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Energizing the Desert: Strategic Multi-Criteria Decision-Making Approaches to Saudi Arabia's Renewable Transition

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Abstract

This paper focuses on identifying and addressing the challenges hindering renewable energy development in Saudi Arabia. A literature review and expert insights pinpointed seven key obstacles: lack of a stable investment climate, political instability, technical expertise, limited institutional capacity, varying environmental conditions, dependence on fossil fuel, and limited public awareness. The analytic hierarchy process (AHP) was employed to prioritize these challenges, revealing that limited public awareness is the most crucial barrier and varying environmental conditions are followed. To counter these challenges, the paper proposes seven strategies: encouraging private sector investment, providing financial incentives, strengthening the regulatory framework, developing a skilled workforce, promoting public awareness, collaborating with international organizations, and implementing policies. The effectiveness of these strategies was assessed using the combined compromise solution (CoCoSo) method, which highlighted policy implementation as the foremost approach. This research aims to guide decision-makers in Saudi Arabia in effectively allocating resources and making informed decisions to facilitate the growth of renewable energy.

Keywords
Multi-criteria decision-making (MCDM), Analytic Hierarchy Process (AHP), Combined Compromise Solution (CoCoSo), Technique for Order Preference, Similarity to Ideal Solution (TOPSIS)

1. Introduction
The global energy sector is undergoing a significant transformation, driven by the dual goals of reducing carbon emissions and meeting the rising energy demand. This transformation is increasingly integrating renewable energy sources like solar and wind power, considered critical for achieving a sustainable future. These sources offer an alternative to fossil fuels and help mitigate ecological impacts (Smith, J., & Brown, A. 2021). Their implementation is not just desirable but necessary for addressing climate change and ensuring global energy security (Lee, Y., & Kim, S. 2021). In Saudi Arabia, a pivotal shift towards alternative energy sources is underway. The nation, known for its significant oil production and consumption, stands at a crucial point in moving towards a sustainable energy path (Al-Saud, M. 2022). The abundance of solar and wind resources presents a significant opportunity for the country to diversify its energy portfolio, enhancing long-term economic sustainability (Mitchell, D., & Vega, S. 2019). This transition is a key aspect of Saudi Arabia's Vision 2030 strategic plan, which aims to develop renewable energy and establish a sustainable energy framework (Ratikainen, K. W. 2017). To realize these goals, a deep understanding of the various factors influencing this transition is essential.

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1.1 Objectives

1. Theoretically contribute by identifying and prioritizing the key challenges in Saudi Arabia's renewable energy initiatives, offering solutions based on expert opinions and literature review (Khan, N., & Abdullah, Z. 2020).
2. Methodologically advance the field using MCDM, AHP, and CoCoSo for analyzing challenges in renewable energy decision-making (Saaty, T. L. 1990).
3. Provide contextual insights into Saudi Arabia's energy sector, analyzing social, environmental, and economic factors for sustainable energy development.

2. Literature Review

Saudi Arabia's shift towards renewable energy, particularly solar and wind power, is a strategic move to transform its energy landscape. This transition is driven by a need to diversify energy sources, reduce reliance on oil reserves, and address environmental concerns (Patel, R., & Wang, L. 2020). The renewable energy sector, especially solar power, offers substantial opportunities for technological innovation in Saudi Arabia (Al Garni, H.Z., & Awasthi, A. 2017). The focus is on developing efficient solar energy solutions and storage systems adapted to the country's unique environmental conditions (Campos-Guzmán, V., et al. 2019). Such advancements are crucial for maximizing the efficiency and effectiveness of renewable energy use (Shorabeh, S. N., et al. 2019). By embracing renewables, Saudi Arabia aims to enhance its energy security. This strategic shift allows the country to conserve its oil reserves, historically used for domestic energy consumption, for more profitable export purposes. This change not only benefits the national economy but also contributes to a more balanced global oil market. The transition to renewable energy is a critical step toward environmental sustainability (Estévez, R. A., et al. 2021). It helps in significantly reducing greenhouse gas emissions, aligning with global efforts to combat climate change. This transition supports Saudi Arabia's commitments to international environmental goals and agreements. The Saudi government is playing a pivotal role in this energy transition (Al-Hanawi, M. K., et al. 2020). Key initiatives, such as the Saudi National Renewable Energy Program, aim to expand the share of renewable energy in the country's energy mix. These initiatives are backed by policies and investments that foster a conducive environment for renewable energy development. While the path to renewable energy adoption in Saudi Arabia comes with various challenges, including technological, infrastructural, and policy-related hurdles, the opportunities are substantial. These include enhancing the country's global energy standing, contributing to environmental conservation, and fostering economic diversification.

