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Multi-Criteria Decision-Making for Ranking Renewable Energy Sources: A Case Study from the Republic of Serbia

Nabankur Mandal[1], Pallab Sarkar[2], Nikola Petrović[3*]

[1] Department of Mechanical Engineering, MCKV Institute of Engineering, 711204 Howrah, India
[2] Elitte College of Engineering Sodepur, 700113 Kolkata, India
[3] Faculty of Mechanical Engineering, University of Niš, 18000 Niš, Serbia

[*] Correspondence: Nikola Petrović (petrovic.nikola@masfak.ni.ac.rs)

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Abstract: Energy remains a cornerstone of national economic development and societal advancement. However, the current trajectory of global energy production—dominated by fossil fuels and driven by escalating demand—is environmentally unsustainable. Electricity, as a versatile and high-grade form of energy, offers the advantage of being generable from both conventional and renewable sources. Nevertheless, fossil fuel–based electricity generation continues to contribute significantly to local and global environmental degradation. In response to the dual imperatives of meeting rising energy demand and reducing greenhouse gas emissions, the identification and prioritisation of sustainable electricity generation technologies have become imperative. Renewable energy sources (RES)—such as solar, wind, hydro, and biogas—offer viable alternatives, yet their relative merits must be evaluated through a rigorous and systematic approach. In this study, a multi-criteria decision-making (MCDM) framework has been employed to assess and rank RES in the Republic of Serbia. Key evaluation criteria have included construction cost, payback period, ecological impact, annual generation capacity, and potential for integration with alternative energy modes. The assessment has been conducted using the FANMA method (a novel hybrid technique named after its developers) and the Weighted Aggregated Sum Product Assessment (WASPAS) method, both of which are established tools for handling complex decision-making scenarios. The findings have provided a data-driven basis for prioritising renewable energy technologies in national energy strategies. The insights derived are expected to inform policy decisions in Serbia and offer a transferable framework for energy planning in other developing economies aiming to transition towards more sustainable power generation systems.

Keywords: Renewable energy; MCDM; FANMA; WASPAS; Solar power plant; Wind power plant; Biogas plant; Small hydropower plant

1 Introduction

Energy plays a key role in the country's economic development, with scientific research showing a strong correlation between economic growth and electricity consumption. Over time, excessive dependence on fossil fuels has led to significant negative impacts on the environment. According to a report by the Intergovernmental Panel on Climate Change [1], by the end of the 21st century, global temperatures could rise by 6 to 7 degrees due to the increased use of fossil fuels. Choosing alternative energy sources requires consideration of multiple dimensions and different parameters at various levels. The growing number of inhabitants and the rising level of pollution indicate a heightened need for alternative energy sources. In particular, global energy demand is expected to grow by about 1% per year until 2040 [2]. Current reports suggest that approximately one billion people worldwide still lack access to electricity. However, significant progress has been made in recent decades in the transition to RES, as evidenced by advances in photovoltaic wind microgrids for electricity generation [3].

As the dynamics of fossil fuel consumption and the constant increase in their prices continue to rise, while their reserves stagnate, the question of utilizing alternative energy sources is increasingly being raised. Despite progress, energy production from renewable sources has not yet kept pace with the steady growth in demand. To tackle the climate crisis and ensure environmental sustainability, many countries are actively pursuing RES. This transition from traditional fossil fuels to cleaner energy sources poses a major challenge, especially for economies dependent on fossil fuel exports. RES, including solar, wind, hydro, geothermal, tidal energy, and biomass (Figure 1), are natural sources that replenish faster than they are consumed [4]. Renewable energy technologies are gaining importance in addressing global energy challenges and mitigating climate change effects. Although the use of RES has increased significantly in recent years, it has not been able to fully meet all global energy needs [5].

