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Comprehensive Analysis and Prioritization of Sustainable Energy Resources Using Analytical Hierarchy Process

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Abstract: The growing global concern for climate change and the need for sustainable energy solutions have driven nations to explore renewable energy alternatives. This research focuses on a developing country heavily reliant on imported electricity and evaluates the potential of renewable energy resources. Using the Analytical Hierarchy Process (AHP), a multi-criteria decision-making method (MCDM), this study prioritizes sustainable energy resources crucial for energy security and environmental sustainability, given the country's dependence on traditional and imported power and its potential for renewable energy development. This study employs AHP to evaluate and rank various sustainable energy options, emphasizing their technological, economic, environmental, and social impacts. The novelty of this research lies in its comprehensive and systematic approach to integrating diverse expert opinions and utilizing AHP; the development of a robust decision-making model that accommodates the diverse criteria and sub-criteria (SCs) influencing the prioritization of energy resources; and its bridging of the gaps through the integration of varied criteria and SCs, region-specific concerns, and stakeholders' engagement by creating a comprehensive and inclusive prioritization strategy. The key findings highlight solar energy as the most viable sustainable energy resource, followed by wind and hydro energy. These results underscore the significant potential for solar energy development, considering its current technological advancements, economic affordability, social acceptance, and environmental friendliness. This study not only provides a prioritized list of sustainable energy resources but also offers a methodological framework adaptable for similar assessments in other regions facing energy transition challenges. Readers will find a detailed explanation of the AHP methodology, the criteria used for evaluating energy resources, and the implications of the findings for policy and decision making. This research is particularly relevant for policymakers, energy planners, and stakeholders interested in sustainable energy development and strategic planning in similar contexts.

Keywords: sustainability; AHP; energy prioritization; technological assessment; environmental impact; economic viability; social acceptance; decision making

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1. Introduction

The persistent demand for energy, along with the rising environmental crisis, has ushered in a critical period for rethinking and reorganizing the global energy landscape. Traditional energy resources, based on finite fossil fuels, have fostered detrimental environmental repercussions, leading to a paradigm shift towards sustainable and renewable alternatives [1]. As civilizations wrestle with the need for a cleaner, more sustainable energy future, the identification and prioritization of viable energy resources become paramount [2].

While the move to sustainable energy is a worldwide need, each region's own contextual complexities, variable energy demands, and diverse environmental challenges necessitate a more nuanced approach [3]. Understanding these complexities is critical for establishing tailored strategies that not only meet energy needs but also correspond with local environmental and socioeconomic objectives [4].

To have a thorough understanding of sustainable energy resource prioritization, it is critical to recognize the importance of regional variations and contextual considerations [5]. As part of this research, we examine Afghanistan as a compelling case study. Afghanistan, located at the crossroads of Central and South Asia, offers a unique set of potential, difficulties in the field of sustainable energy, and hurdles in providing its energy needs while also transitioning to a more sustainable energy model [6]. The country faces a variety of physical settings, socioeconomic challenges, and energy infrastructure limits, all of which highlight the importance of a personalized and region-specific approach to sustainable energy planning. Meanwhile, Afghanistan's solar, hydro, wind, biomass, and geothermal resource potentials are 222 GW, 23 GW, 67 GW, 4 GW, and 3 to 3.5 GW, respectively [7,8]. By delving into the Afghan context, we hope to extract unique ideas that contribute not only to the global conversation on sustainable energy but also to the specific needs of a region undergoing critical transitions [9].

Moreover, the need to embrace sustainable energy goes far beyond preventing climate change, embracing economic rewards, promoting social fairness, and guaranteeing long-term energy security. Sustainable energy technologies, which range from solar and wind to biomass and hydropower, have the potential to transform energy systems. They provide not only lower carbon footprints but also chances for job creation, economic diversification, and community development [10].

Furthermore, the pursuit of sustainable energy aligns with global agendas such as the UN Sustainable Development Goals (SDGs). As nations strive to balance economic growth with environmental stewardship, understanding the holistic significance of sustainable energy becomes imperative [11]. This research aims to contribute to this understanding by systematically analyzing and prioritizing diverse sustainable energy resources [12].

Additionally, this research endeavors to provide a comprehensive and regionally sensitive analysis of sustainable energy resources. By utilizing the Analytical Hierarchy Process (AHP) as a decision-making tool, we aim to develop a robust decision-making model that accommodates the diverse criteria and sub-criteria (SCs) influencing the prioritization of energy resources. This model seeks to capture the intricate interplay between environmental impact, economic viability, social acceptance, technological feasibility, and resource availability [13].

In addition, the main objectives of this research are to conduct an in-depth review of the existing literature on sustainable energy resources, prioritization methodologies, and regional energy challenges; apply the developed AHP model to prioritize a diverse set of sustainable energy resources, considering specific criteria and SCs tailored to regional contexts; assess the robustness of the prioritization model through sensitivity analyses, considering variations in criteria weights and data inputs; and provide evidence-based policy implications and recommendations derived from the prioritized sustainable energy resources, considering regional disparities and challenges [14].

Through these objectives, this research not only contributes to the academic discourse on sustainable energy but also offers a comprehensive evaluation framework adaptable for similar assessments in other regions facing energy transition challenges, provides a holistic perspective on resource prioritization, offers a methodological framework adaptable for similar assessments in other regions facing energy transition challenges, offers a robust decision-making model that accommodates the diverse criteria and SCs and bridges the gaps through the integration of varied criteria and SCs, region-specific concerns, and stakeholders' engagement; and provides practical insights for policymakers, energy planners, and stakeholders involved in the global energy transition [15].