3. Methods

MCDM is a pivotal tool when navigating decisions involving several competing criteria (Hester, P. T., et al. 2013). It functions by pinpointing pertinent criteria, assigning weights to each based on their significance, and subsequently comparing the alternatives with these benchmarks (Saaty, T. L. 1994). The spectrum of MCDM methodologies is vast, spanning from foundational models such as the weighted sum to intricate ones like the AHP and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). MCDM's versatility finds utility across domains like commerce, engineering, and governance, offering stakeholders a structured mechanism to steer through multifaceted decision-making scenarios.

3.1 Analytic Hierarchy Process (AHP)

AHP, developed by T. L. Saaty, uses the multi-functional hierarchical analysis model. This approach facilitates complex decision-making processes with multiple criteria. This is important for project selection and supplier evaluation.

The decision criterion allocates all potential decisions and evaluates a specific position's quantitative or qualitative benefits. It should help evaluate selection preferences. In multi-criteria models, each decision alternative is evaluated. AHP ranks alternatives by multiple criteria. Importantly, each of them uses the same criteria to some extent. The following steps are used for this decision-making:

1. The construction of a hierarchical model
2. The establishment of a matrix for pairwise comparison of individual criteria
3. The calculation of the Consistency Ratio (C.R.) and potential adjustments to assessments
4. Evaluating and prioritizing decision alternatives

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An advantage of AHP over non-linguistic methods is its ability to accommodate non-measurable criteria. This means criterion values need not be quantified. To evaluate comprehensively, show how one criterion outperforms the other in achieving the goal.

3.2 Combined Compromise Solution (CoCoSo)

Yazdani et al. proposed the CoCoSo MCDM method, which combines the exponentially weighted product model with simple additive weighting (Yazdani, Morteza, et al. 2019). The CoCoSo method ranks strategies according to the criteria in this study. When applied to m alternatives and n criteria, the CoCoSo model, a common decision-making tool, has five steps:

1. Step 1: Determine the decision-making matrix $X = (X_{ij})_{m \times n}$, which represents the relationship between the ith alternative and the jth criterion.
2. Normalizing the decision-making matrix

$$r_{ij} = \frac{x_{ij} - min_{ij}}{maxx_{ij} - min_{ij}} \qquad (1)$$

3. Calculate the power weight of comparability (Si) and the total power weight of comparability (Pi) sequence for each alternative.

$$S_i = \sum_{j=1}^{n} (w_j r_{ij}) \qquad (2)$$

$$P_i = \sum_{j=1}^{n} (r_{ij}^{w_j}) \qquad (3)$$

4. Compute three aggregated performance scores.

$$k_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m} (P_i + S_i)} \qquad (4)$$

$$k_{ib} = \frac{S_i}{minSi} + \frac{P_i}{minPi} \qquad (5)$$

$$k_{ic} = \frac{\lambda(S_i) + (1-\lambda)P_i}{\lambda maxS_i + (1-\lambda)maxP_i} \qquad (6)$$

5. Obtain each alternative's performance score (k_i):

$$k_i = (k_{ia} k_{ib} k_{ic})^{\frac{1}{3}} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic}) \qquad (7)$$

The computation of performance scores is used to determine the final ranking of the alternatives, with the alternative with the highest score deemed optimal.

4. Data Collection

The method of collecting data was with the help of experts in the field, these experts are from the Ministry of Energy. A survey was conducted to help the experts give their answers about each criterion and each strategy. The survey was conducted using Microsoft Excel. All criteria (referred to as barriers) and strategies followed a systematic approach, wherein each criterion was accompanied by the name and reference of the author who identified it. Similarly, the strategies were presented with a concise description. A confirmation box indicated whether a particular barrier or strategy was applicable. A comment box was also included for experts to provide feedback or comments on specific criteria or strategies. Subsequently, the research team appended an additional sheet to conduct a criteria assessment. This document conducted a comprehensive comparison between each criterion and all other criteria. Experts were tasked with completing a designated box to indicate the result. Table 1 and Table 2 list the barriers and strategies that were proposed to the experts.

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Table 1. Criteria (Barriers) and its description and authors.

