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Application of the Z-Information-Based Scenarios for Energy Transition Policy Development

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Abstract: The development of an energy transition policy that ensures a rational combination of the requirements of sustainable development and the country's priorities is a key factor determining the success of its development. The complexity and importance of this task increase in the case of countries in which oil and natural gas export revenues play a key role in the formation of the budget and development of the country. In this paper, the solution to this problem is studied using the example of Azerbaijan. Considering that the task requires addressing the uncertainty and limitations of available information and statistical data, we used an approach based on the use of fuzzy scenarios and expert information. Scenarios have been described using linguistic variables and the formalism of Z-numbers. Z-numbers allow us to simultaneously formalize uncertainty and reliability in the information. Solving the problem involves integrating approximate methods of Z-reasoning and multi-criteria decision-making. This approach considers economic, social, environmental, and technological criteria and allows for the generation, analysis, and evaluation of transition scenarios. The results obtained demonstrate the effectiveness of the proposed methodology for constructing energy transition scenarios for countries producing and exporting oil and gas. The solution suggests a moderate increase in natural gas and hydropower production, along with a significant rise in solar and wind energy production. The results highlight the effectiveness of a rational combination of traditional and renewable energy sources during the transition period. The rule base developed in this article can be adapted to account for the priorities and constraints of a specific oil- and gas-producing and -exporting country, and the fuzzy scenarios approach can be successfully applied to address the transition challenge.

Keywords: fuzzy scenarios; Z-numbers; energy system transition; Z-reasoning; Z-MCDM

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1. Introduction

Sustainable development requirements compel almost all countries to replace harmful natural energy resources with more environmentally friendly alternatives. Every country, depending on its economic conditions and opportunities, priorities, and targets, chooses a different approach, pathway, and pace of energy transition. Researchers distinguish gradual or stepwise replacement, phase-down, or phase-out transition policies [1–4]. However, unforeseen circumstances, such as conflicts, wars, and pandemics, directly impact economic development and significantly complicate energy policy development in almost all countries. In such circumstances, long-term energy planning solutions become less justified and more vulnerable due to the multiplicity and diversity of future unexpected events. Approaches to solving this problem differ significantly between exporters and consumers of energy resources. Countries with limited energy resources and a lower contribution of energy to their GDP have greater flexibility in energy-related decisions. This allows them to switch between suppliers and resources more quickly. For example, many European countries that are not gas producers have decided to change their gas suppliers due to the war in Ukraine. In contrast, net producers that export energy resources face constraints in their energy policy options due to the need to balance the market demands, environmental constraints, as well as past and new energy policies. Examples of compromises are the 10% increase in gas production and export by Norway in 2024, the 5% increase in gas production by Azerbaijan, and the study of the opportunities for increasing the export of natural gas to European countries by Azerbaijan and Turkmenistan. The drastic increase in the demand for natural gas forces oil- and gas-producing countries to increase production volumes. Energy policy, especially that of net producers, has been forced to combine the aftereffects of past decisions with new priorities and opportunities.

In such conditions, a scenario-based approach to policy development is preferable because it is more flexible, can effectively integrate alternatives, ensures consistency in successive choices, and facilitates a seamless transition from one energy policy to another. A well-justified scenario considers previous experiences, current situations, opportunities, and goals. However, underlining that decision-making processes regarding energy transition lack sufficient accumulated statistical data for individual countries or groups of countries categorized by specific characteristics is necessary. Due to the incompleteness and/or inaccuracy of the required information, the decision-making process happens in conditions of high-level uncertainty. Accordingly, the energy policy development approach must ensure the possibility of presenting and processing incomplete and uncertain information in the formulation of the initial task and the processing of its solution.

Currently, there are different (probabilistic, possibilistic, interval calculations, etc.) approaches to decision-making under conditions of high-level uncertainty [5]. The fuzzy-probabilistic approach, which allows operating with imperfect information, is the most suitable for scenario-based energy policy development. Considering this circumstance, the use of two-component *Z*-numbers is proposed [6], which allows us to simultaneously determine the uncertain variables' values and their degree of confidence. *Z*-numbers can be regarded as a relevant and efficient formalism that helps us consider the high degree of uncertainty of the decision-making environment, preferences, and priorities of decision-makers. This will enable decision-makers to convey their views and experiences more efficiently, particularly in areas where sufficient statistical data have not yet been accumulated. Given the complexity and multidimensionality of the problem, this study combines *Z*-number-based reasoning with *Z*-extensions of various MCDM methods (based on distance, rank, and value/benefit function), particularly Z-TOPSIS, Z-PROMETHEE, and Z-SAW. Fuzzy rules-based approaches are preferable for establishing the relationship between the available resources and possible scenarios. This is because they can be considered universal approximators of complex (nonlinear) functional dependencies in many intellectual tasks. As the core of the *Z*-reasoning mechanism, *Z*-number-based IF–THEN rules provide a more relevant formalization of the dependences between input (X) and output (Y) variables to consider the fuzzy–probabilistic nature of high uncertainties. The *Z*-reasoning mechanism allows for a rule-based determination of criterion values for scenarios involving multiple resource development using the criteria values specified for each resource individually. Then, knowing the criterion values and determining the criterion importance weights based on the Z-number-based pairwise comparison matrix, Z-MCDM determines the best scenario.

As will be seen in subsequent sections of the present study, relatively few studies are devoted to developing the energy transition scenarios for developing countries rich in oil and natural gas resources. The reasons for the limited number of studies are different and exploring them is not the focus of our article. Our study aims to partially fill this gap and present a scenario approach to implementing an energy transition for a developing country rich in oil and gas resources. The proposed approach considers the issues of scenario construction and the tools for their assessment. The research aims to identify an optimal, sustainable energy transition scenario for hydrocarbon-rich developing countries such as Azerbaijan by integrating scenario approaches, fuzzy–probabilistic models, and MCDM methods. Azerbaijan's energy sector predominantly relies on non-renewable resources, with oil and gas accounting for approximately 90% of the country's export revenues [7–9]. This heavy dependence on fossil fuels underscores the urgency of developing a robust and sustainable energy transition strategy. Despite its rich hydrocarbon reserves, Azerbaijan is increasingly vulnerable to fluctuations in the global market and geopolitical risks, making diversifying its energy portfolio through renewable resources not just a priority but a necessity.

Given the high level of uncertainty and the lack of accumulated statistical data, how can oil and gas-producing countries develop a sustainable and resilient energy transition policy that balances their reliance on fossil fuels with the need to integrate renewable energy sources? To answer this question, this study extends the research on the energy transition in hydrocarbon-exporting countries. It addresses gaps in the existing studies, particularly within the context of Azerbaijan and other countries in positions similar to those of both energy producers and consumers. Given the scarcity of reliable statistical data on energy transitions in oil- and natural gas-exporting countries like Azerbaijan, this study proposes a scenario-based approach using Z-information-based reasoning and multi-criteria decision-making (MCDM) techniques. These methods are well-proven approaches to decision-making in complex management situations involving multiple criteria (objects) arising from considerations of social, economic, and environmental situations, and in some cases, all of them together. It allows for evaluations of alternatives based on all criteria by following existing preferences and the simultaneous coverage of qualitative and quantitative criteria.

Z-numbers, which allow for the quantification of uncertainty and confidence in decision-making, provide a more nuanced framework for developing energy transition policies under high levels of uncertainty. This approach is particularly relevant in Azerbaijan, where the energy sector's future is increasingly uncertain due to external pressures and internal economic dependencies. By filling the gap in the literature on transition models in Azerbaijan, this research can provide valuable recommendations to stakeholders involved in the energy transition.

Section 2 provides an overview of the literature on energy transition tasks, multiple-criteria decision-making approaches, and the formalization of uncertainty in energy source selections. Section 3 covers operations with Z-numbers, Z-reasoning, and calculation techniques using the Z-information-based TOPSIS, PROMETHEE, and SAW methods. Section 4 details the development of transition scenarios and the calculations based on fuzzy methods, as described in Section 3. Section 5 discusses the key ideas of the proposed approach and evaluates the selected alternatives. The study concludes with a summary of the need for a rational balance between renewable and conventional energy sources, highlighting the advantages of the proposed approach.

2. Literature Review

Researchers consider the transition problem to renewable energy sources at global, regional, and country levels, and city areas. At the national level, special attention is given to whether countries are developed, developing, or oil and gas producers and exporters. There are also a few articles that focus on projection methodology. Researchers have used a scenario-based approach as the main tool for transition process modeling. Scenarios give an overall strategic paradigm for broad-view thinking and decision-making in high uncertainty. They are tools for investigating possible paths and understanding energy transition issues at various levels [10]. As underlined in [11], the world energy transition is a complex, multidimensional, non-linear, non-deterministic, and highly uncertain process. Transition speed is the process's most critical parameter, and no unambiguous assessment exists. Two possible scenarios have been envisioned: the slow pace of transition providing time for adaptation and the fast and revolutionary pace of transition disrupting business models of the oil-producing countries and companies. Given the uncertainties inherited from the transition process, countries and companies must develop strategies adaptable to future market conditions. In the case of oil-producing countries, there is no serious conflict between renewable investment and hydrocarbon business. However, decision-makers must consider that geopolitical and economic uncertainties are key factors influencing the volatility of oil and gas trade, supply, and prices. These factors will continue to require close attention from researchers and will play a crucial role in determining the success or failure of transition policies.

The scenarios are also used to study the energy transition at the regional and global levels. A total of 177 net-zero energy scenarios, analyzing their long-term technological and regional characteristics in the context of current energy policies, are considered in [12], and it is emphasized that countries are implementing energy policies aimed at achieving high levels of renewable or zero-carbon electricity in the next few decades. Four decarbonization pathways for the EU up to the year 2050 are analyzed, with the results indicating that rapid decarbonization can be achieved through high electrification rates [13]. In another study [14], the energy transition of the EU-28 countries from 2000 to 2019 is examined, focusing on reducing greenhouse gas emissions, increasing renewable energy adoption, and improving energy efficiency. Four distinct transition profiles emerge, highlighting disparities among the EU-28 members. Northern and Scandinavian countries perform best, driven by an effective mix of policies and innovation. However, advanced countries such as Germany, Ireland, and the Netherlands lagged in achieving their targets. In [15], baseline and transition scenarios with varying shares of renewable energy for Finland and Italy are defined and analyzed according to their renewable energy potential. The study explores whether and how these transitions could occur and their impact on climate change. The EnergyPLAN model 11.4 was used to analyze energy systems with hourly resolution. The results show that Finland's energy system emphasizes biomass and district heating, achieving up to a 75% renewable energy share in future scenarios. Italy's renewable energy potential lies in solar, wind, and geothermal energy. Scenarios with 35% and 60% renewable energy shares focus on reducing import dependence and lowering CO_2 emissions by up to 64% compared to 1990. These newly modeled scenarios can inform future national plans, providing insights into investment priorities and assessing the level of decarbonization achievable. Four scenarios for the future of renewable energy are defined and analyzed: Business as Usual (2010–2030), Focus on Climate Change (2010–2060), Focus on Energy Security (2010–2030), and a Clean and Secure Energy Future (2010–2100) [16]. According to the Business as Usual scenario, it is projected to double the world's renewable electricity generation from 2015 to 2035. The Focus on Climate Change scenario projects a temperature increase depending on the stabilization level of the CO_2 equivalent. The Focus on the Energy Security scenario projects sharp increases in fossil energy during the period of 2010–2030 in combination with a significant increase in renewables. The Clean and Secure Energy Future scenario reflects continuous improvements in the energy systems from 2010 to 2100. The study shows that the most favorable scenarios involve clean energy use, although these options require significant effort and investment. The relationships between European countries' economic, environmental, social, and energy development scenarios were investigated in [17]. The results confirmed a positive relationship between renewable energy consumption and factors such as GDP per capita, foreign direct investment, and energy depletion, while showing negative relationships between renewable energy consumption and CO_2 emissions and domestic gas emissions. An overview of global energy transition scenarios [18] developed by various international organizations presents the primary purposes, assumptions, and characteristics used for scenario projections and compares different scenarios. Another report [19] combines a global assessment of energy scenarios up to 2050 with case studies on energy access and low-carbon efforts worldwide. It also reviews the technological shifts, investments, policies, and governance structures needed to meet the global energy demand. The PROMETHEE II multi-criteria decision analysis of socio-economic, environmental, and energy impacts is applied to assess each alternative scenario of the European region's climate and energy policy [20]. Using this method, the proposed scenarios are ranked based on decision-makers' preferences, with the robustness of the results evaluated through a sensitivity analysis.

