wind turbines are rotating machines that convert extracted kinetic energy from wind into mechanical energy through the motion of their blades. Afterwards, a generator converts the mechanical energy into power [49]. In 2023, wind energy generation increased by 216 TWh, representing a 10% rise and bringing the total to over 2330 TWh. Among all RE power technologies, it ranked second after solar PV. However, to get on track with the Net Zero Emissions by 2050 (NZE) Scenario, the sector must increase its mean yearly growth rate to around 17% [50]. The development of wind energy is highly beneficial in terms of the environment. It is estimated that 1 MWh of wind energy would avoid 0.75 tons of CO₂ emissions on average [51]. The generated power of wind turbines could be connected to the grid or supplied to the equipment and systems that need power. RO desalination is one of the systems that can potentially be connected to wind turbines. In wind-powered RO systems, the power generated by the wind turbine through the generator is applied to the electricity-consuming components, such as pumps, of the RO system, as represented in Fig. 2.

4 Materials and methods

MADM problem is a type of MCDM that is mainly applied in cases where there are discrete decision variables and the number of decision-making schemes is restricted [53]. This study applies TOPSIS techniques to prioritize sites for installing RO desalination systems powered by wind turbines.

4.1 TOPSIS method

The TOPSIS method is one of the MADM techniques that is applicable to decision-making related to energy systems. In this section, the method is described as presented in references [20, 54]. Suppose that in the problem under consideration, the

Table 1. Explanations of the considered criteria

Criteria	Explanations
Potential of wind energy (C1)	Wind energy potential significantly affects the produced power. Higher wind potential would lead to higher power generation and lower cost of electricity in the same conditions.
Availability of saline water (C2)	Since the goal of the study is selection of best choice for powering RO desalination by use of wind energy, availability of saline water has high importance to be used in the desalination plant.
Need for desalinated water (C3)	Requirement for desalinated water would affect the prioritization of the alternatives. Higher requirement for desalinated water means higher importance of the installation of the plant. This criterion is influenced by different factors such as the population, activities require desalinated water, availability of freshwater, etc.
Status of substructures (C4)	This criterion refers to the condition and state of the structure, which supports the equipment necessary for the installation of the plant.
Social acceptance (C5)	This criterion refers to the state of the installation of a wind-powered RO system.
Land availability (C6)	It refers to the level of support and approval for the project that is received from the local individuals. For success and development of the projects, social acceptance is critical.
Land cost (C7)	Land cost refers to the all expenses associated with the preparing and acquiring the land for the present project.
Effect on surrounding region development (C8)	Similar to any project, installation and development of wind-powered project could lead to development of surrounding regions. This factor can impact the attitude of the decision-makers.
Project safety (C9)	This criterion refers to the risks and hazards related to the project.
Brine disposal capacity (C10)	It refers to the potential and ability of the considered alternatives in disposal as well as management of the salty wastewater obtained from desalination process.

number of criteria and alternatives is n and m , respectively. To define the positive-ideal solution, Equation (1) is used as follows [20, 54]:

$$c^* = (c_1^*, \dots, c_j^*, \dots, c_n^*) \quad (1)$$

where c_j^* is the maximum value of the number j criteria. Similarly, Equation (2) is used to define the negative-ideal solution [20, 54].

$$c^- = (c_1^-, \dots, c_j^-, \dots, c_n^-) \quad (2)$$

In Equation (2), c_j^- is the minimum value of the number j criteria. The normalized vector is obtained by use of Equation (3) as follows [20, 54]:

$$r_{ij} = \frac{c_{ij}}{\sqrt{\sum_{i=1}^m c_{ij}^2}} \quad i = 1, \dots, m; j = 1, \dots, n \quad (3)$$

where r_{ij} refers to the value of normalized vector for the number i alternatives in the number j criteria and c_{ij} is the score of number i alternatives in the number j criteria. These values are presented in the tables. Subsequently, Equation (4) is applied to determine the weighted normalized value [20, 54].