Acronym	Dimension	Description	Reference
C1	Lack of a stable investment climate	This barrier refers to the fact that many countries lack a stable investment climate, which can deter private investment in renewable energy projects. This can be due to factors such as political instability, regulatory uncertainty, and corruption.	World Bank, & International Finance Corporation. (2019).
C2	Political instability and security concerns	This barrier refers to the fact that political instability and security concerns can make it difficult and costly to develop and operate renewable energy projects. This is especially true in conflict-affected countries.	Moe, E., & Midford, P. (Eds.). (2014).
C3	Lack of technical expertise and skilled labor in the renewable energy sector	This barrier refers to the fact that many countries lack the technical expertise and skilled labor needed to develop and operate renewable energy projects. This can make it difficult and expensive to develop and implement renewable energy projects.	Baruah, B., Ward, T., Jackson, N., & Gbadebo, A. (2018)
C4	Limited institutional capacity and regulatory framework for renewable energy deployment	This barrier refers to the fact that many countries lack the institutional capacity and regulatory framework needed to support the deployment of renewable energy. This can include factors such as a lack of clear and supportive policies for renewable energy, as well as cumbersome and time-consuming permitting procedures.	Moorthy, K., Patwa, N., & Gupta, Y. (2019).
C5	Varying environmental and climatic conditions across the country that require customized renewable energy solutions	This barrier refers to the fact that the varying environmental and climatic conditions across countries can require customized renewable energy solutions. This can make it more difficult and expensive to deploy renewable energy in some countr.ies	Paul, S., Dey, T., Saha, P., Dey, S., & Sen, R. (2021).
C6	Dependence on fossil fuel exports as a major source of revenue for the country	This barrier refers to the fact that countries that are heavily dependent on fossil fuel exports face a number of challenges in transitioning to renewable energy. This is because renewable energy can reduce the demand for fossil fuels and thus reduce the revenue that these countries generate from fossil fuel exports.	Tishchenko, I. (2022, November).
C7	Limited public awareness and education about the potential benefits of renewable energy, and the need to transition to a more sustainable energy mix	This barrier refers to the fact that many people are not aware of the potential benefits of renewable energy, and the need to transition to a more sustainable energy mix. This can make it difficult to build public support for renewable energy projects.	Lucas, H., Carbajo, R., Machiba, T., Zhukov, E., & Cabeza, L. F. (2021).

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Table 2. Strategies and its description and authors.

Acronym	Dimension	Description	Reference
S1	Encouraging private sector participation by creating a stable regulatory and policy framework to attract investment and financing for renewable energy projects	By creating a stable and supportive environment for renewable energy, governments can reduce the risks associated with renewable energy investment and make it more attractive for private companies to invest in renewable energy projects.	Fleta-Asín, J., & Muñoz, F. (2021)..
S2	Establishing a feed-in tariff scheme or other incentives to promote investment in renewable energy	This strategy involves providing financial incentives, such as feed-in tariffs or tax breaks, to renewable energy projects. This can help to reduce the upfront cost of renewable energy projects and make them more attractive for investors.	Eko, Bambang, Supriyanto., Jayan, Sentanuhady., Wisnu, Hozaifa, Hasan., A, D, Nugraha., Muhammad, Akhsin, Muflikhun. (2022).
S3	Strengthening the institutional capacity of relevant government agencies and regulatory bodies to support renewable energy deployment	This strategy involves investing in the development of the necessary institutional capacity and regulatory framework to support the deployment of renewable energy. This can include factors such as developing clear and supportive policies for renewable energy, as well as streamlining permitting procedures.	Carla, De, Laurentis., Peter, J., G., Pearson. (2021).
S4	Developing a skilled workforce through training and education programs to support the growth of the renewable energy sector	This strategy involves investing in training and education programs to develop the technical expertise and skilled labor needed for the renewable energy sector. This can help to reduce the cost of renewable energy projects and make them more attractive for investors.	Shahryar, Jafarinejad., Lauren, E., Beckingham., Mandar, Kathe., Kathy, Henderson. (2021).
S5	Promoting public awareness and education to increase understanding of the potential benefits of renewable energy and the need to transition to a more sustainable energy mix	This strategy involves raising public awareness of the potential benefits of renewable energy, and the need to transition to a more sustainable energy mix. This can help to build public support for renewable energy projects.	Abdulaziz, M., Almulhim. (2022).
S6	Collaborating with international organizations and other countries to access technical expertise, financing, and best practices for renewable energy deployment	This strategy involves working with international organizations and other countries to share technical expertise, financing, and best practices for renewable energy development. This can help to accelerate the deployment of renewable energy in developing countries.	Shakila, Aziz., Sheikh, Morshed, Jahan. (2023).
S7	Developing and implementing policies and measures to improve the stability and security of the country, which could help to attract investment and financing for renewable energy projects	This strategy involves making it easy and profitable for private companies to invest in renewable energy projects. This can be done by implementing policies such as feed-in tariffs and renewable portfolio standards, as well as creating a predictable and transparent regulatory environment.	Seema, Agrawal. (2023).