Developed countries actively use scenario approaches in various options for the energy sector transition. This has led to numerous studies and reports developing energy transition scenarios, identifying influencing factors and development paths in the US, China, the EU (especially Germany), and Central and South America. Thus, the report presented in [21] generalizes the experiences of ten countries (Germany, Finland, Japan, Italy, Denmark, The Netherlands, United Kingdom, Australia, United Arab Emirates, and Brazil) using scenarios for clean energy transitions. China's comprehensive plan to phase down the coal-fired power capacity for 2020–2030 with measurable milestones combines near-term coal retirements with rapid renewable energy deployment, efficiency improvements, and cross-region balancing [22]. Scenarios for the phasing out of coal-fired power plants in Germany before the end of their technical service life, as well as scenarios and strategies for the energy transition in Germany, are discussed in detail in [23,24]. The focus is on the primary energy demand, shares of renewable energy, and direct energy-related CO_2 emissions. Two possible scenarios for the transition of the Polish energy sector are based on analyzing four diagnostic features: electricity production, electricity prices, the share of renewable energy sources (RESs) in final energy consumption, and CO_2 emission reduction [25]. Both scenarios, which focus on the gradual phase-out of coal, assume that the development of RESs is too slow, the expansion of natural gas use is limited, and nuclear energy is introduced. The 70 scenarios projecting the possible evolution of the U.S. electricity sector through 2050 with a 95% reduction in CO_2 emissions cover a wide range of key drivers, such as the cost and performance of technologies and fuels. Scenario assumptions reflect technological, market, and policy changes [26].

Using scenario approaches involves analyzing and selecting the most appropriate alternatives. The choice of tools for analysis is no less important than creating scenarios. The selection of contextual factors, expert interviews, and supply and demand models form the basis for developing socio-technical scenarios and strategies for the German energy transition, focusing on the primary energy demand, the share of renewable energy, and direct energy-related CO_2 emissions [23]. The MESSAGE (Model of Energy Supply Strategy Alternatives and their Overall Environmental Impacts) energy system model is used to analyze the impact of increasing domestic electricity generation in Lithuania, the results of which demonstrate the substitutability of electricity imports and local generation, and that scenarios with higher levels of domestic electricity generation may be less efficient under certain conditions [27]. Using the Delphi method, five energy scenarios for Finland up to 2030 were developed [28], including (1) Business as Usual, (2) Energy Saving and Decarbonization, (3) Climate-Friendly Transformation, (4) Green Growth, and (5) Degrowth. In [29], the scenario approach analyzes the energy transition models of Colombia and Germany. The study highlights that the dependence on fossil fuel exports and the complex socio-environmental challenges in implementing projects such as wind farms in Indigenous territories substantially impact Colombia's energy transition. Unlike Germany, greenhouse gases in Colombia are mainly related to agriculture and land use (59%), highlighting the need for diversified strategies beyond the decarbonization of the energy sector. Another key difference is Colombia's limited local technological expertise and its heavy reliance on international funding and cooperation for infrastructure and technology development.

Developing countries are also actively trying to address issues related to the energy transition. The scenarios developed for the transition of the Chilean energy system [30] to 100% renewable energy by 2050 include scenarios from Chile's Long-Term Energy Planning Process (PELP), scenarios using a smart energy system approach, and optimized emission reduction scenarios created with the EPLANoptMAC tool. In [31], an example of the Global South and Guyana highlights that in developing countries, the key challenges are inefficient grids, large rural populations, and limited access to affordable finance, which slow the uptake of renewable technologies. The recommended pathways prioritize mature, deployable renewable energy sources such as hydropower, geothermal energy, and bioenergy, along with improved grid efficiency, regional energy trade, and climate-resilient agricultural practices. The potential of renewable and non-renewable energy resources in Kenya is discussed in [32], and it is highlighted that the significant challenges in the energy sector are the limited availability of modern energy, high pressure on biomass supplies, rising energy prices, and unmet high demand for electricity. Transition studies for Bangladesh, which analyze the risks and vulnerabilities associated with the transition process, develop four energy policy scenarios to balance current and future renewable energy decisions [33]. The Global Energy System Model (GENeSYS-MOD) was used for the optimization of pathways for the Mexican energy system using numerical modeling, and the findings provide policymakers with valuable insights for designing and implementing specific targets and policies for decarbonizing the heating and transportation sectors by determining the cost-optimal share of renewables in each sub-sector [34]. Three scenarios—the Current Policy Scenario (CPS), the Natural Gas and Nuclear Scenario (NGNS), and the Renewable and Import Scenario (RIS)—were constructed using a normative and modeling approach for two metropolitan regions in eastern China [35]. Five scenarios were developed based on a key factor analysis to predict and compare future trends in energy consumption, renewable energy development, and carbon emissions in the Beijing–Tianjin–Hebei (BTH) region [36]. In the case of Guyana, which is experiencing an oil and gas boom, the country is adopting low-carbon strategies but faces obstacles such as the high cost of renewable energy, a shortage of technical skills, and limited consumer confidence [37]. Community participation and energy justice are vital elements for a just energy transition. However, these aspects are often ignored in developing countries' policies.

Although on a much smaller scale, the scenario approach is used to study the fossil fuel-rich developing countries' energy transition. In [38], it is noted that the global energy transition is changing geopolitics, favoring countries with investments in renewable technologies and posing challenges for fossil fuel-rich countries. Regions such as the Middle East and North Africa are at risk because of their significant reliance on fossil fuel income. Furthermore, using essential minerals in renewable energy technologies creates additional geopolitical problems due to their unequal distribution worldwide, complex extraction processes, and reliance on specific countries. Energy transition pathways for such countries using Ecuador as a case study were analyzed [39]. The study evaluates economic development options under different conditions. According to another study of the example of Iran [40], energy systems modeling in oil-rich countries allows for an adequate assessment of energy-related decisions, where the EnergyPLAN system was used. Based on the analysis of five different scenarios, the authors conclude that increasing the efficiency of thermal energy and integrating renewable energy resources helps reduce the total primary energy consumption, CO_2 emissions, and variable costs. In [11], two scenarios differing in the speed of energy transition are considered; it also noted the multidimensionality, complexity, and high uncertainty of the energy transition and emphasized that in the long term, the main challenge for many oil countries will be the diversification of their economies and revenues. To address the challenges facing fossil fuel exporters, it proposes diversification into renewable energy, improved fiscal discipline, and support for the worker transition. It also emphasizes the importance of technological innovations such as carbon capture and cleaner extraction processes [41].

A topical review [42] highlights recent research integrating the energy economy, capacity expansion, and power sector planning paradigms into a comprehensive framework. Reviewing current modeling practices and expert elicitation workshops, the authors identify the best practices, emphasizing the importance of avoiding black box models, having clear modeling objectives, and developing transparent practices. The methodology for developing the Arctic energy infrastructure, assessing technological demand, and justifying development [43] is based on scenario modeling, which considers consumer needs, available technologies, and identified risks. The scenarios and modeling results indicate that by 2035, gas will provide up to 50% of the energy balance, with an increasing role for carbon-free sources. A new analytical framework for assessing changes in the energy sector—a matrix of four ocean (black, grey, red, and green) scenarios is presented in a study [44]. The scenarios developed for the example of Poland are determined by the proportion of state and local community participation. A selected group of experts assessed these scenarios within the suggested approach, and the business model was analyzed using six components that generate economic and social value: energy sources, energy producers, transmission networks with infrastructure, energy storage, energy system management, and energy consumers. Expanding the capabilities of the scenario approach for energy transition tasks as a strategic planning instrument that provides structured decision-making by combining it with tools for processing imperfect information allows for the improved study of the possible outcomes of various decisions and actions under uncertainty. Since fossil fuels have greatly influenced the current energy system, the transition to renewables becomes highly complex when combined with the uncertainty surrounding the costs, technologies, and energy transition policies [2]. Ways to improve scenarios and quantitative approaches in the energy industry were considered in [45]. They emphasized adapting scenario development methods according to the context and objectives, integrating various approaches, and dealing with uncertainty. They also underlined that these topics are potential areas for future research. Energy scenarios were used as an estimation tool to evaluate the changes necessary to achieve environmental objectives, define general development directions, and assess associated risks [46]. As underlined in [47], the rapid pace of technological development for energy generation, storage, digitalization, and the development of new markets for energy and energy services are the factors that significantly complicate decision-making by policymakers compared to previous strategies for energy-system development. In such circumstances, modeling future scenarios and taking a long-term view in an uncertain decision-making environment by describing hypothetical possible futures and their corresponding pathways has become an extremely significant tool in planning for the energy transition. The study also provides a comparative analysis of scenarios for China and Denmark, which shows that both countries have complex energy transition scenarios with some similarities and differences in the overall energy policy strategy. The interdisciplinary nature of the energy transition challenge and the critical role of technical policy in addressing it was emphasized in [48]. In this study, thirty university researchers and top executives from energy companies ranked four energy transition scenarios from the least to the most feasible. According to the survey results, developing talent for future energy transition projects is optimal. Three transition scenarios for global energy systems based on historical data and probabilistic cost forecasting methods running from 2021 to 2070 are presented in [49]. The Monte Carlo approach has been used to apply probabilistic technology cost forecasting methods in a given scenario. The probabilistic approach assesses fast, slow, and no transition scenarios for renewable energy sources. It shows that the faster deployment of renewable energy sources leads to lower system costs, with the fast transition scenario offering the most significant economic and environmental benefits. In [50], the effects of Environmental Policy Stringency (EPS), Energy Transition Index (ETI), and Gross Domestic Product (GDP) on CO_2 emissions have been studied by applying wavelet local multiple correlation (WLMC) procedures on 2000–2020 statistical data describing BRICS member countries. According to the results, EPS, ETI, and GDP have increasing and varying effects on CO_2 emissions in all BRICS countries, and the effect of EPS is quite small compared to GDP and ETI in all countries except South Africa.

Studies show that the transition of energy systems is characterized by a high degree of uncertainty and limited statistical data. It is generally accepted that fuzzy logic is a powerful tool for solving a decision-making task in the case of high uncertainty and information deficiency. Fuzzy logic-based scenarios can successfully solve decision-making tasks within the scenario approach under conditions of uncertainty and imprecision. The PathPED methodology in [51] employs a fuzzy agent-based system to define the 2020, 2030, and 2050 urban transition scenarios. Urban districts were evaluated in these scenarios based on the increase in renewable energy, efficiency, and carbon neutrality. The results indicate that meeting the Paris Agreement requires 100% renewable energy use, complete electro-mobility, and significant improvements in energy efficiency. A fuzzy TOPSIS-based approach was applied to evaluate alternative policy scenarios for achieving the 2030 renewable energy targets in European Member States [52]. This approach helps reduce uncertainty in energy and climate policy. A Fuzzy Cognitive Map (FCM)-based approach was used to develop scenarios for the national wind energy sector [53]. Expert panels provided the information for these scenarios, focusing on key factors such as energy security, financial resource scarcity, climate change, and greenhouse gas emissions. The scenarios outline the future landscape of the wind energy sector. The Fuzzy Logic Toolbox in MATLAB was used to select the best renewable energy scenario from 13 alternatives for electricity generation [54]. Various energy scenarios for city areas have been analyzed using fuzzy logic and Geographic Information Systems (GIS), and the feasibility of the scenarios has been assessed using a specially developed Energy Potential Index (EPI) [55].