$$v_{ij} = w_j r_{ij} \quad (4)$$

In Equation (4), w_j refers to the number j criteria weight. Equations (5) and (6) are used to calculate the normalized quantity of C^* and C^- , respectively [20, 54].

$$C^* = \{v_1^*, \dots, v_j^*, \dots, v_n^*\} = \{\max v_{ij}\} \quad (5)$$

$$C^- = \{v_1^-, \dots, v_j^-, \dots, v_n^-\} = \{\min v_{ij}\} \quad (6)$$

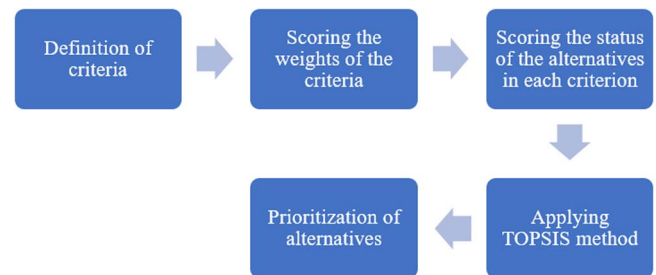


Figure 3. The process of prioritization of the alternatives.

To calculate separations from positive- and negative-ideal solutions, Equations (7) and (8) are used as follows [20, 54]:

$$S_i^* = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^*)^2}, i = 1, \dots, m \quad (7)$$

$$S_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2}, i = 1, \dots, m \quad (8)$$

Finally, to compare the results, C_i^* , similarities to positive-ideal solution, is calculated by use of Equation (9) [20, 54].

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \quad (9)$$

4.2 The prioritization is done based on the descending values of C_i^* : criteria and alternatives

The present work aims to implement wind-powered desalination systems with a capacity of approximately 500 m³/day, requiring an estimated electricity supply of 1250 to 1750 kWh/day [55–57]. Ten criteria were considered for decision-making and prioritizing suitable locations for installing wind turbines to power RO desalination systems.

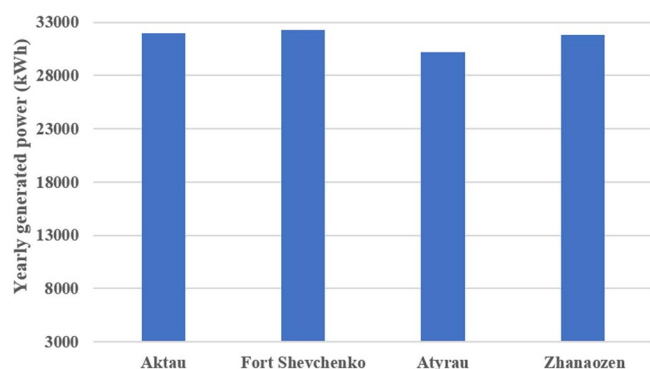


Figure 4. Yearly generated power by a 10-kW generic wind turbine in different locations (without consideration of temperature effect).

The criteria include: potential of wind energy (C1), availability of saline water (C2), need for desalinated water (C3), status of substructures (C4), social acceptance (C5), land availability (C6), land cost (C7), effect on surrounding region development (C8), project safety (C9), and brine disposal capacity (C10). These criteria are briefly explained in Table 1. In the designed questionnaire, provided in Appendix I, a 1 to 7 scale is applied for the evaluation of the criteria (to determine their weights) and status of the alternatives in each criterion. According to this scale, 1 is the lowest value and indicates the least level of importance and 7 is the highest score, which indicates the highest possible level of importance in decision-making. To evaluate the status of alternatives for each criterion, the scholars were asked to use the same scale, in which 7 represented the excellent condition and 1 represented the unsatisfactory condition. It should be noted that to guide the respondents, the potential of power generation by use of a Generic 10 kW wind turbine was calculated and mentioned in the questionnaire to provide them with deeper insight into the power generation capacity of wind turbines in the considered regions. The calculation of power generation was performed by use of HOMER 3.18.3 software and the data resources related to weather and wind were applied in the software from NASA Prediction of Worldwide Energy Resource, which considers monthly mean speed of wind at 50 m above the earth surface over a 30-year period between January of 1984 and December of 2013. The used questionnaire is provided in Appendix I.