2. Literature Review

The increasing global emphasis on sustainable energy has led to a significant body of research focused on identifying, evaluating, and prioritizing renewable energy resources. Various methodologies have been employed in these studies, including the Analytic Hierarchy Process (AHP), multi-criteria decision-making (MCDM), and other hybrid approaches. This literature review aims to provide a comprehensive overview of these methodologies and their applications, with a focus on identifying best practices and gaps that our research aims to address.

Renewable energy resources are numerous, including solar, wind, hydro, geothermal, biomass, and tidal energy [16]. Each resource has unique characteristics, benefits, and challenges. Solar energy, for example, captures sunlight using photovoltaic cells to provide clean and abundant power. Wind energy uses the kinetic energy of the wind to generate electricity, whereas hydropower uses the energy of flowing water. A thorough awareness of these resources is necessary for efficient prioritization [17].

In addition, the historical evolution of sustainable energy resources follows the path of technological advances, legislative frameworks, and society attitudes. Early adoption and integration issues have given way to inventive solutions, market expansion, and increased public acceptance [18]. Exploring this progression reveals insights into the elements that shape the current landscape and guides the prioritization process [19].

Furthermore, several studies have tried to prioritize sustainable energy resources using various techniques [20]. Common methods include multi-criteria decision analysis (MCDA), life cycle assessment (LCA), and system dynamics modeling [21]. A critical review of these models indicates the wide range of criteria examined, methodological variations, and the necessity for an open and adaptive approach [22].

Moreover, a study utilized MCDA to prioritize renewable energy sources in China. The criteria included environmental impact, economic cost, resource availability, technological maturity, and social acceptance. Their approach highlighted the importance of considering a diverse set of criteria to capture the multifaceted nature of energy resources [23]. To add to this, a study examined the application of MCDA in energy planning across various countries. Common criteria identified include environmental sustainability, cost-effectiveness, technological feasibility, and social acceptance. The study emphasized the necessity of integrating local contextual factors into the decision-making process [24].

Meanwhile, A study applied MCDA to the energy planning process in Greece, using criteria such as economic viability, environmental impact, technical potential, and societal acceptance. Their findings underscored the critical role of stakeholder engagement in ensuring the relevance and acceptance of the selected criteria [25]. In another study, a fuzzy MCDA approach was used to assess renewable energy options in Turkey. The criteria included economic cost, environmental benefits, energy efficiency, and social impacts. The fuzzy approach allowed for handling uncertainties and subjective judgements in the decision-making process [26].

Meanwhile, a variety of studies have highlighted the importance of sustainable energy resources in mitigating climate change and promoting energy security. For instance, the integrated AHP and fuzzy TOPSIS methods were applied to evaluate renewable energy options in Pakistan, emphasizing the critical role of environmental and economic criteria [27]. Similarly, an integrated approach is used to prioritize renewable energy systems in Tunisia, considering factors such as cost, efficiency, and environmental impact [28]. Also, several studies have investigated sustainable energy transitions and the use of the AHP in similar contexts. However, a specific focus on regional variations and the development of a robust decision-making model that accommodates the diverse criteria and SCs within the existing literature is limited [14]. Studies on sustainable energy have often addressed the challenges of conventional energy resources, highlighting the need for diversified and sustainable alternatives [29]. Additionally, AHP applications in energy planning have been observed in various countries, showcasing its adaptability and effectiveness [30].

MCDA techniques, particularly AHP, have been extensively used to prioritize energy resources. A study demonstrated the application of AHP in prioritizing renewable energy sources, integrating stakeholders' preferences into the decision-making process [12]. In another study, AHP was utilized to assess the potential of various renewable energy sources in South Korea, incorporating technological, economic, and environmental criteria [31].

As a matter of fact, previous studies have made major contributions to the subject; criticisms frequently focus on the absence of standardized methodology, inadequate consideration of regional disparities, lack of primary and comprehensive criteria and SC consideration, and insufficient stakeholder participation [32]. Lessons from these critiques guide the construction of a more robust and adaptive prioritization model that addresses the highlighted limitations [33].

Next, AHP is a structured decision-making approach that allows for systematic examination and prioritization of complex alternatives [34]. Saaty developed AHP, which involves breaking down complex judgements into a hierarchical structure of criteria and SCs, giving weights to each, and using pairwise comparisons to assess their relative relevance. AHP has been widely used in a variety of sectors, including sustainable energy planning and resource allocation, making it an important tool for our research into the prioritization of sustainable energy supplies [35].

Likewise, studies demonstrating the use of AHP in energy planning emphasize its effectiveness in dealing with the complex nature of energy decisions. AHP has been used to prioritize renewable energy technologies, evaluate the viability of energy projects, and inform policy formulation [36]. Understanding these applications helps to design a personalized AHP model for prioritizing sustainable energy resources [12].

Despite extensive research in sustainable energy, gaps remain, particularly in the integration of varied criteria and SCs, region-specific concerns, and stakeholder engagement. Bridging these gaps is critical to creating a comprehensive and inclusive prioritization strategy [11].

While AHP has proven useful in decision-making, applying it to sustainable energy resource prioritization presents certain obstacles. Critiques include vulnerability to subjective judgements, potential biases, and the necessity for transparency in model development. Addressing these deficiencies ensures the creation of a strong and broadly applicable AHP model [4].

By synthesizing these aspects of the literature, this review establishes the foundation for the development of a novel AHP-based model for sustainable energy resource prioritization [11].

3. Methodology

An MCDM approach has been used in this research. Decision making is one of the most crucial parts of every research [32]. Wherever, one right decision can give an effective result for a whole study that has been conducted by an individual or group. And, one wrong decision can destroy the whole plan of implementation of research and could make the research vulnerable. A decision is one of the important factors in the analysis of a problem that has a direct impact on the result [37].