The overview demonstrates that the scenario approach offers extensive possibilities for addressing transition tasks in the energy sector and allows a consideration of a country's peculiarities. This approach can be effectively employed to design broad country-level energy policies and develop specific policies related to energy resources used for electricity production. Approaches to decision-making based on Z-numbers have become increasingly widespread [56], and acceptable results were obtained in medical diagnostics, risk analysis, and management [57]. Models based on Z-number-based IF–THEN rules have been successfully implemented for studying hydro-climatologic processes [58], for solving civil engineering design and construction problems [59], in dynamic plant control [60], and in determining food security [61]. However, relatively few studies have been related to using Z-numbers to solve problems associated with renewable energy sources. The following works are noteworthy: An approach using subjective and objective criteria based on Z-numbers and the COPRAS-Z methodology was employed to select renewable energy alternatives in India [62]. The methodology combining Z-number-based MCDM methods such as DEMATEL and VIKOR was used to evaluate hydrogen energy storage technologies for Turkey [63]. Another study addressed complex decision problems, such as RES investment, through Z-number-based evaluation, DEMATEL, and OWA [64]. Suitable RESs were selected by combining Z-numbers with the Additive Ratio Assessment (ARAS) method [65]. Z-number-based models can be an effective tool for formalizing high-level uncertainties in energy decision-making tasks. These approaches present problems to be solved in forms that are understandable to humans and allow for operations with imperfect information while considering reliability.

An analysis of the research papers in the field of energy transition reveals that researchers are using scenario-based approaches for the solution to the problem at the global, regional, country, and area levels. Time series and probabilistic models based on statistical data have often been used. Researchers underline that the transition problem is characterized by high uncertainty. In most cases, despite the development of several scenarios considering individual indicators and priorities, such as the transition speed, costs, net zero level emissions, etc., the multiplicity of the scenarios in the assessment and selection criteria remains outside the scope of research. In this regard, of particular interest is developing an approach to solving the transition problem that considers the high degree of uncertainties in the decision-making environment and the decision implementation processes, the multi-criteria nature of the problem, and the need to find a compromise solution. Moreover, most researchers develop projections based on extrapolation without considering expected changes and foresight. For the problem solution, an approach based on fuzzy energy transition scenario development and the selection of the best scenario by applying the fuzzy MCDM method was developed.

The presented work can be considered a continuation of one study [66] and contributes to developing approaches for formalizing energy transition scenarios in countries producing and exporting fossil fuels. Given the high level of uncertainty in determining the optimal energy transition, there is a need for new approaches that utilize both Z-reasoning and multi-criteria decision-making (MCDM) models tailored to oil- and gas-producing countries. These approaches are particularly relevant to the current energy transition demands of oil- and gas-dependent countries such as Azerbaijan. The choice of Azerbaijan as an example is due to several key factors: Azerbaijan historically has extensive experience in the production and export of oil and gas; the country is one of the ten countries most dependent on hydrocarbon production; and oil and gas account for approximately 90 percent of export earnings, about 60 percent of the country's finances, and about 48 percent of GDP. These peculiarities of the country significantly complicate transition tasks and require a well-balanced compromise of the renewables and oil and gas production during the transition period. Given the complexity of the transition task for Azerbaijan, the model and methods used for this case can be successfully adapted and applied in similar or less complicated cases. This study addresses a gap in the literature by providing a nuanced and context-specific methodology.

3. Methodology

The flowchart of the research process is presented in Figure 1.

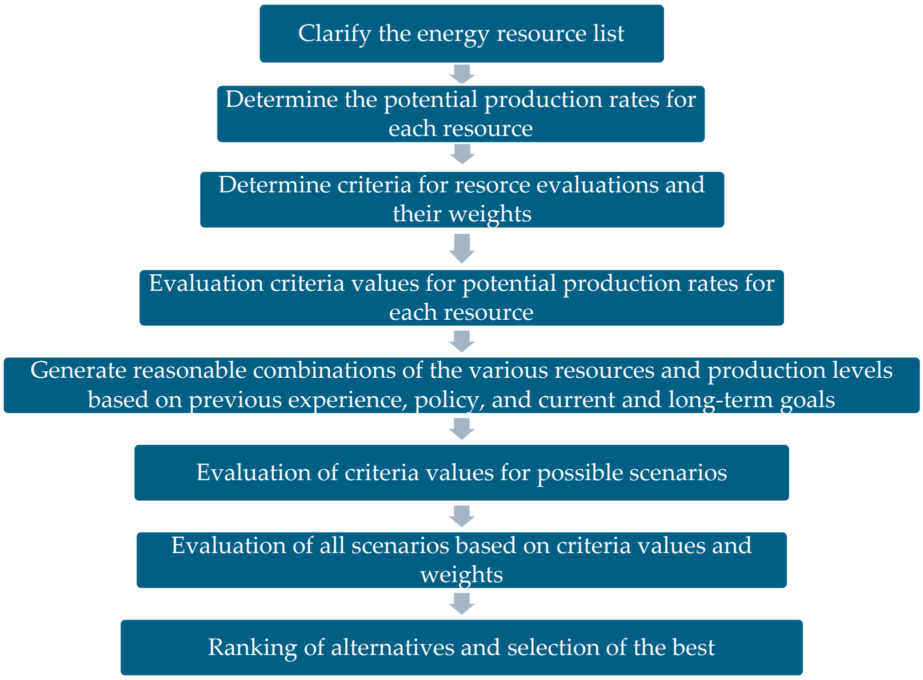

Figure 1. Research flowchart.

The features of each stage of the study will be shown further in the relevant sections.

3.1. Z-Information-Based Calculations

Operations on Z-numbers are more complex to describe and implement than operations on fuzzy numbers; so, we will limit ourselves to presenting the main ideas in this article. Some information about Z-number-based arithmetic operations, ranking, and distance calculation for decision-making tasks is given in [67]. Below, we present some additional definitions related to Z-numbers.

3.1.1. Basic Definitions

Definition 1. *A similarity measure of Z-numbers. The similarity measure between two Z-numbers is determined based on the distance between them according to Formula (1).*

$$S(Z_1,\ Z_2) = \frac{1}{D(Z_1, Z_2) + 1}\,. \tag{1}$$

Here, $D(Z_1, Z_2)$ is the distance between two Z-numbers. Refs. [68–70] specify possible calculation methods.

Definition 2. *Z-number-valued reciprocal pairwise comparison matrix* (*RPCM*).

A square matrix $Z^{matrix} = \|Z_{ij}\|$, the elements of which are Z-numbers, is referred to as a reciprocal pairwise comparison matrix (PCM) when

$$\|Z_{ij}\| = \begin{pmatrix} Z_{11} = (1,1) & \ldots & Z_{1n} = (A_{1n}\,, B_{1n}) \\ & \ldots & \\ \frac{1}{Z_{1n}} & & Z_{nn} = (1\,,1) \end{pmatrix} \tag{2}$$

$Z_{ij} = (A_{ij}, B_{ij})$, $i, j = 1, \ldots, n$—Z-number express the preference of i-th criteria over j-th.

Definition 3. *An inconsistency level of Z-RPCM [71]. The inconsistency level of the Z-RPC matrix*$\|Z_{ij}\|$*can be calculated according to the following equation:*

$$K((Z_{ij})) = \max_{i<j<k}\min\left\{ D\left(Z(1,1), \left(\frac{Z_{ik}}{Z_{ij}Z_{jk}} \right) \right) D\left(Z(1,1), \left(\frac{Z_{ij}Z_{jk}}{Z_{ik}} \right) \right) \right\}, \quad (3)$$

where$Z(1,1) = (A, B)$*is a Z-number with fuzzy singletons*$A = 1$*and*$B = 1$*components.*

D—distance between Z-numbers.

3.1.2. Z-Valued IF–THEN Rules

Unlike traditional IF–THEN rules, Z-valued IF–THEN rules [68] allow the value and reliability to be considered in approximate reasoning and can be represented as follows:

If X_1 is Z_{1x} and X_2 is Z_{2x} and . . . Then Y_1 is Z_{1y} and Y_2 is Z_{2y}

Obtaining a complete Z-valued knowledge base is challenging; using interpolation-based methods is justified, and the linear combination of conclusion parts can determine the output Z-values. If we have m relevant Z-rules, then the value of the j-th output variable for the consequent part can be defined as follows:

$$Z_{j\ output} = \sum_{i=1}^{m} \omega_i \cdot Z_{j\ output\ i} \quad (4)$$

Here, $Z_{j\ output}$—value of the j-th output variable;
$Z_{j\ output\ i}$—the Z-number-based j-th output of the conclusion in the i-th rule;
m—number of relevant Z-rules;
ω_i —the weight of i-th rule.

To determine the weight (scalar coefficient) of each rule involved in the reasoning, first, the calculation of the degrees of similarity between the input information and the conditional part of this rule is necessary. The corresponding values of the conditional part of each rule and the input information are compared, and the minimum value is determined in the set of similarity measures obtained for each rule.

For example, if the values in the conditional part of the i-th rule are specified by the Z-numbers Z_{i1}^{ri}, Z_{i2}^{ri}, . . ., Z_{in}^{ri}, and the input information is given by the values $Z_{i1}^{input\ i}$, . . . , $Z_{in}^{input\ i}$, then for the i-th rule, the minimum similarity measure (SM) is defined as

$$SM_i = \min_{k=1\ldots,\ m} SM((Z_k^{ri},\ Z_{ik}^{input}\Big),\ i = 1,\ \ldots,\ n$$

Here, m is the number of input values and n is the number of Z-rules.

Next, those rules are selected from the rule base whose SM values are higher than the specified value (threshold) SM_i, $i = 1, \ldots p$.

By calculating the normalized values of similarity measures, scalar coefficients are determined for the rules that will be used to determine the resulting output value. Thus, for the i-th rule, the weight coefficient will be calculated using the following formula:

$$\omega_i = \frac{SM_i}{\sum\limits_{k=1}^{p} SM_k}$$

Even though operations over Z-rules have a high computational complicacy [72], Z-reasoning allows one to consider information reliability. Despite conversion-based approaches [57], direct Z-reasoning avoids possible information losses in transformation cases.

3.2. Scenario-Based Approach

3.2.1. Stages of the Approach

The scenario approach can be summarized as a set of sequential stages:

Stage 1. Clarifying the list of energy resources available in the country.
Stage 2. Determining the potential rates of production for each resource.
Stage 3. Generating scenarios as reasonable combinations of the various resources and production levels based on previous experience, policy, and current and long-term goals.
Stage 4. Application of Z-reasoning for the scenario criteria evaluation.
Stage 5. Formulating scenario selection problems as a multi-criteria decision-making task and applying of Z-MCDM.
Stage 6. Selection of the alternatives.
Stage 7. Problem solution and analysis.

Let us analyze in detail the content and specifics of each stage.

3.2.2. Analyzing Available Resources

A resource analysis allows us to solve the problems of the first two stages specified in Section 3.2.1.

First, after analyzing the energy resources used in the previous time horizon and identifying new potential sources available for the next long-term period, finalizing a list of sources that can be used for policy development is necessary.

In the second stage, for each resource, we must determine the capacity variation interval from a long-term planning standpoint and describe the various levels of the increments in linguistic terms, approximating the variation interval. For example, for the i-th resource variation interval $[x_i(min),\ x_i(max)]$, potential changes in resource use can be described using the terms very small, small, medium, large, and very large.

Based on the time horizon and goals, finalizing a list of resources to be used and their corresponding production levels is essential. This is a critically important decision. For example, environmental regulations and policies might necessitate a substantial increase in renewable energy utilization. However, long-term trade commitments and the crucial role of natural gas revenues in GDP and budgeting could compel the continued dominance of conventional energy sources in the country's energy mix while simultaneously expanding renewable production. The production level for each resource depends on its value in the previous time horizon and any desired or justified adjustments to this value.