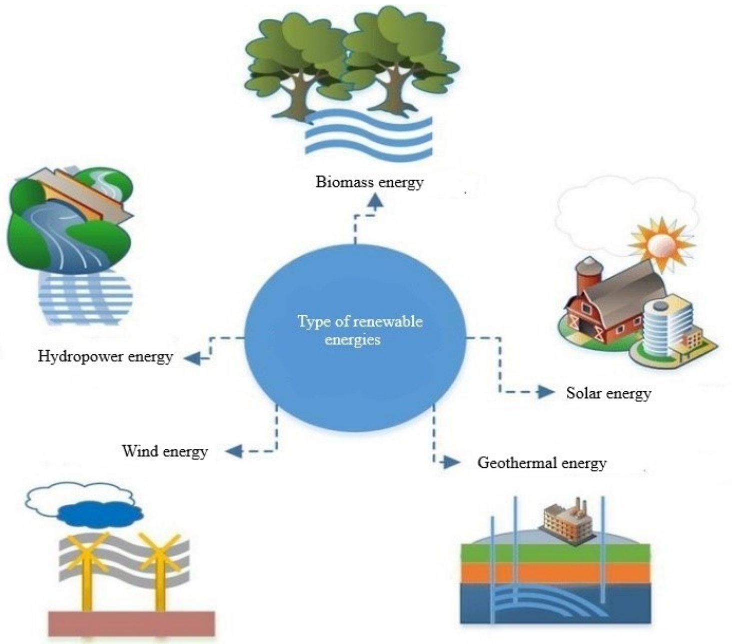

Figure 1. RES

Within the global efforts to achieve the Sustainable Development Goals (SDGs) defined by the United Nations, the period from 2020 to 2030 represents a critical timeframe [6]. Goal 7, which is about ensuring affordable, reliable, sustainable, and modern energy for all, is particularly important. This goal encompasses three key aspects: universal access to energy services, increasing the share of RES in total energy consumption, and strengthening international cooperation in the field of energy technologies [7]. According to these definitions, RES have a central role in the implementation of the goals set by 2030, as they are directly linked not only to Goal 7 but also to other SDGs [8].

In Europe, the production of electricity from renewable sources has been encouraged for many years through subsidized electricity sales prices, tax breaks, etc.

The Republic of Serbia belongs to the richest countries with wind [9]; it was established that annually in our country winds blow from 2250 to 3750 hours suitable for the nominal power of the wind power plant. In addition, the geometeorological conditions are very favorable because there are enviable expanses in the plains and on the tops of hills.

The selection of a high-renewable energy system is a complex decision-making process, driven by a variety of factors, such as economic feasibility, environmental impact, technological compatibility and regional specificities [10]. Furthermore, the assessment criteria are often intertwined, while the objectives themselves may conflict with each other. Conventional decision-making approaches, which rely solely on intuition or simple cost-benefit analyses, are insufficient to adequately capture these complexities. Therefore, the need for a structured and systematic methodological framework that allows for a comprehensive evaluation of RES system alternatives is more important than ever.

The global demand for climate change mitigation and the transition to sustainable energy solutions has placed the renewable energy sector at the very center of energy policy and investment strategies. Systems based on a high share of RES, such as wind, solar, hydropower, and biomass, represent a promising model for reducing greenhouse gas emissions and improving the environmental sustainability of the energy sector. However, the success of their implementation depends on the precise selection of the most optimal system configuration, a process accompanied by numerous challenges and subtleties.

Mini hydropower plants represent a significant segment of RES, with particular importance in decentralized electricity supply [11]. Depending on the national regulation and context, mini hydropower plants are most often defined as plants with a capacity of up to 10 MW. Their main characteristic is the use of the natural flow and fall of water for the production of electricity, with a minimal impact on the environment compared to large hydroelectric plants.

Wind power plants, i.e., wind farms, represent one of the key types of use of RES based on wind energy [12]. They form integrated wind turbine systems that convert the kinetic energy of the wind into electrical energy. In modern energy strategies, wind farms are recognized as key actors in the process of decarbonizing the energy sector and reducing dependence on fossil fuels.