The alternatives for the installation of the plant in the present study are Aktau, Fort Shevchenko, Atyrau, and Zhanaozen, which are all located in the western part of the country. In the following paragraphs, these alternatives are briefly introduced.

Aktau: Aktau is a city located in the west of Kazakhstan, nestled along the shores of the Caspian Sea. As of 2024, the population is estimated to be around 284 000 residents [58]. The city plays a key role in the country's economy, primarily due to its oil industry, port activities, and mineral resources. The strategic location of this city as a coastal city makes it a key point for shipping and trade, particularly in the energy sector [59]. Aktau is poised for growth through planned infrastructure development, including the expansion of its port facilities and improved transport links. Moreover, a growing emphasis is placed on enhancing tourism by utilizing the city's picturesque coastline and contemporary urban areas [60].

Fort Shevchenko: Fort Shevchenko is a small but historically rich town located in the centre of the Tupkaragan district in the west of Kazakhstan. It was estimated to have a population of about 8000 in 2024 [58], and is one of the smallest settlements in the region. The economy of Fort Shevchenko is based on fishing, agriculture, and local commerce. The future plans for Fort Shevchenko include popularizing its cultural heritage as a tourist attraction and developing local infrastructure to improve the residents' quality of life [61]. Restoration projects aimed at preserving historical monuments that emphasize the city's unique history are also underway [62].

Atyrau: This city, located at the confluence of the Ural River and the Caspian Sea, is an important industrial centre of Western Kazakhstan. The city's population is expected to reach approximately 41 400 by 2025 [58]. Atyrau is known for its oil and gas industry and is home to many key players in Kazakhstan's energy sector. In addition to energy, the city also serves as a trade and transport link between Europe and Asia, which increases its logistical importance. Further efforts are being made to diversify the city's economy and solve environmental problems. The plans include upgrading urban infrastructure, decreasing environmental pollution, and enhancing sustainable development via investments in education and technology [63].

Zhanaozen: This city is located in the Mangystau region and has been associated with oil production in Kazakhstan. It was estimated to have a population of around 152 000 in 2024 [58]. The development of RE systems for power generation in this region is planned. Furthermore, the government considers modernizing water treatment plants to supply drinking water and provide life support for the town.

5 Results and discussion

Figure 3 illustrates the overall process followed in the study. Scoring the weights of the criteria to determine the relative importance of each criterion is a key step in this study. Six local experts were asked to score the weights of the criteria and the status of each alternative for the considered criteria using a questionnaire. In the first step, wind potential for the considered alternatives was evaluated by use of HOMER Software (version 3.18.3) to help the experts better score the wind potential in the considered locations. In Fig. 4, the yearly generated power by use of a Generic 10 kW wind turbine, which exists in the library of the software, is compared. As mentioned in the previous sections, wind energy potential in the west of Kazakhstan is very high, and the installation of wind turbines for power generation in this region of Kazakhstan is technically feasible. It can be seen that all of the considered locations for the installation of wind turbines for electrification have considerable potential. The maximum value belongs to Fort Shevchenko, which is 32 271 kWh, which means that the generated power by a wind turbine is maximum among the considered alternatives, and the minimum value belongs to Atyrau that is 30 196 kWh that stands for the minimum power generation by the wind turbines among the alternatives of the present study. To get better insight into the wind potential of these locations, average wind speeds in different months of the year are compared in Fig. 5. According to these data, the installation of wind turbines in these locations would be technically feasible since there is considerable potential for power generation.