Z-number-based evaluations are applied to describe recommendations for resources using linguistic expressions like "increase notably", "slightly decrease", and "increase moderately", and express confidence in these recommendations as "very sure", "extremely sure" and so on. Then, a set of scenarios formally can be presented in the following form:

$$S_1 \ = \ X_1\ is\ (A_{11},\ B_{11})\ and\ X_2\ is\ (A_{12},\ B_{12})\text{and } \ldots \text{and } X_m\ is\ (A_{1m}, B_{1m})$$

$$S_2 \ = \ X_1\ is\ (A_{21},\ B_{21})\ and\ X_2\ is\ (A_{22},\ B_{22})\text{and } \ldots \text{and } X_m\ is\ (A_{2m},\ B_{2m})$$

$$\ldots\ldots\ldots\ldots$$

$$S_k \ = \ X_1\ is\ (A_{k1},\ B_{k1})\ and\ X_k\ is\ (A_{k2},\ B_{k2})\text{and } \ldots \text{and } X_m\ is\ (A_{km},\ B_{km}),$$

where A_{ij} and B_{ij} are representing fuzzy values and confidence in this value, respectively.

3.2.3. Scenario Composition

Scenario composition is not a formal procedure for combining different sub-alternatives with different production rates. This process requires a rational analysis and evaluation of the various resource production rates from an applicability point of view. In any applied task, various constraints decrease the rationale options.

The implementation of the scenario model can be formalized as the following multi-stage process:

1. Analysis of a previous period energy policy, mid-term and long-term economic goals and strategies, and country-specific peculiarities of sustainable development.
2. Determining potential energy resources X_i, i = 1, . . ., m to be used in the next time horizon.
3. Select representation formalisms for the A and B parts of the Z representation of the sub-alternatives. Triangular representations can be successfully utilized in applied tasks.
4. Deciding on the number of terms used for approximating A and B. At this stage, ensuring a unified approach for A and B formal representations is necessary. Such an approach allows, to a certain extent, the information acquisition and processing process to be standardized. Five-term-based representations generally assure the required accuracy of the sub-alternatives' formal descriptions and experts' opinions.
5. Clarifying the list of terms applicable to each sub-alternative. This procedure allows the exclusion of non-reasonable resource production rates from the scenarios and, respectively, the exclusion of non-justified scenarios from the general list. For example, in the case of renewables like solar and wind, the terms "Decrease moderately" or "Decrease significantly" are most often not relevant from an energy policy development standpoint. Accordingly, scenarios with these terms are not appropriate.
6. Determining the composition of scenarios Renewables have higher priorities in a transition process, which must be reflected in the scenarios. However, the scenario composition process is not straightforward. The country's medium-term economic priorities can force developers of the decision-making models to slow down the transition process and continue keeping, in some capacity, environmentally unfriendly resources as part of the transition solution.
7. Finalizing a list of the potential scenarios considering the expected internal and external factors influencing economic and energy policies.

If the number of resources to be used in scenarios is equal to m and each resource j (j = 1, 2, . . ., m) has r_j different and reasonable rates of production, then the total number of the various scenarios is

$$R = r_1 * r_2 \ , \ \ldots, \ r_{m-1} * r_m \ . \tag{5}$$

with an increase in the number of potential energy resources to be used, the number of scenarios available also will increase. However, the excessive growth of the scenarios is being restrained by a limited number of resource production rates that are of interest to decision-makers. Assume that the scenarios developer operates with 5 levels for each resource: *Increase significantly*, *Increase moderately*, *Maintain as usual*, *Decrease moderately*, and *Decrease significantly*. Depending on economic conditions and constraints, only two or three production rates are of practical interest in applied tasks for each resource.

For example, let us assume that we have the following scenario to be evaluated: S_i = *"Slightly decrease NG, very sure; maintain hydro, as usual, extremely sure; increase notably solar, very sure and moderately wind, very sure"*. The scenario described by this expression has four resources. With certain degrees of confidence, this scenario recommends slightly decreased natural gas production, keeping hydro at levels used on the previous time horizon, increasing notable solar, and moderately using wind resources. It is necessary to note that all perception-based linguistic variables have some reference points, and experts are rating variables against these points. If we compare the terms "moderately increase the natural gas" and "moderately increase hydro", the absolute values of the expected increases are contextual and quite different. When evaluating the scenario as a single aggregated alternative, these circumstances must be considered.

3.3. Evaluation of the Criteria for a Scenario

Let us consider the scenario evaluation procedure. Possible scenarios are assessed based on the values of 8 criteria [66]. These are Government policy and regulation (C_1), Social acceptance (C_2), Labor impact (C_3), Cost efficiency (C_4), Spillover effects (C_5), Technology efficiency and reliability (C_6), Resource availability (C_7), and Environmental impact (C_8). The choice of these criteria is also determined by the connection of energy transitions with social and cultural factors and economic and ecological effects [2]. The analysis of possible implementations of an energy transition usually includes technical, social, economic, energy, technological, society, and environmental aspects [39,40]. Moreover, the above criteria are the most important when selecting resources to ensure sustainable development. In addition, one should consider such a circumstance as the number of scenarios that are directly proportional to the diversity of resources and the variability of their assessments (see Formula (5)).

On the other hand, due to the nature of decision-making regarding energy transit, the use of approaches other than fuzzy may be complex. Considering that the resulting scenarios are combinations of resources and estimates of their production levels and that the estimates of resource use depend on the same parameters as the scenarios, approximate reasoning methods can be used to calculate criteria for the scenarios. To do this, through IF–THEN rules, a relationship is established between the resource $R_{i'}$s production level and the values of the criteria c_j.

$$\text{If } R_i = r_{ij} \text{ then } C_1 = c_1 \text{ and } C_2 = c_2 \text{ and } C_3 = c_3 \text{ and } C_4 = c_4$$

$$(i = 1, \ldots, N\text{—number of possible resources})$$

$$(j = 1, \ldots, K\text{—number of production level of } i)$$

Next, using approximate reasoning, the value is calculated for scenarios describing using all N resources simultaneously.

To calculate the values of the criteria for a scenario that includes several resources, the corresponding Z-rules are interpolated, a linear combination of the output values (corresponding criteria values) of these rules is calculated according to the approach specified in Section 3.2, and we obtain the values of the criteria for each scenario.

For example, if you need to calculate the values of the criteria for a scenario that includes three resources R_1, R_2 and R_3 with the corresponding production levels r_{1k}, r_{2l}, and r_{3m}, where $k \in K$, K is the number of production levels of resource R_1; $l \in L$, L is the number of production levels of resource R_2; and $m \in M$, M is the number of production levels of resource R_3, then the rules that contains these resources and their production levels will be fired.

$$\text{If } R_1 = r_{1k} \text{ Then } C_1 = c_{11} \text{ and } C_2 = c_{12} \text{ and } C_3 = c_{13} \text{ and } C_4 = c_{14}$$

$$\text{If } R_2 = r_{2l} \text{ Then } C_1 = c_{21} \text{ and } C_2 = c_{22} \text{ and } C_3 = c_{23} \text{ and } C_4 = c_{24}$$

$$\text{If } R_3 = r_{3m} \text{ Then } C_1 = c_{31} \text{ and } C_2 = c_{32} \text{ and } C_3 = c_{33} \text{ and } C_4 = c_{34}$$

The resulting criteria weights will be determined through linear combinations (Formula (4)) of the corresponding values of the right sides of these rules, and we obtain the following dependence expressed through the *Z*-rule, which specifies the correspondence of the criteria values to a specific scenario.

IF $R_1 = r_{1k}$ and $R_2 = r_{2l}$ and $R_3 = r_{3m}$ THEN $C_1 = c'_1$ and $C_2 = c'_2$ and $C_3 = c'_3$ and $C_4 = c'_4$

3.4. Definition of the Importance of Criteria Weights

The importance of the weights of criteria is defined in four essential steps [71]:

(1) A Z-number-based RPCM (Formula (2)) is constructed according to the A part of degrees of preference expressed in the linguistic values and the form of triangle fuzzy numbers shown below.

- equal or unknown importance (Eq)—(0.9, 1, 1.1);
- moderate importance of one over another (MI)—(1.8, 2, 2.2);
- essential or strong importance (EI)—(2.7, 3, 3.3);
- demonstrated or strong importance (SI)—(3.5, 4, 4.5);
- absolute importance (AI)—(4.5, 5, 5.5).

Part B of the degrees of preference can be expressed below

- Extremely sure (ES)—(0.8, 0.9, 1);
- Very sure (VS)—(0.7, 0.8, 0.9);
- Average (A)—(0.6, 0.7, 0.8);
- Not very sure (NVS)—(0.5, 0.6, 0.7);
- Not Sure (NS)—(0.4, 0.5, 0.6).

(2) Generating the consistent RPCM closest to the given matrix.

Due to the nature of the expert's judgment, the starting preference matrix is often inconsistent. If the inconsistency ratio (Formula (3)) is irrelevant, then the necessity of addressing this task is raised.

(3) Solving the equation for the calculation of the eigenvector and the maximal eigenvalue.

$$\left(Z'_{ij}\right) \cdot \left(Z_{x_j}\right) = Z_\lambda \cdot \left(Z_{x_j}\right) \tag{6}$$

Here $\left(Z'_{ij}\right)$ is a consistent RPCM, Z_{x_j} is an eigenvector, and Z_λ is the eigenvalue.

(4) Normalization of eigenvector components and finding a vector of criteria weights.

3.5. Z-MCDM Techniques for Scenario Selection

The stages of the best scenario selection task are outlined below.

Stage 1. Defining the initial *Z*-number-based DM (*ZDM*) with *m* alternatives and *n* criteria.

$$ZDM = \begin{bmatrix} Z_{11} & \dots & Z_{1n} \\ \dots & \dots & \dots \\ Z_{m1} & \dots & Z_{mn} \end{bmatrix}$$

Stage 2. Normalization of the decision *Z*-matrix [73] performing the linear scale transformation for the A parts and using B_{ij} as $B_{ij}{}^{norm}$.

Stage 3. Defining cost/beneficial criteria and then a vector of criteria weights.

Stage 4. Application of the *Z*-extension of TOPSIS, PROMETHEE, and SAW.

Stage 5. Ranking of alternatives.

Steps 1–3 cover defining criteria and their types, constructing and normalizing the decision matrix with the values of alternatives regarding the criteria, and obtaining a weighted normalized matrix. Regardless of the approaches used, these steps can be considered identical for different MCDM methods. Therefore, describing the Z-extensions of methods will be briefer and to the point.

3.5.1. Z-Extension of TOPSIS

Z-extension of TOPSIS can be described as follows:

a. After normalizing the decision matrix and determining the criteria vector, the Z-number-based weighted normalized decision matrix is calculated.
b. The distance from each alternative to the Z-number-based ideal-positive Z(1,1) and Z-number-based ideal-negative solution Z(0,0) is calculated. Distances between the *i*-th alternative and the ideal solutions [67] are calculated as

$$d_i^+ = \sum_{j=1}^{N} d\left(Z_{ij}, Z_{pis}\right)$$

$$d_i^- = \sum_{j=1}^{N} d\left(Z_{ij}, Z_{nis}\right)$$

where N is the number of criteria.

c. Calculate the relative closeness to the best alternative.

$$Z_{cc_i} = \frac{d_i^-}{d_i^+ + d_i^-}$$

d. Ranking of the alternatives according to their relative closeness.

3.5.2. Z-Extension of PROMETHEE [73]

a. Calculate the differences between the Z-number-based values of alternatives according to the degree of optimality after the normalization of the decision matrix and the determination of the criteria vector.
b. Apply the Z-value-based preference function.

If Z_{ij} is not dominant over Z_{ji} ($do(Z_{ij}, Z_{ji}) \leq do(Z_{ji}, Z_{ij})$), then value of the preference function $P_j(Z_{ij}, Z_{ji})$ is 0, otherwise value of preference function $P_j(Z_{ij}, Z_{ji}) = do(Z_{ij}, Z_{ji}) - do(Z_{ji}, Z_{ij})$.