Meanwhile, AHP is one of the most widely adopted MCDM methods and has been used by many scholars in various scientific fields [30]. AHP is the best solution for complexity and multi-criteria and SC issues. In this study, we are going to prioritize one of the alternatives as the most sustainable resource for Afghanistan and rank all of them based on various criteria and SCs that have a direct impact on the alternatives [37]. MCDM methods have gained recognition in the field of renewable energy. They serve as effective tools for addressing complex problems in the energy sector, particularly those involving multiple and sometimes conflicting criteria and SCs [5].

Additionally, the first step in AHP is to set a goal for analysis and build a hierarchy for decisions. And, the defined goal is to prioritize the alternative that is most sustainable among the other alternatives [38]. Following that, four criteria, specifically technological, environmental, economical, and social one, have been defined as having a considerable impact on decision making, and the criteria determination steps include, but are not limited to, stakeholder identification, criteria definition, sustainable energy resource selection, assigning weights for criteria, pairwise comparison, consistency check, score aggregation sensitivity analysis, ranking and prioritization, and validation and review [39]. At the third level of the hierarchy, 15 SCs, inclusive of efficiency, reliability, maturity, installed capacity, greenhouse gases (GHGs), environmental damage, land requirement, noise, investment cost, electric cost, service life, net present value (NPV), political acceptance, job creation, and social acceptance (SC1. . . SC15) are considered, which helps to decrease the complexity of the hierarchy and prioritize the factors that have the greatest impact on the alternatives [40]. Figure 1 illustrates a detailed schematic diagram of the research design and data collection, and Figure 2 illustrates the AHP process [30].

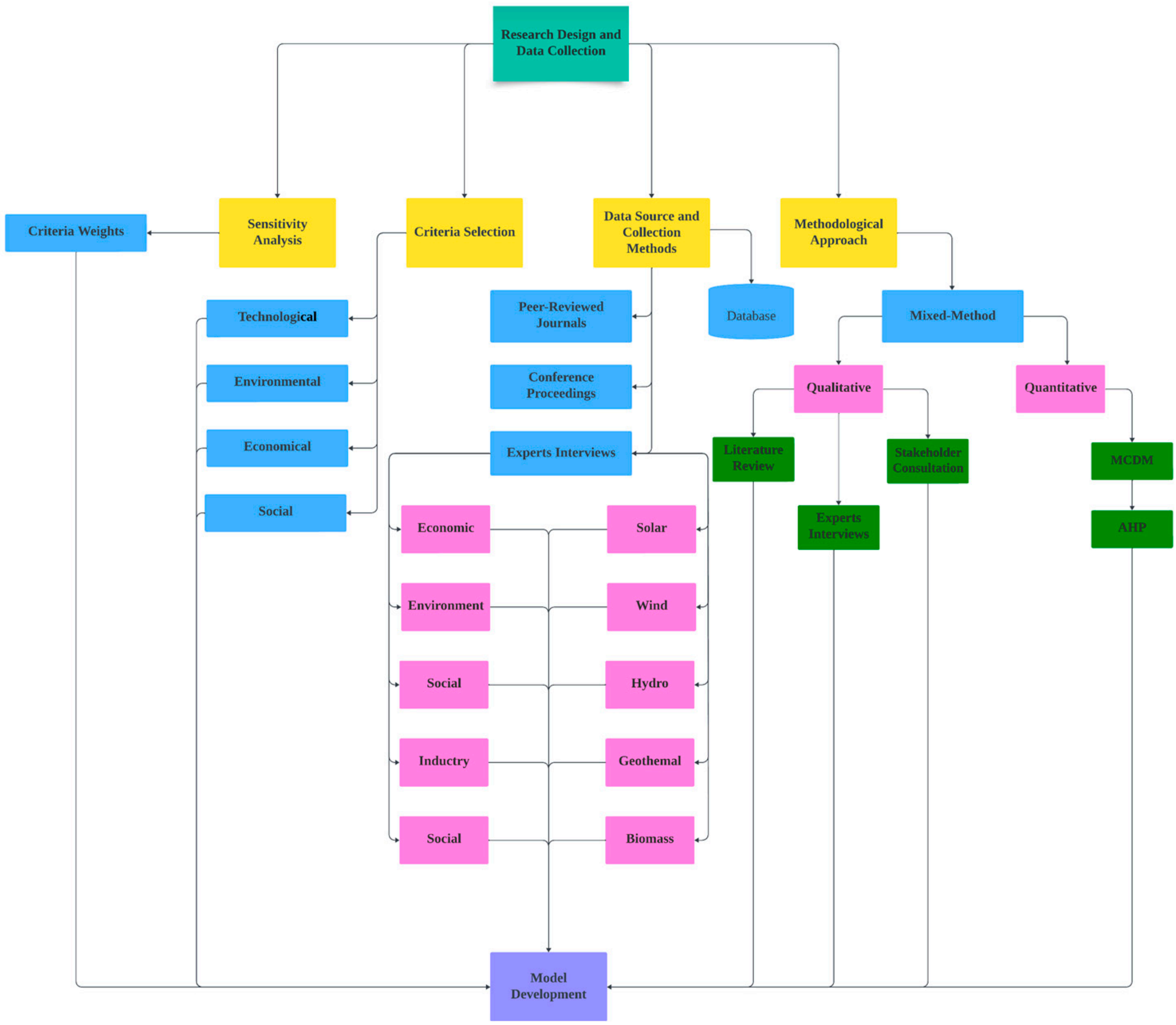

Figure 1. Detailed schematic diagram of research design and data collection.