Solar power plants represent one of the most important types of use of RES, based on the direct conversion of solar energy into electricity [13]. Their application is becoming increasingly important in modern energy systems, due to global efforts to reduce the share of fossil fuels and increase energy efficiency, while simultaneously preserving the environment.

Biogas power plants represent a significant segment of RES, with a special emphasis on the circular economy and sustainable management of biomass [14]. By using organic waste and biomass for the production of biogas, these power plants enable the production of electricity and heat, while at the same time solving the problem of waste disposal and reducing the emission of gases with the greenhouse effect.

MCDM methods enable the resolution of complex energy planning issues with minimal requirements [15, 16]. They ensure transparent and objective decision-making in the selection of sustainable energy alternatives by providing a structured and rigorous process for evaluating alternatives based on multiple criteria and objectively assessing the importance of each criterion [17]. MCDM approaches are crucial for the selection of RES because they provide a systematic and structured way to evaluate and compare multiple criteria and objectives. In the field of energy, MCDM is of particular importance for sustainability assessment, integration of RES, environmental management, and planning of infrastructure projects.

Although the single-criteria approach is still applicable in smaller and simpler systems, the modern energy sector is characterized by numerous objectives and criteria that are often in conflict with each other. This requires a holistic approach that encompasses technical, economic, social, and environmental parameters. Therefore, the application of multi-criteria analysis (MCA) is necessary to ensure sustainable development and support strategic decision-making processes in complex systems.

This paper aims to identify the most suitable renewable energy source at the state level using the FANMA and WASPAS methods, taking into account environmental, economic, and technological criteria.

2 Review of Relevant Literature

Many countries still rely heavily on fossil fuels such as coal and oil to meet their energy needs. However, dependence on these limited resources comes at a high environmental cost. The combustion of fossil fuels releases harmful greenhouse gases, contributing to global climate change and air pollution [18]. The continued high exploitation of non-RES poses serious risks to humans, with the Earth's average temperature rapidly increasing [19]. One solution is to remove fossil fuel subsidies to reduce wasteful energy consumption and to use more reliable and environmentally friendly energy solutions.

Energy is the foundation of industrialization and the key to the development of any nation. The dramatic increase in energy needs, driven by industrialization, economic development, and population growth, has led to an increased demand for energy sources. To meet this growing demand and, at the same time, mitigate global challenges such as climate change, RES are gaining increasing importance. Various factors contribute to this growth, including the reduction of operating costs and the reduction of greenhouse gas emissions. To achieve an optimized outcome, it is necessary to take into account all the key parameters that influence decision-making. MCDM is one of the most reliable and efficient tools for making decisions based on multiple criteria that characterize the adopted alternatives. This approach focuses on prioritizing the available alternatives within the decision space by taking into account the influential factors (or parameters) and their relative importance in the overall decision-making process. Since the analysis performed using the MCDM method uses algorithms to generate results, the application of the MCDM approach to identify key criteria that are essential for renewable energy technology systems is emphasized. Therefore, it is becoming increasingly important to meet the ever-increasing energy demands in order to achieve sustainable development [20].

However, the planning, management, and evaluation of RES projects is a complex undertaking that must include numerous criteria (potentials, constraints, legislation, etc.) as well as many stakeholders who often have conflicting interests, which can lead to a conflicting framework.

Alizadeh et al. [21] provided a framework for renewable energy systems, which includes the identification of constraints that hinder the use of RES. When designing policies for RES, the key factors are their low cost, sustainability, and efficiency. Solar energy, in particular, has proven to be one of the most efficient sources of electricity production. Various renewable energy technologies are being explored to meet the growing demand for sustainable energy, including in the transport sector, which accounts for almost a quarter of total carbon dioxide emissions. Electric vehicles, with the potential for zero emissions, are seeing annual demand growth of around

185%. Given this surge in demand, it is necessary to pay attention to how the global electricity demand will be met.