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The targeted experts for this research had to be highly experienced and very educated to have authentic and accurate data to work on. The Ministry of Energy in Saudi Arabia has many experts, and their specialties are similar to the aim of this paper. Table 3 shows the panel of experts who participated in the survey.

Table 3. The Field of Experts

No. of Experts	Expert	Qualification	Years of experience
4	Professors	Ph.Ds.	20-30
3	Managers	Masters & Ph.Ds.	5-6
2	Engineers	Masters	3-9
4	Sr. Managers	Masters & Ph.Ds.	10-15
2	Academicians	Post-Doc	3-5

5. Results and Discussion

Numerical Results

After the experts viewed the barriers and learned the rating system, they compared each criterion using the AHP rating method, the results are shown in Table 4.

Table 4. Expert Evaluation Results for the Barriers

	C1	C2	C3	C4	C5	C6	C7
Lack of a stable investment climate (C1)	1	1/5	1/6	1/4	1/5	1/2	1/5
Political instability and security concerns (C2)	5	1	1/2	2	1	3	1/2
Lack of technical expertise and skilled labor in the renewable energy sector (C3)	6	2	1	2	1	5	1/2
Limited institutional capacity and regulatory framework for renewable energy deployment (C4)	4	1/2	1/2	1	1/3	4	1/2
Varying environmental and climatic conditions across the country that require customized renewable energy solutions (C5)	5	1	1	3	1	5	1
Dependence on fossil fuel exports as a major source of revenue for the country (C6)	2	1/3	1/5	1/4	1/5	1	1/4
Limited public awareness and education about the potential benefits of renewable energy, and the need to transition to a more sustainable energy mix (C7)	5	2	2	2	1	4	1

Next was the strategies ranking. The strategies were ranked from 0 to 100 based on the requirements of the CoCoSo method. The experts received all the strategies with the barriers, compared each strategy with every barrier, and graded every strategy with all the barriers on a scale from 0 to 100. The results are shown in Table 5.

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Table 5. Expert Evaluation Results for the Strategies

	C1	C2	C3	C4	C5	C6	C7
Encouraging private sector participation by creating a stable regulatory and policy framework to attract investment and financing for renewable energy projects (S1)	80	90	60	80	75	70	85
Establishing a feed-in tariff scheme or other incentives to promote investment in renewable energy (S2)	50	55	65	70	65	75	95
Strengthening the institutional capacity of relevant government agencies and regulatory bodies to support renewable energy deployment (S3)	80	85	60	70	90	85	80
Developing a skilled workforce through training and education programs to support the growth of the renewable energy sector (S4)	55	60	50	95	60	55	50
Promoting public awareness and education to increase understanding of the potential benefits of renewable energy and the need to transition to a more sustainable energy mix (S5)	65	65	65	70	70	55	95
Collaborating with international organizations and other countries to access technical expertise, financing, and best practices for renewable energy deployment (S6)	75	70	75	70	60	80	85
Developing and implementing policies and measures to improve the stability and security of the country, which could help to attract investment and financing for renewable energy projects (S7)	90	90	75	75	70	70	80

The primary criterion weighted the highest, Table 6 is the most important table, and it shows how experts initially assessed different ways to overcome barriers.

Table 6. Normalize Matrix

	C1	C2	C3	C4	C5	C6	C7
S1	0.7500	1.0000	0.4000	0.4000	0.5000	0.5000	0.7778
S2	0.0000	0.0000	0.6000	0.0000	0.1667	0.6667	1.0000
S3	0.7500	0.8571	0.4000	0.0000	1.0000	1.0000	0.6667
S4	0.1250	0.1429	0.0000	1.0000	0.0000	0.0000	0.0000
S5	0.3750	0.2857	0.6000	0.0000	0.3333	0.0000	1.0000
S6	0.6250	0.4286	1.0000	0.0000	0.0000	0.8333	0.7778
S7	1.0000	1.0000	1.0000	0.2000	0.3333	0.5000	0.6667

The decision process is concluded by utilizing an aggregated multiplication rule to determine the ranking of the alternatives. According to the findings presented in Table 7, alternative S7 is the most optimal alternative.