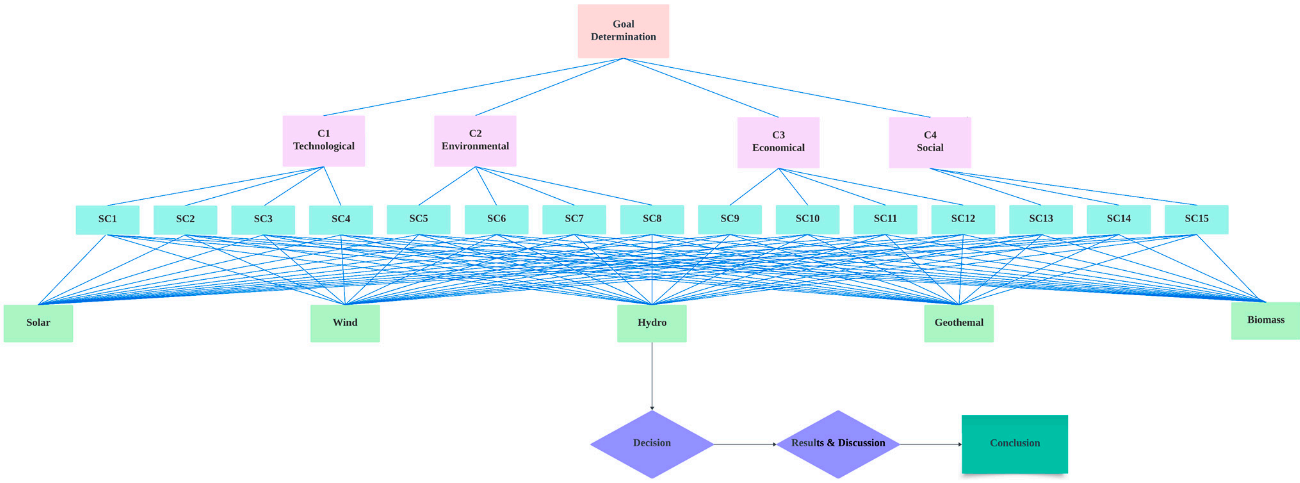

Figure 2. The AHP process.

A pairwise comparison matrix, as depicted in Table 1, was utilized to evaluate the relative significance of criteria and sub-criteria in the AHP. This matrix facilitated the assignment of weights to each criterion and sub-criterion, ensuring a systematic assessment of their importance in the decision-making process [41]. The scale provided in Table 1 allowed experts to quantify the level of importance, ranging from equal significance to extreme importance, thus enabling a nuanced analysis of the criteria influencing the prioritization of sustainable energy resources [12].

Following the research design and data collection, criteria selection, sensitivity analysis, and criteria weight determination completion steps, the AHP model was constructed hierarchically with the goal of prioritizing sustainable energy resources at the top level [42]. Subordinate levels included the identified criteria, which assisted us in the prioritization of the most sustainable alternative [2,43] and, beneath them, the SCs that contribute to the overall evaluation. Pairwise comparisons between the criteria and SCs were conducted, and corresponding weights were derived to quantify their relative importance [41].

Both the criteria and SCs have been scored by experts in the field, and the experts selected for the AHP were chosen based on their extensive experience and expertise in the fields of renewable energy resources, renewable energy technologies, environmental science, economics, and related disciplines. We aimed to ensure a diverse representation of viewpoints by selecting experts from academia, industry, government agencies, non-governmental organizations (NGOs), and other relevant stakeholders. Additionally, efforts were made to consider demographic factors, geographic representation, and stakeholder perspectives among the selected experts to enhance the diversity of viewpoints. The scoring process involved utilizing the pair-wise comparison scale. The scores were determined through the creation of a pair-wise comparison matrix, employing a scale of relative importance [44].

Table 1. The pair-wise comparison matrix with the relative significance scale [45].

Significance	Meaning	Presentation
1	Equal Importance	Elements A and B make an equivalent contribution to the objective
3	Moderate Importance	Based on experience and judgment, there is a slight preference for Element A compared to B
5	Strong Importance	Based on experience and judgment, there is a clear preference for Element A over B

Table 1. *Cont.*

Significance	Meaning	Presentation
7	Very Strong Importance	Element A is significantly preferred over B, and its dominance is evident in practical application
9	Extreme Importance	The evidence supporting Element A over B is of the utmost degree of affirmation
2,4,6,8	Intermediate Values	In instances where compromise is necessary, such as finding a middle ground between 1 and 3, one may choose to use 2 as an intermediate value
1/3,1/5,1/7,1/9	Values for Inverse Comparison	1/3 moderately less important, 1/5 strongly less important

A specialized tool was used to facilitate AHP calculations, ensuring correctness, consistency, and efficiency when dealing with complicated matrices. Popular AHP tools, such as Expert Choice and Saaty's AHP, were used because of their user-friendly interfaces and proven reliability [46].

The AHP model's robustness was assessed using a sensitivity analysis. This phase is critical for evaluating the model's sensitivity to changes in criteria weights, since it ensures that differences in preferences or data do not disproportionately influence the prioritization conclusion [46].

In addition, sensitivity was assessed by systematically altering the weights allocated to criteria and evaluating the effects on overall prioritization [1]. Sensitivity to fluctuations in data inputs was also evaluated to improve the model's flexibility to dynamic real-world settings [4].

Using this comprehensive technique, this study seeks to provide a detailed and transparent examination of sustainable energy resources, providing significant insights for policymakers and stakeholders involved in energy planning and decision making [4].

4. Criteria for Prioritization

Prioritizing sustainable energy resources necessitates a comprehensive set of criteria that reflect the different viewpoints and interests of stakeholders [39]. Active engagement of stakeholders is vital for delineating pertinent criteria and formulating a holistic strategy that encompasses environmental, economic, social, and technological aspects. This participation entails a diverse range of key stakeholders, such as governmental entities at various levels, local and national authorities, executives of environmental and energy enterprises, advocates for environmental causes, non-governmental organizations (NGOs) dedicated to environmental preservation, scientists and researchers, financial institutions, labor representatives, academic institutions, experts, and members of the community [29,47].

Different criteria, including technological, environmental, economic, and social factors, can be considered when prioritizing sustainable energy resources [48]. Some of these criteria found in the literature are shown in Table 2.