Where $do(Z_{ij}, Z_{ji})$ is the degree of optimality.

c. Use the Z-number-based weighted preference function.

$$Z_{\pi w}\left(Z_{ij}, Z_{ji}\right) = P_j\left(Z_{ij}, Z_{ji}\right) \cdot Z_{CW_i}$$

d. Determine net (outranking) flows $\Phi_{Z_j}(a)$ for each alternative based on leaving (positive outranking) and entering (negative outranking) flows.

$$\Phi_{Z_j}(a) = \sum Z_{\pi w}(a, b) - \sum Z_{\pi w}(b, a)$$

e. Finalize the ranking according to the calculated values of net flows.

3.5.3. Z-Extension of SAW

a. Obtain a weighted normalized DM.
b. Calculate the Z-score for each alternative.

$$Z_{Ai} = \sum_{j=1}^{n} Za_{ij}$$

Here, Za_{ij} is the normalized weighted Z-value of *i*-th alternative concerning the *j*-th criterion, and

n is the number of criteria.

c. Compare the total Z-scores for each alternative.
d. Calculate the distance between the Z-scores and Z(1,1). The closest alternative is the best.

The above Z-number-based calculation procedures, including Z-reasoning, criteria importance definition, and Z-MCDMs, have been reflected in the literature cited in this article and other sources and used to solve numerical examples or minor practical problems. In this study, the methods mentioned above were integrated and implemented for the first time to solve a complex management problem related to energy transition under conditions of imperfect information. The following section demonstrates the integrated approach's practical realization and sufficient effectiveness.

4. Scenario Application for Energy Policy Development: The Case of Azerbaijan

4.1. Composition Energy Transition Scenario for Azerbaijan

Azerbaijan is an oil- and gas-producing country with rich historical experience in hydrocarbon export. Moreover, the country is on the list of countries most dependent on oil and gas production (seventh position). For sustainable development, a country needs an energy transition policy that rationally compromises economic growth and environmental protection objectives and constraints. These peculiarities, to a certain extent, complicate the content of the transition task and require the development of an approach that ensures a rational compromise of opposing interests and priorities. In the case of the Azerbaijan energy system [74–76], a Z-information scenario-based transition model has been developed to ensure energy policy continuity and compromise during the transition. The model incorporates the following characteristics of the country's energy sector [76,77]: a steady decline in highly polluting oil production (25% reduction in the last decade), an increasing reliance on relatively cleaner natural gas (60% increase in production over the past decade due to its dual role as an export and energy resource), substantial wind and solar potential, moderate hydro expansion potential, and limited geothermal, biomass, and waste resources. Given these factors, natural gas, hydro, wind, and solar are identified as the primary controllable elements for the transition energy policy, as declining, fixed, or insignificant capacity resources are deemed irrelevant for long-term planning.

Two different tasks have been solved using the scenario approach:

- The transition of the energy mix for electricity production;
- The transition of the country's energy system.

These tasks have different opportunities and requirements; solving them independently allows us to make more precise and justified solutions.

In the numerical model development process, following Stage 5 (according to Section 3.2.3) of the scenario development process, the following terms were used for each resource:

In the example, three resources have two levels of discrimination that are of interest for scenario composition, and one variable has three levels of discrimination. Accordingly, the total number of alternative combinations (Formula (5)) that are of interest is equal to

$$3 * 2^3 = 24$$

As shown in Table 1, in our case, given the resource specifics for the country, three terms are of interest for decision model formalization: Maintain as usual (M), Increase moderately (IM), and Increase significantly (IS). The scenarios' formal presentations are given below.

Table 1. Linguistic terms used for the description of the energy resource production rates.

Resources	Terms Applied	Resource Specifics	Terms Available
Natural gas	Maintain as usual, Increase moderately, Increase Significantly	Key export product and relatively less environmental unfriendliness	Maintain as usual, Increase moderately, Increase Significantly, Decrease moderately, Decrease significantly
Wind	Increase moderately, Increase Significantly	Environmental friendliness and high capacity	
Solar	Increase moderately, Increase Significantly	Environmental friendliness and high capacity	
Hydro	Maintain as usual, Increase moderately	Environmental friendliness and limited capacity	

Based on Table 1, the following scenarios describing the country's various energy policies were developed:

S1—"Maintain NG and hydro as usual, and increase significantly solar and wind";

S2—"Maintain NG and hydro as usual, and increase moderately solar and significantly wind";

S3—"Maintain NG and hydro as usual, and increase significantly solar and moderately wind";

S4—"Maintain NG and hydro as usual, and increase moderately solar and wind";

S5—"Maintain NG as usual, increase moderately hydro, and increase significantly solar and wind";

S6—"Maintain NG as usual, increase moderately hydro, and increase moderately solar and significantly wind";

S7—"Maintain NG as usual, increase moderately hydro, increase significantly solar, and increase moderately wind";

S8—"Maintain NG as usual, increase moderately hydro, and increase moderately solar and wind";

S9—"Increase moderately NG, maintain hydro as usual, and increase significantly solar and wind";

S10—"Increase moderately NG, maintain hydro as usual, and increase moderately solar and significantly wind";

S11—"Increase moderately NG, maintain hydro as usual, increase significantly solar, and increase moderately wind";

S12—"Increase moderately NG, maintain hydro as usual, and increase moderately solar and wind";

S13—"Increase moderately NG and hydro, and increase significantly solar and wind";

S14—"Increase moderately NG and hydro, increase moderately solar, and increase significantly wind";

S15—"Increase moderately NG and hydro, and increase significantly solar and moderately wind";

S16—"Increase moderately NG and hydro, and increase moderately solar and wind";

S17—"Increase significantly NG, maintain hydro as usual, and increase significantly solar and wind";

S18—"Increase NG significantly, maintain hydro as usual, increase moderately solar, and increase significantly wind";

S19—"Increase significantly NG, maintain hydro as usual, increase significantly solar, and increase moderately wind";

S20—"Increase significantly NG, maintain hydro as usual, and increase moderately solar and wind";

S21—"Increase significantly NG, increase moderately hydro, and increase significantly solar and wind";

S22—"Increase significantly NG, increase moderately hydro, and increase moderately solar and significantly wind";

S23—"Increase significantly NG, increase moderately hydro, increase significantly solar, and increase moderately wind".

S24—"Increase significantly NG, increase moderately hydro, and increase moderately solar and wind".

The abovementioned eight criteria were used to evaluate resource and production levels (sub-scenarios). Linguistic terms used in the sub-scenarios reflect the succession of the energy policy, priority of the transition, and capacity of the resources. For example, for natural gas, the options "Increase moderately", "Increase significantly", and "Maintain as usual" are used. Given the role of natural gas in the country's economy, the option "Decrease" is unreal. Considering the limited availability of hydro resources, the terms "Maintain as usual" and "Increase moderately" are used. For wind and solar energy resources, the linguistic terms "Increase significantly" and "Increase moderately" are used. Decreasing the country's natural gas production during the next few decades seems unrealistic, given its capacity, export potential, and role in electricity generation. Linguistic values and related triangle fuzzy numbers for parts A and B of the *Z*-numbers used are shown in Table 2.

Table 2. Linguistic values of the A and B parts of Z-numbers.

LV–Part A	TMF	LV–Part A	TMF	LV–Part B	TMF
Extremely low (EL)	(0, 1, 2)	Maintain as usual (MU)	(0, 0.25, 0.5)	Not sure	(0, 0.25, 0.5)
Very low (VL)	(1, 2, 3)	Increase moderately (IM)	(0.25, 0.5, 0.75)	Sure	(0.25, 0.5, 0.75)
Low (L)	(2, 3, 4)	Increase significantly (IS)	(0.5, 0.75, 1)	Very sure	(0.5, 0.75, 1)
Below average (BA)	(3, 4, 5)			Extremely sure	(0.75, 1, 1)
Average (A)	(4, 5, 6)				
Above average (AA)	(5, 6, 7)				
High (H)	(6, 7, 8)				
Very high (VH)	(7, 8, 9)				
Extremely high (EH)	(8, 9, 10)				

4.2. Evaluation of Each Resource, Scenario Assessment, and Ranking

4.2.1. Evaluation of Each Resource According to the Criteria Values

The following dependencies were established, expressed by *Z*-number-based rules, for the corresponding level production of each resource and the values of the criteria:

(1) If NG is MU, ES Then C_1 is L, ES and C_2 is VH, ES and C_3 is EL, ES and C_4 is L, ES and C_5 is EL, ES and C_6 is A, ES and C_7 is EH, ES and C_8 is H, ES;

(2) If NG is IM, ES Then C_1 is AA, ES and C_2 is H, ES and C_3 is BA, ES and C_4 is A, ES and C_5 is BA, ES and C_6 is AA, ES and C_7 is VH, ES and C_8 is A, ES;

(3) If NG is IS, ES Then C_1 is EH, ES and C_2 is A, ES and C_3 is H, ES and C_4 is H, ES and C_5 is H, ES and C6 is H, ES and C7 is H, ES and C8 is L, ES;
(4) If Wind is IM, ES Then C_1 is AA, ES and C_2 is H, ES and C_3 is A, ES and C_4 is A, ES and C_5 is A, ES and C_6 is A, ES and C_7 is EH, ES and C_8 is EH, ES;
(5) If Wind is IS, ES Then C_1 is EH, ES and C_2 is EH, ES and C_3 is VH, ES and C_4 is VH, ES and C_5 is EH, ES and C_6 is H, ES and C_7 is VH, ES and C8 is H, ES;
(6) If Solar is IM, ES Then C_1 is BA, ES and C_2 is H, ES and C_3 is L, ES and C_4 is BA, ES and C_5 is L, ES and C_6 is A, ES and C_7 is AA, ES and C_8 is EH, ES;
(7) If Solar is IS, ES Then C_1 is H, ES and C_2 is EH, ES and C_3 is AA, ES and C_4 is H, ES and C_5 is AA, ES and C_6 is H, ES and C_7 is BA, ES and C_8 is H, ES;
(8) If Hydro is MU, ES Then C_1 is L, ES and C_2 is A, ES and C_3 is EL, ES and C_4 is A, ES and C5 is EL, ES and C6 is AA, ES and C_7 is EH, ES and C_8 is EH, ES;
(9) If Hydro is IM, ES Then C_1 is H, ES and C_2 is H, ES and C_3 is BA, ES and C_4 is H, ES and C_5 is L, ES and C_6 is VH, ES and C_7 is H, ES and C_8 is H, ES.

4.2.2. Assessment of the Scenarios by *Z*-Rule-Based Reasoning

Next, using the logical inference mechanism for the *Z*-rules, the criteria values were calculated for each of the 24 scenarios. As a result, we obtained the decision matrix, presented in Table 3, for the energy transition task.

Table 3. Decision matrix.