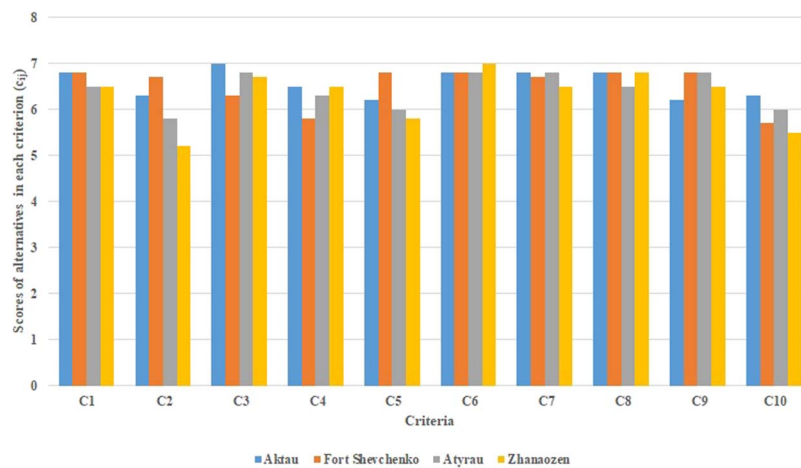


Figure 5. Average wind speed in different months for the considered alternatives.

Table 2. Scores of alternatives for each criterion (c_{ij} , where i is the number of alternatives and j is the number of criteria)

Alternatives	Criteria									
	C1	C2	C3	C4	C5	C6	C6	C8	C9	C10
A1	6.8	6.3	7	6.5	6.2	6.8	6.8	6.8	6.2	6.3
A2	6.8	6.7	6.3	5.8	6.8	6.8	6.7	6.8	6.8	5.7
A3	6.5	5.8	6.8	6.3	6	6.8	6.8	6.5	6.8	6
A4	6.5	5.2	6.7	6.5	5.8	7	6.5	6.8	6.5	5.5

Table 3. Calculated values of normalized vector or r_{ij} (where i is the number of alternatives and j is the number of criteria)

Alternatives	Criteria									
	C1	C2	C3	C4	C5	C6	C6	C8	C9	C10
A1	0.5111	0.5227	0.5220	0.5174	0.4991	0.4963	0.5074	0.5055	0.4711	0.5355
A2	0.5111	0.5559	0.4698	0.4617	0.5474	0.4963	0.4999	0.5055	0.5167	0.4845
A3	0.4886	0.4812	0.5071	0.5015	0.4830	0.4963	0.5074	0.4832	0.5167	0.5100
A4	0.4886	0.4314	0.4996	0.5174	0.4669	0.5109	0.4850	0.5055	0.4939	0.4676

Table 4. Calculated values C^+ and C^-

Alternatives	Criteria									
	C1	C2	C3	C4	C5	C6	C6	C8	C9	C10
C^+	3.4928	3.7060	3.6541	3.1043	3.4668	3.5764	3.3825	3.3699	3.3588	3.1235
C^-	3.3387	2.8763	3.2887	2.7700	2.9570	3.4742	3.2333	3.2212	3.0624	2.7269

In Fig. 6, average weights of the criteria based on the scores obtained from the questionnaire are presented. It can be seen that the highest values of the weights among the considered criteria belong to C3 (need for desalinated water) and C6, with a value of 7, and the minimum weight belongs to C10 (brine disposal capacity), with a value of 5.83. The higher weight of a criterion means its importance is higher for decision-making and has a greater impact on selecting the best choice. In addition, the determined scores of each alternative in each criterion are presented in Table 2. After obtaining the scores of the alternatives and the weight of the criteria, the TOPSIS method is applied to prioritize the alternatives. Determined scores of each alternative in each criterion (c_{ij}), the normalized vector (r_{ij}), and values of C^+ and C^- are presented in Tables 2–4, respectively. As shown in Fig. 7, Aktau ranks first among the considered alternatives, with the maximum value of C_i^+ , that

is followed by Fort Shevchenko. The first rank of Aktau is mainly attributed to its high scores in the criteria with the high weights. Although the score of Zhanaozen is high in one of the criteria with the maximum weights, C6, its low score in some criteria, such as availability of saline water and brine disposal capacity, cause its lowest ranking among the considered alternatives.

6 Future Works

In the previous section, four sites were prioritized for the installation of wind-powered RO systems. Apart from site selection, such MADM techniques are applicable to other aspects of these systems, including the selection of a wind turbine [64]. Additionally, other renewable energy options such as solar PV or hybrid systems, which combine multiple

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