Following stakeholder engagements, a structured criterion-weighting procedure began. The criteria were weighted according to their perceived importance, as assessed by quantitative surveys, interviews, or expert panels. This guarantees that the prioritization model accurately represents the relative importance of each criterion in the decision-making process [19,49,50].

The environmental criterion evaluates the ecological impact of each sustainable energy resource. GHG emissions, land requirements, noise, and other environmental damages were the main contributing factors. This criterion seeks to prioritize resources that reduce negative environmental impacts while promoting ecological sustainability [5,13].

Table 2. Summary of Criteria Identified in Literature Review.

Criteria		Study
Technological	Efficiency	[2,26,28]
	Maturity	[23]
	Installed Capacity	[48]
	Technical Potential	[25]
Environmental	GHG	[23–28,31]
	Environmental Damage	[24]
	Land Requirements	[31]
	Noise	[27]
	Environmental Benefits	[26]
Economical	Economic Viability	[24]
	Investment Cost	[23]
	Electric Cost	[26]
	Service Cost	[27,28,31]
	NPV	[23–28]
Social	Social Acceptance	[23–28,31]
	Political Acceptance	[36]
	Job Creation	[29]

Additionally, economic viability assessed the financial feasibility of using and integrating each sustainable energy resource. Considerations include investment cost, electric cost, NPV, and service life. Prioritizing economically viable resources ensures that financial resources are efficiently allocated [43].

Furthermore, social acceptance measured the level of public and community support for each energy resource. Factors include political acceptance, social acceptance, and job creation. Resources with higher social acceptance are more likely to garner support and cooperation, fostering successful implementation [39].

Moreover, technological feasibility evaluated the maturity, reliability, efficiency, and installed capacity of each energy resource's technologies. Considerations include the availability of proven technology, R&D requirements, and future breakthroughs [14]. Prioritizing technically possible resources ensures realistic execution while reducing the chance of technological setbacks [51].

Moreover, recognizing the links and dependencies between criteria is critical for achieving nuanced prioritization. For example, a resource may have a favorable environmental impact but face difficulties in gaining societal acceptance. Understanding these interdependencies informs the weighting process, resulting in a balanced and integrated judgement [14].

Also, resource availability considers the geographic distribution and accessibility of renewable energy resources [52]. Regional abundance, accessibility to demand centers, and potential resource extraction or collection issues are all important considerations [5]. Assessing resource availability gives information on the logistical aspects of resource use.

Additionally, anticipating future resource availability is crucial for sustainable long-term planning. Climate change, technological advancements, and evolving socioeconomic conditions can impact the availability of certain resources [5]. The prioritization model considers these dynamic factors, ensuring adaptability to changing circumstances.

Through the careful consideration of these criteria, this research aims to develop a robust and comprehensive model for prioritizing sustainable energy resources. The criteria not only capture the diverse dimensions of sustainability but also reflect the varying priorities and preferences of stakeholders, contributing to a holistic decision-making framework [42,51].

5. Results and Discussion

The AHP yields a complete ranking of sustainable energy resources based on four prioritized criteria. The priority weights attributed to environmental effect, economic viability, social acceptance, technological feasibility, and resource availability are combined to produce an overall ranking for each resource. With respect to the country's current situation from different aspects, only five resources—solar, wind, hydro, biomass, and geothermal energy—were considered for the analysis. The findings provide significant information about the relative importance of these parameters in shaping the prioritization outcome. See the pictorial representation of the five alternative resources and their ranking based on the assigned criteria, weights, and the calculated consistency ratio (CR) in Figure 3.