	Z_{C1}						Z_{C2}						Z_{C3}						Z_{C4}					
S_1	4.5	5.5	6.5	0.8	0.9	1	6.75	7.75	8.75	0.8	0.9	1	3	4	5	0.8	0.9	1	4.75	5.75	6.75	0.8	0.9	1
S_2	3.75	4.75	5.75	0.8	0.9	1	6.25	7.25	8.25	0.8	0.9	1	2.25	3.25	4.25	0.8	0.9	1	4	5	6	0.8	0.9	1
S_3	3.75	4.75	5.75	0.8	0.9	1	6.25	7.25	8.25	0.8	0.9	1	2.25	3.25	4.25	0.8	0.9	1	4	5	6	0.8	0.9	1
S_4	3	4	5	0.8	0.9	1	5.75	6.75	7.75	0.8	0.9	1	1.5	2.5	3.5	0.8	0.9	1	3.25	4.25	5.25	0.8	0.9	1
S_5	5.5	6.5	7.5	0.8	0.9	1	7.25	8.25	9.25	0.8	0.9	1	3.75	4.75	5.75	0.8	0.9	1	5.25	6.25	7.25	0.8	0.9	1
S_6	4.75	5.75	6.75	0.8	0.9	1	6.75	7.75	8.75	0.8	0.9	1	3	4	5	0.8	0.9	1	4.5	5.5	6.5	0.8	0.9	1
S_7	4.75	5.75	6.75	0.8	0.9	1	6.75	7.75	8.75	0.8	0.9	1	3	4	5	0.8	0.9	1	4.5	5.5	6.5	0.8	0.9	1
S_8	4	5	6	0.8	0.9	1	6.25	7.25	8.25	0.8	0.9	1	2.25	3.25	4.25	0.8	0.9	1	3.75	4.75	5.75	0.8	0.9	1
S_9	5.25	6.25	7.25	0.8	0.9	1	6.5	7.5	8.5	0.8	0.9	1	3.75	4.75	5.75	0.8	0.9	1	5.25	6.25	7.25	0.8	0.9	1
S_{10}	4.5	5.5	6.5	0.8	0.9	1	6	7	8	0.8	0.9	1	3	4	5	0.8	0.9	1	4.5	5.5	6.5	0.8	0.9	1
S_{11}	4.5	5.5	6.5	0.8	0.9	1	6	7	8	0.8	0.9	1	3	4	5	0.8	0.9	1	4.5	5.5	6.5	0.8	0.9	1
S_{12}	3.75	4.75	5.75	0.8	0.9	1	5.5	6.5	7.5	0.8	0.9	1	2.25	3.25	4.25	0.8	0.9	1	3.75	4.75	5.75	0.8	0.9	1
S_{13}	6.25	7.25	8.25	0.8	0.9	1	7	8	9	0.8	0.9	1	4.5	5.5	6.5	0.8	0.9	1	5.75	6.75	7.75	0.8	0.9	1
S_{14}	5.5	6.5	7.5	0.8	0.9	1	6.5	7.5	8.5	0.8	0.9	1	3.75	4.75	5.75	0.8	0.9	1	5	6	7	0.8	0.9	1
S_{15}	5.5	6.5	7.5	0.8	0.9	1	6.5	7.5	8.5	0.8	0.9	1	3.75	4.75	5.75	0.8	0.9	1	5	6	7	0.8	0.9	1
S_{16}	4.75	5.75	6.75	0.8	0.9	1	6	7	8	0.8	0.9	1	3	4	5	0.8	0.9	1	4.25	5.25	6.25	0.8	0.9	1
S_{17}	6	7	8	0.8	0.9	1	6	7	8	0.8	0.9	1	4.5	5.5	6.5	0.8	0.9	1	5.75	6.75	7.75	0.8	0.9	1
S_{18}	5.25	6.25	7.25	0.8	0.9	1	5.5	6.5	7.5	0.8	0.9	1	3.75	4.75	5.75	0.8	0.9	1	5	6	7	0.8	0.9	1
S_{19}	5.25	6.25	7.25	0.8	0.9	1	5.5	6.5	7.5	0.8	0.9	1	3.75	4.75	5.75	0.8	0.9	1	5	6	7	0.8	0.9	1
S_{20}	4.5	5.5	6.5	0.8	0.9	1	5	6	7	0.8	0.9	1	3	4	5	0.8	0.9	1	4.25	5.25	6.25	0.8	0.9	1
S_{21}	7	8	9	0.8	0.9	1	6.5	7.5	8.5	0.8	0.9	1	5.25	6.25	7.25	0.8	0.9	1	6.25	7.25	8.25	0.8	0.9	1
S_{22}	6.25	7.25	8.25	0.8	0.9	1	6	7	8	0.8	0.9	1	4.5	5.5	6.5	0.8	0.9	1	5.5	6.5	7.5	0.8	0.9	1
S_{23}	6.25	7.25	8.25	0.8	0.9	1	6	7	8	0.8	0.9	1	4.5	5.5	6.5	0.8	0.9	1	5.5	6.5	7.5	0.8	0.9	1
S_{24}	5.5	6.5	7.5	0.8	0.9	1	5.5	6.5	7.5	0.8	0.9	1	3.75	4.75	5.75	0.8	0.9	1	4.75	5.75	6.75	0.8	0.9	1

Table 3. *Cont.*

	$\mathbf{Z_{C1}}$						$\mathbf{Z_{C2}}$						$\mathbf{Z_{C3}}$						$\mathbf{Z_{C4}}$					
	Z_{C5}						Z_{C6}						Z_{C7}						Z_{C8}					
S_1	3.25	4.25	5.25	0.8	0.9	1	5.25	6.25	7.25	0.8	0.9	1	6.5	7.5	8.5	0.8	0.9	1	6.5	7.5	8.5	0.8	0.9	1
S_2	2.5	3.5	4.5	0.8	0.9	1	4.75	5.75	6.75	0.8	0.9	1	7	8	9	0.8	0.9	1	7	8	9	0.8	0.9	1
S_3	2.25	3.25	4.25	0.8	0.9	1	4.75	5.75	6.75	0.8	0.9	1	6.75	7.75	8.75	0.8	0.9	1	7	8	9	0.8	0.9	1
S_4	1.5	2.5	3.5	0.8	0.9	1	4.25	5.25	6.25	0.8	0.9	1	7.25	8.25	9.25	0.8	0.9	1	7.5	8.5	9.5	0.8	0.9	1
S_5	3.75	4.75	5.75	0.8	0.9	1	5.75	6.75	7.75	0.8	0.9	1	6	7	8	0.8	0.9	1	6	7	8	0.8	0.9	1
S_6	3	4	5	0.8	0.9	1	5.25	6.25	7.25	0.8	0.9	1	6.5	7.5	8.5	0.8	0.9	1	6.5	7.5	8.5	0.8	0.9	1
S_7	2.75	3.75	4.75	0.8	0.9	1	5.25	6.25	7.25	0.8	0.9	1	6.25	7.25	8.25	0.8	0.9	1	6.5	7.5	8.5	0.8	0.9	1
S_8	2	3	4	0.8	0.9	1	4.75	5.75	6.75	0.8	0.9	1	6.75	7.75	8.75	0.8	0.9	1	7	8	9	0.8	0.9	1
S_9	4	5	6	0.8	0.9	1	5.5	6.5	7.5	0.8	0.9	1	6.25	7.25	8.25	0.8	0.9	1	6	7	8	0.8	0.9	1
S_{10}	3.25	4.25	5.25	0.8	0.9	1	5	6	7	0.8	0.9	1	6.75	7.75	8.75	0.8	0.9	1	6.5	7.5	8.5	0.8	0.9	1
S_{11}	3	4	5	0.8	0.9	1	5	6	7	0.8	0.9	1	6.5	7.5	8.5	0.8	0.9	1	6.5	7.5	8.5	0.8	0.9	1
S_{12}	2.25	3.25	4.25	0.8	0.9	1	4.5	5.5	6.5	0.8	0.9	1	7	8	9	0.8	0.9	1	7	8	9	0.8	0.9	1
S_{13}	4.5	5.5	6.5	0.8	0.9	1	6	7	8	0.8	0.9	1	5.75	6.75	7.75	0.8	0.9	1	5.5	6.5	7.5	0.8	0.9	1
S_{14}	3.75	4.75	5.75	0.8	0.9	1	5.5	6.5	7.5	0.8	0.9	1	6.25	7.25	8.25	0.8	0.9	1	6	7	8	0.8	0.9	1
S_{15}	3.5	4.5	5.5	0.8	0.9	1	5.5	6.5	7.5	0.8	0.9	1	6	7	8	0.8	0.9	1	6	7	8	0.8	0.9	1
S_{16}	2.75	3.75	4.75	0.8	0.9	1	5	6	7	0.8	0.9	1	6.5	7.5	8.5	0.8	0.9	1	6.5	7.5	8.5	0.8	0.9	1
S_{17}	4.75	5.75	6.75	0.8	0.9	1	5.75	6.75	7.75	0.8	0.9	1	6	7	8	0.8	0.9	1	5.5	6.5	7.5	0.8	0.9	1
S_{18}	4	5	6	0.8	0.9	1	5.25	6.25	7.25	0.8	0.9	1	6.5	7.5	8.5	0.8	0.9	1	6	7	8	0.8	0.9	1
S_{19}	3.75	4.75	5.75	0.8	0.9	1	5.25	6.25	7.25	0.8	0.9	1	6.25	7.25	8.25	0.8	0.9	1	6	7	8	0.8	0.9	1
S_{20}	3	4	5	0.8	0.9	1	4.75	5.75	6.75	0.8	0.9	1	6.75	7.75	8.75	0.8	0.9	1	6.5	7.5	8.5	0.8	0.9	1
S_{21}	5.25	6.25	7.25	0.8	0.9	1	6.25	7.25	8.25	0.8	0.9	1	5.5	6.5	7.5	0.8	0.9	1	5	6	7	0.8	0.9	1
S_{22}	4.5	5.5	6.5	0.8	0.9	1	5.75	6.75	7.75	0.8	0.9	1	6	7	8	0.8	0.9	1	5.5	6.5	7.5	0.8	0.9	1
S_{23}	4.25	5.25	6.25	0.8	0.9	1	5.75	6.75	7.75	0.8	0.9	1	5.75	6.75	7.75	0.8	0.9	1	5.5	6.5	7.5	0.8	0.9	1
S_{24}	3.5	4.5	5.5	0.8	0.9	1	5.25	6.25	7.25	0.8	0.9	1	6.25	7.25	8.25	0.8	0.9	1	6	7	8	0.8	0.9	1

4.2.3. Determination of the Criteria Weights

After selecting criteria, they must be compared in pairs to determine their importance weights. In [66], the fuzzy values of weights for the calculations were specified. The order of the criteria is $C_3 < C_5 < C_2 < C_6 < C_1 < C_4 < C_7 < C_8$. Based on this information, the expert's preferences regarding the importance of the criteria is determined. In the present study, an expert's preferences for criteria importance are formalized by a 9×9 Z-RPCM. The initial *Z*-number-based preference matrix is shown in Table 4.

Table 4. Z-number-valued preference knowledge about criteria importance.

	$\mathbf{C_1}$	$\mathbf{C_2}$	$\mathbf{C_3}$	$\mathbf{C_4}$	$\mathbf{C_5}$	$\mathbf{C_6}$	$\mathbf{C_7}$	$\mathbf{C_8}$
C_1	Z(1, 1)	MI, ES	SI, ES	1/MI, ES	EI, ES	MI, ES	1/EI, ES	1/EI, ES
C_2	1/MI, ES	Z(1, 1)	MI, ES	1/MI, ES	Eq, ES	Eq, ES	1/SI, ES	1/SI, ES
C_3	1/SI, ES	1/MI, ES	Z(1, 1)	1/SI, ES	1/MI, ES	1/MI, ES	1/AI, ES	1/AI, ES
C_4	MI, ES	MI, ES	SI, ES	Z(1, 1)	EI, ES	MI, ES	Eq, ES	Eq, ES
C_5	1/EI, ES	Eq, ES	MI, ES	1/EI, ES	Z(1, 1)	1/MI, ES	1/EI, ES	1/EI, ES
C_6	1/MI, ES	Eq, ES	MI, ES	1/MI, ES	MI, ES	Z(1, 1)	MI, ES	MI, ES
C_7	EI, ES	SI, ES	AI, ES	Eq, ES	EI, ES	1/MI, ES	Z(1, 1)	Eq, ES
C_8	EI, ES	SI, ES	AI, ES	Eq, ES	EI, ES	1/MI, ES	Eq, ES	Z(1, 1)

Z_{ij} denotes a *Z*-number-valued degree to which the *i*-th criterion is preferred to the *j*-th one. For example, Z_{17} is a degree to which C_1 is preferred to C_7—in linguistic form—(absolute importance, very sure) or (AI, ES) and in the form of TrFN (4.5, 5, 5, 7) (0.8, 0.85, 0.95, 1).

Because of subjective judgment, the initial preference matrix is usually inconsistent. As a result, the problem of inconsistency needs to be solved. Suppose the inconsistency ratio exceeds the level the decision maker gives. In that case, it becomes necessary to generate a new RPCM. According to the described approach [71], a consistency matrix is constructed (inconsistency level below 0.25), and a fragment is shown in Table 5.

Table 5. Z-number-valued pair-wise consistent preference matrix.