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Table 7. Final Aggregation and Ranking

Alternatives	Ka	Ranking	Kb	Ranking	Kc	Ranking	Ki
S1	0.1885	2.0000	6.9479	2.0000	0.9921	2.0000	3.8008
S2	0.1058	6.0000	4.4543	6.0000	0.5569	6.0000	2.3460
S3	0.1685	3.0000	6.9171	3.0000	0.8867	3.0000	3.6685
S4	0.0745	7.0000	2.0000	7.0000	0.3920	7.0000	1.2102
S5	0.1318	5.0000	5.2375	5.0000	0.6935	5.0000	2.8032
S6	0.1408	4.0000	5.5589	4.0000	0.7407	4.0000	2.9805
S7	0.1900	1.0000	7.2976	1.0000	1.0000	1.0000	3.9444

6. Conclusions

Renewable energy in Saudi Arabia faces many obstacles. This study identified seven challenges and seven solutions to overcome them. The obstacle weights were determined using AHP. Meanwhile, CoCoSo was used to rank the suggested options by effectiveness. The most significant obstacles were limited public awareness and education about the potential benefits of renewable energy and the need to transition to a more sustainable energy mix, followed by varying environmental and climatic conditions across the country that require customized renewable energy solutions and a lack of technical expertise and skilled labor in the renewable energy sector. Developing and implementing policies to improve country stability and security, which could attract investment and financing for renewable energy projects, was the most important strategy to overcome the obstacles. This study may help Saudi Arabian decision-makers make informed choices and efficiently allocate resources to renewable energy. Renewable energy development in Saudi Arabia is essential for economic growth, energy security, and environmental sustainability. Saudi Arabia can achieve its renewable energy development goals and contribute to global climate change mitigation by acknowledging and resolving the stated obstacles. The findings of this research could help other nations facing similar challenges in developing sustainable energy sources. Sustainable economic growth, energy security, and environmental sustainability depend on renewable energy development in Saudi Arabia. By acknowledging and resolving the stated obstacles, Saudi Arabia can achieve its renewable energy development goals and contribute to global climate change mitigation. The findings of this research could help other nations facing similar challenges in developing sustainable energy sources.

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Biographies

Ammar Y. Alqahtani, PhD, is an associate professor of Industrial Engineering at King Abdulaziz University in Jeddah, Saudi Arabia. He received his BS degree with first honors from the Industrial Engineering Department of King Abdulaziz University, Jeddah, Saudi Arabia, in May 2008. Being awarded with a full scholarship by the King Abdulaziz University (KAU), he received his MS degree in Industrial Engineering from Cullen College of Engineering, University of Houston. In September 2012, he started his PhD studies in Industrial Engineering at Northeastern University, Boston, Massachusetts. He received his PhD degree in 2017. He has been employed as a faculty member by King Abdulaziz University since December 2008. His research interests are in the areas of environmentally conscious manufacturing, product recovery, reverse logistics, closed-loop supply chains (CLSC), sustainable operations and sustainability, simulation and statistical analysis and modeling with applications in CLSC and multiple life-cycle products. He has published two books, titled *Warranty and Preventive Maintenance for Remanufactured Products Modeling & Analysis* and *Responsible Manufacturing Issues Pertaining to Sustainability*. He has coauthored several technical papers published in edited books, journals and international conference proceedings. At Northeastern University, he won the Alfred J. Ferretti research award. He also received the 33rd Quality.

Ahmed S. Bujeir, born on March 7, 2001, in Jeddah, Saudi Arabia, is a senior industrial engineering student with a steadfast commitment to enhancing his skills and knowledge. He is dedicated to expanding his expertise to achieve a superior degree of professionalism. Efficiently juggling multiple tasks, Ahmed maintains a positive attitude. He is recognized for his excellent abilities in communication, problem-solving, and analysis. In his industrial engineering studies, Ahmed has consistently leveraged his academic education and additional insights to aid in improving the operational efficiency of various businesses.

Abdulaziz M. Junaid, a senior industrial engineering student, was born on February 25, 2000, in Jeddah, Saudi Arabia. He is highly focused on his goals and pays meticulous attention to detail. Continuously striving to enhance his abilities and education, he is passionate about expanding his knowledge and expertise to achieve professional excellence. Known for his ability to handle multiple tasks simultaneously, he maintains a positive outlook. He possesses exceptional skills in communication, problem-solving, and analysis. Throughout his industrial engineering studies, Abdulaziz has effectively utilized his academic learning and additional knowledge to contribute to the improved functioning of various organizations.

Sharaf A. Alshareef, born on August 11, 2001, in Winnipeg, Canada, is a dedicated senior industrial engineering student committed to continual personal and professional development. He is keen on broadening his skills and expertise to attain a high level of professionalism. Known for his capability to manage various tasks efficiently, Sharaf maintains an upbeat demeanor. He excels in communication, problem-solving, and analytical thinking. Throughout his journey in industrial engineering, he has consistently applied his academic insights and additional knowledge to assist companies in enhancing their operations.

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