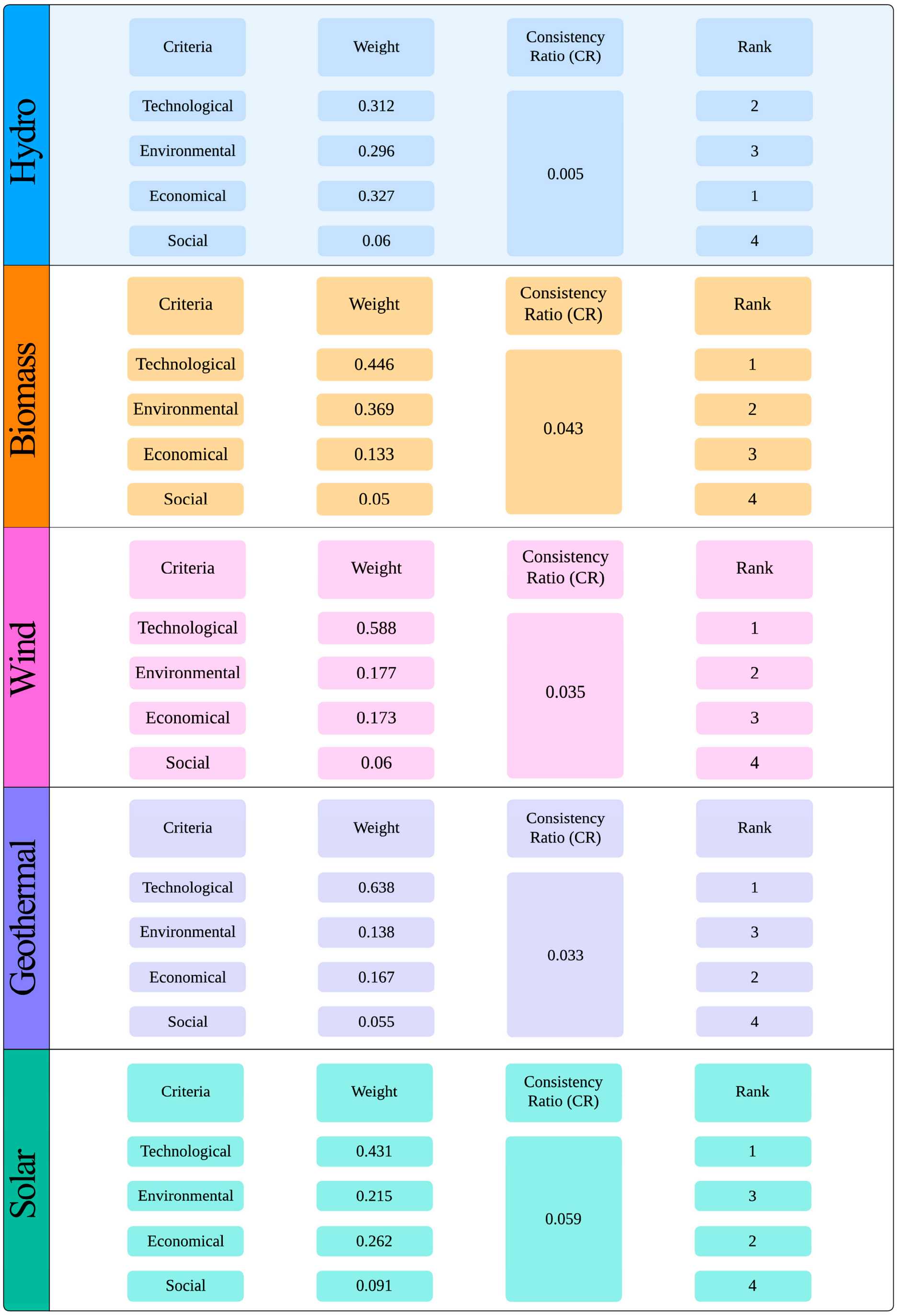

Figure 3. Prioritization and ranking of resources based on predefined criteria and weighted attributes.

Meanwhile, at the third level of the AHP, SCs were calculated. These SCs were selected based on their influence on both the criteria and alternative resources. The calculation of SCs involves considering the CR for each criterion, local weight (LW), and global weight (GW). For solar energy, the CR weights associated with the technological, environmental, economical, and social criteria are 0.021, 0.032, 0.028, and 0.013, respectively. Similarly, for wind energy, the CR weights for the same criteria are 0.031, 0.028, 0.047, and 0.055.

For hydro, biomass, and geothermal energy, the CR weights for technological, environmental, economical, and social criteria are 0.078, 0.018, 0.094, and 0.030; 0.068, 0.062, 0.077, and 0.036; and 0.085, 0.050, 0.081, and 0.083, respectively. Figure 4 illustrates the detailed and all-encompassing process of SC calculation.

	SC	LW (Solar)	GW (Solar)	LW (Wind)	GW (Wind)	LW (Hydro)	GW (Hydro)	LW (Biomass)	GW (Biomass)	LW (Geothermal)	GW (Geothermal)
Criteria 1 (Technological)	SC1	0.338	0.146	0.289	0.170	0.581	0.182	0.619	0.276	0.584	0.373
	SC2	0.358	0.154	0.412	0.243	0.235	0.073	0.225	0.100	0.153	0.098
	SC3	0.108	0.046	0.109	0.065	0.800	0.025	0.076	0.034	0.153	0.098
	SC4	0.193	0.083	0.188	0.111	0.102	0.032	0.077	0.034	0.109	0.070
Criteria 2 (Environmental)	SC5	0.433	0.093	0.480	0.085	0.611	0.181	0.665	0.245	0.582	0.080
	SC6	0.282	0.060	0.204	0.036	0.153	0.046	0.135	0.050	0.154	0.021
	SC7	0.226	0.048	0.242	0.043	0.175	0.052	0.137	0.050	0.134	0.019
	SC8	0.056	0.012	0.073	0.013	0.059	0.018	0.061	0.022	0.128	0.018
Criteria 3 (Economical)	SC9	0.644	0.169	0.669	0.121	0.571	0.187	0.505	0.067	0.720	0.121
	SC10	0.146	0.038	0.146	0.025	0.153	0.050	0.242	0.032	0.149	0.025
	SC11	0.169	0.044	0.107	0.019	0.192	0.063	0.163	0.021	0.074	0.013
	SC12	0.038	0.010	0.046	0.008	0.082	0.027	0.088	0.011	0.055	0.009
Criteria 4 (Social)	SC13	0.387	0.035	0.658	0.040	0.747	0.047	0.527	0.026	0.414	0.023
	SC14	0.514	0.047	0.156	0.009	0.119	0.008	0.332	0.016	0.499	0.028
	SC15	0.097	0.008	0.185	0.011	0.133	0.008	0.139	0.007	0.085	0.005

Figure 4. Detailed and all-encompassing process of SC calculation.

The results of the GW of SCs for each alternative and the GW of SCs after normalization are illustrated in Tables 3 and 4.

The prioritization model identified a diverse set of sustainable energy resources, each carrying distinct advantages and challenges. The numerical values obtained through the model represent not only the intrinsic characteristics of these resources but also their alignment with Afghanistan's unique socioeconomic and environmental context.

Table 3. The GW of sub-criteria for each alternative.

	Solar	Wind	Hydro	Biomass	Geothermal
SC1	0.146	0.170	0.182	0.276	0.373
SC2	0.154	0.243	0.073	0.100	0.098
SC3	0.046	0.065	0.025	0.034	0.098
SC4	0.083	0.111	0.032	0.034	0.070
SC5	0.093	0.085	0.181	0.245	0.080
SC6	0.060	0.036	0.046	0.050	0.021
SC7	0.048	0.043	0.052	0.050	0.019
SC8	0.012	0.013	0.018	0.022	0.018
SC9	0.169	0.121	0.187	0.067	0.121
SC10	0.038	0.025	0.050	0.032	0.025
SC11	0.044	0.019	0.063	0.021	0.013
SC12	0.010	0.008	0.027	0.011	0.009
SC13	0.035	0.040	0.047	0.026	0.023
SC14	0.047	0.009	0.008	0.016	0.028
SC15	0.008	0.011	0.008	0.007	0.005

Table 4. The GW of sub-criteria post normalization.