	C_1	...	C_8
C_1	(0.95, 1.0, 1.05), (0.97, 0.98, 1.0)		(0.456, 0.48, 0.504), (0.97, 0.98, 1.0)
C_2	(0.652, 0.685, 0.721), (0.97, 0.98, 1.0)		(0.285, 0.3, 0.315), (0.97, 0.98, 1.0)
C_3	(0.363, 0.381, 0.401), (0.97, 0.98, 1.0)	...	(0.159, 0.167, 0.175), (0.97, 0.98, 1.0)
C_4	(1.652, 1.734, 1.826), (0.97, 0.98, 1.0)		(0.722, 0.76, 0.798), (0.97, 0.98, 1.0)
C_5	(0.523, 0.549, 0.578), (0.97, 0.98, 1.0)		(0.229, 0.241, 0.253), (0.97, 0.98, 1.0)
C_6	(0.795, 0.835, 0.879), (0.97, 0.98, 1.0)		(0.348, 0.366, 0.384), (0.97, 0.98, 1.0)
C_7	(1.909, 2.004, 2.11), (0.97, 0.98, 1.0)		(0.835, 0.879, 0.923), (0.97, 0.98, 1.0)
C_8	(1.984, 2.084, 2.193), (0.97, 0.98, 1.0)		(0.95, 1.0, 1.05), (0.97, 0.98, 1.0)

It should be noted that a complete reflection of the results of Z-number-based calculations requires many large-scale tables, and so we prefer to reflect on the results.

In the next stage, based on Table 5, the weights are calculated.

For this purpose, we calculate the eigenvector and maximum eigenvalue of the obtained consistent matrix using Formula (6). Then, based on the eigenvector $(Z_x) = [Z_{x1} = (A_{x1}, B_{x1}), \ldots, Z_{x8} = (A_{x8}, B_{x8})]^{\mathrm{T}}$, we have to find the vector of criteria weights $(Z_w) = [Z_{w1} = (A_{w1}, B_{w1}), \ldots, Z_{w8} = (A_{w8}, B_{w8})]^T$ via the normalization of the (Z_x) component. Since the reliability of information does not change in the normalization process, $B_{wi} = B_{xi}$, $i = 1, \ldots, 0$, the approach proposed in [71] is used to find A parts.

The calculated Z-eigenvector Z_x $(Z_{x1}, Z_{x2}, Z_{x3}, Z_{x4}, Z_{x5}, Z_{x6}, Z_{x7}, Z_{x8}, Z_{x9})$ is

([[[0.0841 0.2515 0.3446] [0.28 0.28 0.2884]], [[0.0538 0.1609 0.2206] [0.28 0.28 0.28]], [[0.0306 0.0915 0.0915 0.1254] [0.28 0.28 0.28 0.3045]], [[0.1428 0.4264 0.4264 0.5848] [0.28 0.28 0.28 0.28]], [[0.0462 0.138 0.138 0.1894] [0.28 0.28 0.28 0.28]], [[0.072 0.2149 0.2149 0.2948] [0.28 0.2963 0.2963 0.4962]], [[0.1768 0.5274 0.5274 0.724] [0.28 0.28 0.28 0.28]], [[0.188 0.5608 0.5608 0.7701] [0.28 0.28 0.28 0.2828]]]).

After the normalization of components of Z-eigenvector Z_x, we obtain the Z-valued vector of weights Z_w $(Z_{wc1}, Z_{wc2}, Z_{wc3}, Z_{wc4}, Z_{wc5}, Z_{wc6}, Z_{wc7}, Z_{wc8})$ as

Z_{wc1} = (0.1058 0.1061 0.1062) (0.28 0.2813 0.3719), Z_{wc2} = (0.0677 0.0679 0.068) (0.28 0.3568 0.5696), Z_{wc3} = (0.0385 0.0386 0.0387) (0.2805 0.5988 0.6304), Z_{wc4} = (0.1796 0.1798 0.1802) (0.3198 0.4414 0.4414), Z_{wc5} = (0.0582 0.0582 0.0584) (0.28 0.3487 0.3487), Z_{wc6} = (0.0906 0.0906 0.0909) (0.3122 0.3441 0.3967), Z_{wc7} = (0.2223 0.2224 0.2231) (0.28 0.2821 0.2994), and Z_{wc8} = (0.2365 0.2365 0.2373) (0.2998 0.326 0.6401).

4.2.4. Applications of Z-MCDM

Results from the application of Z-TOPSIS

For Z-TOPSIS calculations, the decision matrix obtained in the previous stage (Table 3) is used. According to the method's procedures, normalizing the decision matrix sequentially is necessary. A fragment of the normalized matrix is presented in Table 6.

Table 6. Normalized decision matrix.

	C1							C8					
S_1	0.647	0.765	0.882	0.8	0.9	1		0.789	0.895	1.000	0.8	0.9	1
S_2	0.559	0.676	0.794	0.8	0.9	1		0.789	0.895	1.000	0.8	0.9	1
S_3	0.559	0.676	0.794	0.8	0.9	1		0.789	0.895	1.000	0.8	0.9	1
S_4	0.471	0.588	0.706	0.8	0.9	1		0.789	0.895	1.000	0.8	0.9	1
S_5	0.706	0.824	0.941	0.8	0.9	1		0.737	0.842	0.947	0.8	0.9	1
S_6	0.618	0.735	0.853	0.8	0.9	1		0.737	0.842	0.947	0.8	0.9	1
S_7	0.618	0.735	0.853	0.8	0.9	1	...	0.737	0.842	0.947	0.8	0.9	1
S_8	0.529	0.647	0.765	0.8	0.9	1		0.737	0.842	0.947	0.8	0.9	1
S_9	0.706	0.824	0.941	0.8	0.9	1		0.737	0.842	0.947	0.8	0.9	1
S_{10}	0.618	0.735	0.853	0.8	0.9	1		0.737	0.842	0.947	0.8	0.9	1
S_{11}	0.618	0.735	0.853	0.8	0.9	1		0.737	0.842	0.947	0.8	0.9	1
S_{12}	0.529	0.647	0.765	0.8	0.9	1	...	0.737	0.842	0.947	0.8	0.9	1
S_{13}	0.765	0.882	1.000	0.8	0.9	1		0.684	0.789	0.895	0.8	0.9	1
S_{14}	0.676	0.794	0.912	0.8	0.9	1		0.684	0.789	0.895	0.8	0.9	1
S_{15}	0.676	0.794	0.912	0.8	0.9	1		0.684	0.789	0.895	0.8	0.9	1
S_{16}	0.588	0.706	0.824	0.8	0.9	1		0.684	0.789	0.895	0.8	0.9	1
S_{17}	0.706	0.824	0.941	0.8	0.9	1		0.684	0.789	0.895	0.8	0.9	1
S_{18}	0.618	0.735	0.853	0.8	0.9	1	...	0.684	0.789	0.895	0.8	0.9	1
S_{19}	0.618	0.735	0.853	0.8	0.9	1		0.684	0.789	0.895	0.8	0.9	1
S_{20}	0.529	0.647	0.765	0.8	0.9	1		0.684	0.789	0.895	0.8	0.9	1
S_{21}	0.765	0.882	1.000	0.8	0.9	1		0.632	0.737	0.842	0.8	0.9	1
S_{22}	0.676	0.794	0.912	0.8	0.9	1		0.632	0.737	0.842	0.8	0.9	1
S_{23}	0.676	0.794	0.912	0.8	0.9	1		0.632	0.737	0.842	0.8	0.9	1
S_{24}	0.588	0.706	0.824	0.8	0.9	1		0.632	0.737	0.842	0.8	0.9	1

Next, by sequentially calculating the normalized weighted matrix, the distance from each alternative to the ideal positive Z (1,1) and ideal negative solution Z (0,0), and the relative closeness to the best alternative, we obtain the following results, which are reflected in Table 7.

Table 7. Final ranking of scenarios based on Z-TOPSIS.

Scenario	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
Rank	4	13	14	22	2	8	9	18
Scenario	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}
Rank	3	11	12	21	1	6	7	17
Scenario	S_{17}	S_{18}	S_{19}	S_{20}	S_{21}	S_{22}	S_{23}	S_{24}
Rank	10	19	20	24	5	15	16	23

Results from the application of Z-PROMETEHHE

For calculations using Z-PROMETHEE, DM from Table 2 is used. Consequently, the Z-value-based preference function is calculated using the degree of optimality, and then the Z-number-based weighted preference function, the leaving and entering flows, and net flows for each alternative are determined. The result is obtained and reflected in Table 8.

Table 8. Final ranking of scenarios based on Z-PROMETHEE.

Scenario	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
Rank	3	9	10	16	1	5	6	16
Scenario	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}
Rank	4	12	13	20	2	7	8	17
Scenario	S_{17}	S_{18}	S_{19}	S_{20}	S_{21}	S_{22}	S_{23}	S_{24}
Rank	14	21	22	24	11	18	19	23

Results from the application of Z-SAW

Given a normalized decision matrix and a vector of weights, the *Z*-score for each alternative is calculated. Instead of transforming the *Z*-scores into fuzzy or crisp numbers that lead to information loss, the ranking according to each alternative's similarity degree of $Z(1, 1)$ and *Z*-score is applied. The results of the final ranking of alternatives are presented in Table 9.

Table 9. Final ranking of scenarios based on Z-SAW.

Scenario	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
Rank	2	13	15	24	6	10	11	3
Scenario	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}
Rank	1	20	21	19	4	8	9	7
Scenario	S_{17}	S_{18}	S_{19}	S_{20}	S_{21}	S_{22}	S_{23}	S_{24}
Rank	12	15	16	22	6	17	18	23

4.3. Sensitivity Analysis

Figure 2 presents comparative calculation results for the three methods. The graph shows that the results of evaluating and ranking alternative transition scenarios based on the Z-MCDM models show low sensitivity to the solution methods.

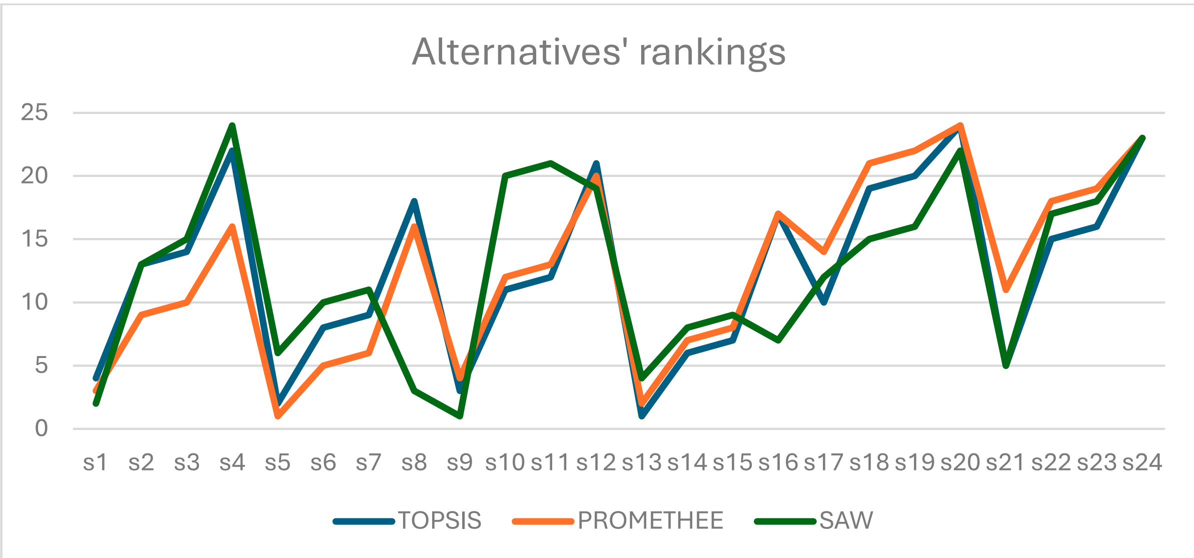

Figure 2. Comparison of the calculation results.

According to the problem solution results, scenarios S_{13}, S_9, and S_5 are the best among the solutions of all models, followed by alternatives S_1 and S_{21}. Changes in rank do not exceed one unit.