	Solar	Wind	Hydro	Biomass	Geothermal
SC1	0.127	0.148	0.158	0.240	0.324
SC2	0.231	0.362	0.109	0.150	0.146
SC3	0.174	0.240	0.092	0.127	0.364
SC4	0.252	0.334	0.096	0.105	0.210
SC5	0.135	0.124	0.263	0.358	0.117
SC6	0.284	0.169	0.213	0.233	0.099
SC7	0.228	0.201	0.244	0.238	0.087
SC8	0.146	0.157	0.210	0.271	0.212
SC9	0.253	0.182	0.281	0.101	0.181
SC10	0.223	0.148	0.293	0.188	0.146
SC11	0.277	0.116	0.392	0.135	0.078
SC12	0.153	0.120	0.409	0.177	0.139
SC13	0.205	0.230	0.274	0.155	0.134
SC14	0.431	0.086	0.069	0.155	0.256
SC15	0.220	0.275	0.209	0.175	0.118

For instance, solar energy emerged as a top priority, reflecting Afghanistan's abundant solar resources and the need to harness this renewable source to meet growing energy demand. Our analysis indicates that investment in solar infrastructure could not only enhance energy security but also create employment opportunities and mitigate environmental impacts associated with conventional energy sources.

Similarly, the prioritization of wind energy underscores its potential to complement solar power and diversify the country's energy mix. By strategically locating wind farms in regions with favorable wind conditions, Afghanistan can further capitalize on its renewable energy potential and reduce dependence on imported fuels.

To augment our analysis, we compared the prioritized energy resources with pertinent country-specific factors. Afghanistan's rugged terrain, limited access to grid infrastructure, and reliance on costly fuel imports present unique challenges and opportunities for sustainable energy development.

For instance, the decentralized nature of renewable energy sources aligns well with Afghanistan's dispersed population centers and remote rural communities. Off-grid solar solutions, coupled with energy storage technologies, can extend electricity access to underserved areas and catalyze socioeconomic development.

Furthermore, our analysis revealed the importance of considering socio-political stability and security concerns in energy planning. Investments in resilient energy infrastructure, coupled with capacity-building initiatives and stakeholder engagement, are essential to ensure the long-term sustainability and viability of energy projects in Afghanistan.

The robustness of the prioritization model is examined by examining its sensitivity to changes in criteria weights. A sensitivity analysis carefully alters the weights allocated to each criterion to determine the effect on the overall ranking. This process ensures that changes in stakeholder preferences or shifting priorities do not have an undue influence on the prioritization decision.

The acquired findings are compared to previous research on sustainable energy resource prioritization. This comparative examination identifies commonalities, contrasts, and probable points of convergence or divergence. Examining the reasons for variances in prioritization decisions leads to a better knowledge of the contextual elements that influence the ranking of sustainable energy resources.

The discussion focuses on the differences and similarities between AHP-based prioritization findings and those from other approaches. Differences in criteria selection, weighting procedures, or the inclusion of region-specific elements may all contribute to variation. Consistencies, on the other hand, demonstrate the AHP model's resilience and reliability in capturing critical features of sustainable energy resource prioritization.

The prioritization results have direct implications for sustainable energy planning and policy development. Resources that emerge with higher priority rankings can inform policymakers about the most strategic investments and interventions. Understanding the specific strengths and weaknesses of each resource guides the formulation of policies that align with environmental goals, economic feasibility, and societal acceptance.

Identifying possible issues with lower-ranked resources is critical for proactive planning. Resources facing economic or societal challenges may necessitate tailored interventions or legislative incentives to increase viability and acceptance. The discussion focuses on potential mitigation measures and policy changes to help overcome hurdles and foster a more inclusive and effective sustainable energy transition.

Based on the impact of various criteria and SCs and all considered parameters, the alternatives have been ranked as follows: solar, hydro, wind, biomass, and geothermal energy, in the first, second, third, fourth, and fifth positions, respectively, as illustrated in Figure 5.

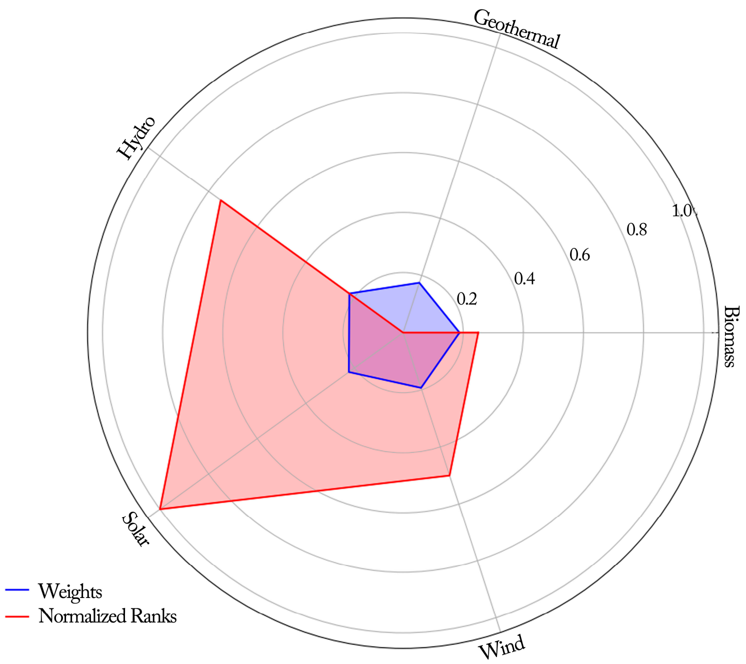

Figure 5. Alternatives by weight and rank.