Next, a sensitivity analysis was conducted to check the stability of the solution when changing the importance of the weights. To provide a final confirmation of decisions, it was decided to assign equal weight to all criteria. The calculation results for different approaches are presented in Table 10.

Table 10. Ranking of scenarios based on an equal importance of weights by the three methods.

TOPSIS	Scenario	S1	S2	S3	S4	S5	S6	S7	S8
	Rank	10	19	20	24	6	11	12	21
	Scenario	S9	S10	S11	S12	S13	S14	S15	S16
	Rank	7	13	14	22	1	8	9	17
	Scenario	S17	S18	S19	S20	S21	S22	S23	S24
	Rank	2	15	16	23	3	4	5	18
PROMETHEE	Scenario	S1	S2	S3	S4	S5	S6	S7	S8
	Rank	8	18	19	23	2	11	12	20
	Scenario	S9	S10	S11	S12	S13	S14	S15	S16
	Rank	4	13	14	22	1	5	6	15
	Scenario	S17	S18	S19	S20	S21	S22	S23	S24
	Rank	7	16	17	24	3	9	10	21
SAW	Scenario	S1	S2	S3	S4	S5	S6	S7	S8
	Rank	1	21	22	24	7	11	12	20
	Scenario	S9	S10	S11	S12	S13	S14	S15	S16
	Rank	8	15	16	23	1	5	6	17
	Scenario	S17	S18	S19	S20	S21	S22	S23	S24
	Rank	3	13	14	18	1	9	10	19

The common trend for the results shown in Table 10 is presented in graphical form in Figure 3.

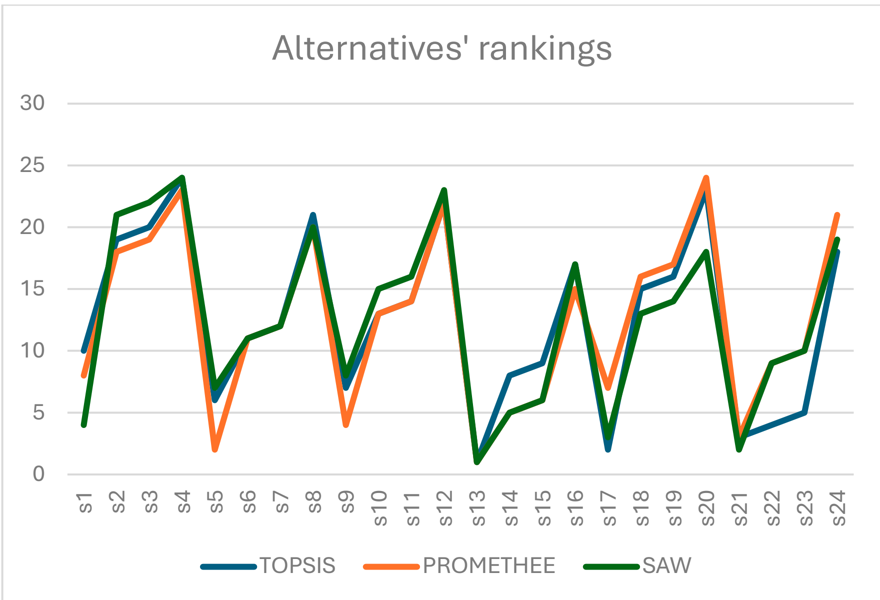

Figure 3. Comparison of the calculation results with equal-importance weights.

The sensitivity analysis shows that alternative S_{13} is the best in four times out of six rankings, and S_5 and S_9 once.

Averaging the ranking results obtained by applying the different methods shows the acceptable stability of solutions. Table 11 shows the average rank values of each scenario for the six calculation methods.

Table 11. Average ranking of scenarios.

Scenario	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
Rank	5	16	19	23	2	9	10	17
Scenario	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}
Rank	3	13	14	21	1	6	7	14
Scenario	S_{17}	S_{18}	S_{19}	S_{20}	S_{21}	S_{22}	S_{23}	S_{24}
Rank	8	18	20	24	4	11	12	21

5. Discussion

Environmental and sustainable development requirements compel countries to develop and implement relevant strategies and programs for the energy transition. Approaches to solving the energy transition problem vary significantly depending on national priorities, objectives, and decision-making factors. A characteristic feature of these approaches is that, regardless of the variety of problem statements, they all operate under conditions of high uncertainty in the decision-making process and subjectivity in the information used for problem formulation and resolution. The decision-making context's irregularity, volatility, and uniqueness significantly limit the availability and use of historical data; in such circumstances, decision-makers must work with imperfect information. It should be noted that, in most cases, the energy transition task is characterized by a high level of subjectivity and uncertainty, which requires developing an approach that can address these peculiarities. Given the specificity of the task, this paper applies a multistage approach based on the fuzzy Z-numbers formalism, which integrates fuzziness and probability concepts and allows for the effective representation and processing of subjective and linguistic information. A fuzzy scenario-based approach, in general, enables the consideration of almost all potential future development paths and the selection of the best one while considering the decision-makers' priorities and key objectives. Bi-modal Z-numbers simultaneously represent the value and reliability of variables; accordingly, the decision-maker receives both a solution and information about the reliability of that solution. Although multi-stage decision-making approaches using Z-numbers are widely used today, integrating Z-reasoning and multi-criteria decision-making methods for energy transition problems is being implemented for the first time.

As shown in Figure 1, the solution to the problem is a multistage process. The starting point for model construction is to decide on the resources to use and their potential rates. In general, the energy resources available in Azerbaijan include oil, natural gas, solar, wind, hydro, geothermal, biomass, and waste. However, four resources are particularly interesting for energy transition scenarios: natural gas, solar, wind, and hydro. Oil production in the country is declining and is highly environmentally unfriendly. The combined potential of geothermal, biomass, and waste is less than 4% of the renewable share, and these resources do not significantly influence energy policy or transition decisions. Natural gas is included in the scenarios due to its decisive role in the country's economy. To increase the flexibility and descriptive capabilities of the decision model, we initially analyzed the applicability of five different resource production levels in the scenarios: Increase significantly, Increase moderately, Maintain as usual, Decrease moderately, and Decrease significantly.

The analysis revealed that, depending on the economic conditions and priorities, only two or three production rates are practically relevant for each resource. For example, the declining renewable production rate is not of interest due to environmental requirements, and the decreasing rate of natural gas production is irrelevant due to economic constraints and national priorities. Considering these factors, 24 scenarios were developed to address the energy transition task. Eight criteria have been used to evaluate the potential scenarios, considering the energy transition paths and the policy's social, legal, economic, environmental, and technological aspects. The importance of objectives has been accounted for by assigning weights. To increase the relevance and reliability of the solution, Z-extensions of three multi-criteria decision-making (MCDM) methods—TOPSIS, PROMETHEE, and SAW—were applied to solve the transition problem. As shown in Figure 3, based on the problem solution results and average rankings, scenarios S13, S5, and S9 are the best solutions across all models, followed by alternatives S1 and S21. Solutions of the energy transition task based on the use of experts' knowledge, fuzzy IF–THEN rules, the transformation of the rules base into a decision matrix, and application of the Z-extensions of the MCDM methods illustrated the robustness and low sensibility of the decision methods applied. The changes in rankings are not significant. The best scenario, S13, which involves moderately increasing natural gas (NG) and hydro while significantly increasing solar and wind, aligns with the country's economic priorities for the coming decades, as well as the environmental requirements and resource availability.

The proposed approaches have a sufficient degree of universality. They can be used for other countries and for solving problems from another sphere that apply the scenario approach. Thus, having defined the available RES resources and their production rates, possible scenarios can be generated through the fuzzy reasoning mechanism. Furthermore, scenarios are assessed and selected based on multi-criteria methods in which the criteria for assessing alternatives are defined based on the decision maker's preferences. The procedures for determining the importance of criteria ensure the consistency of preferences, which is very important in multi-criteria decision-making. Using various MCDMs to assess and select alternatives ensures the validity of decisions. Direct calculations with Z-numbers in the above stages avoid the loss of essential information. The main limitation in applying these approaches is the certain complexity of calculations with Z-numbers, which is compensated for by the ability to process the imperfect information that is often present in complex decision-making tasks.

The results of the problem-solving process confirm the effectiveness of the Z-information-based scenario approach in addressing the energy transition challenge. This study's results show that the complexity of scenario development, analysis, and decision-making directly depends on the number of resources, the choice levels for alternatives, and the number of criteria used for the scenario evaluation. A rule-based intelligent system will be preferable if the numbers of interchangeable resources, production levels, and corresponding decision rules for composition and scenario assessments increase significantly.

In this paper, we studied the energy transition task for a single time horizon. Given that, in general, the energy transition spans a number of successive decades, it would be useful to consider multiple adjacent periods for energy transition tasks in future research and to study opportunities for extending the developed approach to multiperiod decision-making tasks. It should be noted that the approach developed in this paper is general and can be effectively applied to solve tasks related to the selection of interchangeable resource mixes in various areas.

6. Conclusions

The paradigm of sustainable development and environmental protection forces developed and developing countries to accelerate the transition to environmentally friendly green energy. The content of the energy transition program, its time frame, and the pace of transition are fundamentally based on the country's position in the energy market and the role of energy resources in its economy. The energy transition task becomes notably more difficult for developing countries that produce oil and gas, where these resources are decisive for economic development, well-being, and growth. These circumstances require a well-adjusted compromise between traditional and green energy resources during the transition period, gradually replacing environmentally unfriendly resources with renewables. The long-term nature of this task, the uncertainty of the decision-making environment, and the imperfectness and incompleteness of the information related to the formulation and solution of the problem make it much more challenging to develop a practical approach to solving the problem. Given these peculiarities, we formulated the transition task as a multistage fuzzy decision-making problem with uncertain and imperfect information. This allows for formalizing potential energy transition paths as fuzzy scenarios based on experts' knowledge and opinions.

According to the Azerbaijan Energy Profile by the IEA (2023), renewable energy sources, including hydro, contributed 1.5% of the total energy supply in 2022 and 6% (1.8 TWh) to electricity generation. Moreover, approximately 50% of the GDP, the state budget, and 90% of exports are derived from oil and natural gas revenues. In comparison to oil, natural gas is less environmentally harmful. Given this circumstance and the role of natural gas in the country's economy, it was retained as a potential energy resource, alongside renewables, for the transition period.

Considering the importance of reliable long-term solutions for the energy supply and the inherent high degree of uncertainty associated with this task, an approach using Z-number-based reasoning and Z-extensions of MCDM methods was adopted. Three different methods were applied to solve the problem and improve the adequacy and reliability of the solutions. The sensitivity of the solutions was also examined using different solution methods and variations in weight coefficients.

The solutions prioritize a significant increase in solar and wind energy production, along with a moderate increase in hydro and natural gas. The key advantages of the developed approach are the ability to operate with incomplete information; the flexibility provided by the variability of the linguistic terms used, alternative sources, and scenarios; the multidimensionality of the analysis enabled by the multi-criteria approach; and the applicability of the approach in a wide range of areas where it is necessary to select a set of interchangeable resources from various possible options.

The procedures for generating Z-number-based rules and scenarios, synthesizing the decision matrix using IF–THEN rules, applying Z-extensions of multi-criteria solution methods, and selecting scenarios are largely universal. In other applications, they require only the consideration of subject-specific factors when developing rules and the decision matrix. A detailed and justified description of the developed approach in the Methodology section, supported by an illustration of the procedure for solving the energy transition task using the example case of Azerbaijan, creates all the necessary prerequisites for the successful application of this approach to solve similar transition problems in other areas and applications.

The findings of this research are of interest to energy sector policymakers and researchers tackling the challenge of selecting a mix of interchangeable resources under the high degree of uncertainty in the decision-making environment.

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Abbreviations

Abbreviation	Full Term
GDP	Gross Domestic Product
MCDM	Multi-Criteria Decision-Making
TOPSIS	Technique for the Order of Preference by Similarity to the Ideal Solution
PROMETHEE	Preference Ranking Organization Method for the Enrichment of Evaluations
SAW	Simple Average Weighted
EU	European Union
RES	Renewable Energy Source

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