The associated weights of the ranked alternatives are 0.2231, 0.2213, 0.1933, 0.1877, and 0.1745 for solar, hydro, wind, biomass, and geothermal energy, respectively.

6. Policy Implications

The prioritization results obtained through the AHP serve as a foundation for informing sustainable energy policies. Each resource's ranking, influenced by environmental impact, economic viability, social acceptance, technological feasibility, and resource availability, provides policymakers with strategic insights. Integrating these results into policy formulation ensures a data-driven and systematic approach to sustainable energy planning.

Additionally, policies are adapted to prioritize sustainable energy resources, addressing their unique strengths and constraints. Higher-ranked resources are given targeted incentives, expedited permitting processes, and research and development funding. Lower-ranked resources may benefit from policy initiatives that address the highlighted difficulties, promote innovation, and increase public acceptance.

Furthermore, resources with a high economic viability are prioritized for economic incentives, subsidies, and financial assistance. Policymakers use these measures to stimulate private investment, lower initial infrastructure costs, and foster a favorable economic climate for sustainable energy initiatives. Incentivizing economic viability speeds up the shift to economically sustainable energy options.

Moreover, socially acceptable resources are supported by legal frameworks that encourage community participation, address socio-cultural concerns, and enable transparent decision making. Community-based renewable energy projects may be given favorable regulatory treatment, which fosters collaboration and increases social acceptance.

Similarly, policymakers prioritize research and development strategies to enhance the technological feasibility of sustainable energy resources. This includes funding for innovation, collaboration with research institutions, and initiatives to accelerate the deployment of cutting-edge technologies. Advancements in technology contribute to the overall competitiveness and sustainability of prioritized resources.

On the other hand, resources with positive environmental impacts are supported through policies aimed at preserving ecosystems, reducing pollution, and mitigating climate change. Stringent environmental standards and emission reduction targets guide the development of policies that align with global sustainability goals.

However, acknowledging regional variations in resource availability, economic conditions, and societal preferences, policymakers tailor policies to specific regional contexts. This approach ensures that sustainable energy policies are responsive to local needs, fostering regional development and minimizing disparities.

Also, stakeholder engagement is a critical component of policy implementation. Local communities, industrial groups, environmental organizations, and researchers are all actively involved in policymaking processes. This inclusive approach strengthens the legitimacy and effectiveness of programs, gaining support from a variety of perspectives.

Additionally, policies derived from the prioritization results are subject to continuous monitoring and evaluation. Regular assessments ensure that policy objectives are met, resource priorities remain relevant, and any unforeseen challenges are addressed promptly. Continuous feedback loops with stakeholders contribute to the adaptive management of sustainable energy policies.

Policies exhibit flexibility to accommodate emerging sustainable energy technologies. As the landscape evolves, new technologies may emerge, requiring adjustments to policy frameworks. Policymakers maintain agility to incorporate innovations, ensuring that the policy landscape remains dynamic and responsive to advancements in the field.

This study intends to guide sustainable energy planning and facilitate the transition to a more resilient, environmentally friendly, and socially acceptable energy landscape by turning the prioritization results into concrete policies.

7. Conclusions

In conclusion, the AHP applied in this research has provided a comprehensive ranking of sustainable energy resources based on prioritized criteria. Through a meticulous analysis considering environmental impact, economic viability, social acceptance, and technological feasibility, this study identified solar, hydro, wind, biomass, and geothermal energy as the primary alternatives for sustainable energy development. The examination of SCs further enriched the understanding of each resource's strengths and weaknesses, aiding policymakers in strategic planning and intervention design. The AHP prioritized solar energy as the first rank, with a weight of 0.2231; hydro energy second, with a weight of 0.2213; wind energy third, with a weight of 0.1933; biomass fourth, with a weight of 0.1877; and finally, geothermal fifth, with a weight of 0.1745. A sensitivity analysis ensured the robustness of the prioritization model, guarding against undue influence from shifting stakeholder preferences. A comparative analysis with prior research revealed both consistencies and divergences, shedding light on contextual factors influencing prioritization decisions. The prioritization outcomes, with solar energy leading the list, followed by hydro, wind, biomass, and geothermal energy, provide actionable insights for sustainable energy planning and policy formulation. Addressing the challenges faced by lower-ranked resources is crucial for fostering an inclusive and effective energy transition. Tailored interventions and policy changes can enhance the viability and societal acceptance of these resources, contributing to a more balanced and sustainable energy landscape. Overall, this research underscores the importance of holistic evaluation frameworks like AHP in guiding informed decision making towards a greener and more resilient energy future.

This research offers valuable insights into prioritizing sustainable energy resources but acknowledges the limitations that may impact its findings' robustness and applicability. Future studies should address these to enhance decision-making models in sustainable energy planning. One limitation is the potential incompleteness of the criteria selection process. Despite considering environmental impact, economic viability, social acceptance, and technological feasibility, other relevant factors might have been excluded. Future research should refine criterion selection for a more comprehensive evaluation. Efforts to capture stakeholder perspectives were made, but additional views could provide valuable insights. Incorporating diverse perspectives from local communities, industry experts, and policymakers could enrich the decision-making process and improve prioritization outcomes. As sustainable energy evolves rapidly, integrating emerging trends and advancements into decision-making models will become crucial. Future studies should remain current with technological innovations, policy developments, and market dynamics to ensure models remain relevant and adaptable. Improving the adaptability of decision-making models to account for uncertainties and dynamic socioeconomic conditions is imperative. Enhancing flexibility and robustness will be essential for navigating complex environments, especially in regions like Afghanistan with significant socio-political and environmental challenges. Addressing these limitations through future research will refine the decision-making processes in sustainable energy planning, aiding the transition to a greener and more resilient energy future.

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