Bohanec et al. [22] pointed out several factors that are suitable for choosing an energy production system. The complexity and diversity in energy planning cannot be solved by traditional single-objective optimization techniques, which create a significant challenge for the decision-maker. Also, energy planning becomes more complicated due to geographic and topographical limitations. Therefore, MCDM tools were considered unbiased and effective methods to address these limitations.

Qian et al. [23] applied Fuzzy AHP and TOPSIS for site selection for photovoltaic and solar thermal energy production. Wang et al. [24] conducted an analysis based on investment costs, CO2 emissions efficiency, maintenance costs, land use, and job creation.

The paper [25] aims to identify the most suitable renewable energy projects at the regional level, taking into account environmental, economic, technological, and social criteria. In this regard, an innovative hybrid fuzzy MCDM model was applied, which includes the Multi-criteria Optimization and Trade-Off Solution (VIKOR) methods, distance measurement from the average solution, and the additive relationship analysis method. A fuzzy version of Shannon entropy was used to determine the weights of the criteria. This approach includes the creation of an integrated database on RES, based on information collected through field research and statistical analysis. All collected data were entered into Geographic Information System (GIS) software, which enabled the identification of alternative locations with high potential for the application of RES. The North Khorasan province was selected as the study area. The results obtained indicate that, out of the 30 sub-criteria analyzed, the most significant are social acceptance, net present value, and noise level. Projects focused on solar energy took the leading place, while small hydropower ranked second. In addition, the location analysis shows that the city of Jayarm is the most suitable point for the development of renewable energy projects.

In literature [26], MCDM methods were applied to determine the best alternatives, such as solar photovoltaic (PV), concentrated solar power (CSP), wind power, hydroelectric power, and biomass, as options for sustainable electrification of Benin. Eighteen criteria were used in the study to evaluate the alternatives. Subsequently, the importance of the criteria was determined using the correlation between criteria (CRITIC) and entropy methods, which were used to calculate the weights of the criteria, and then included in the evaluation process using the distance-to-average solution (EDAS) method to rank the alternatives. The results obtained by the EDAS method show that solar PV is the most optimal alternative, taking first place, while wind power is ranked second. CSP, hydroelectricity, and biomass ranked third, fourth, and fifth respectively.

Due to its advantages such as ease of use, the existence of many software tools that facilitate and speed up the application of this method, as well as the possibility of performing a sensitivity analysis, in the paper [27] the Analytic Hierarchy Process (AHP) was chosen for the evaluation of solar, wind turbine, PV and biomass sources in Kosovo. Based on the obtained results, the first position is occupied by the hydro alternative. Also, a sensitivity analysis was performed, which showed that the ranking changes only outside the allowed values, which allows the conclusion that the obtained results are relevant.

MCDM methods have become increasingly popular in deciding the location of renewable energy power plants, as they take into account multiple conflicting goals and preferences of decision-makers. In the paper [28], a systematic review of the literature on the application of MCDM methods for the selection of locations for RES was carried out, including a total of 85 papers published from 2001 to 2018 in high-ranking journals. Different energy sources were found to emphasize different criteria; however, there are certain similarities. The most frequently used method for the selection of criteria is literature research and experts' opinions.

The paper [10] addresses a key question, proposing an innovative approach based on the application of MCDM techniques to optimize the HRES system selection process. Specifically, the integration of three prominent MCDM methods is analyzed: AHP, Top-of-Purpose Similarity Ranking Technique (TOPSIS), and Multi-Criteria Optimization Based on Relationship Analysis (MOORA). Combining these methods allows for the formation of a reliable framework that provides decision-makers with an objective basis for evaluating, ranking, and selecting the most appropriate HRES system alternatives, taking into account the complexity of criteria and objectives. The research aims to bridge the gap between renewable energy ambitions and informed decision-making, thus contributing to building an energetically sustainable and environmentally friendly future. A detailed analysis of the results shows that the solar with battery configuration is a reliable choice within both approaches, making it a promising option in the energy planning process.

3 Decision Support Methodology and Input Parameters

3.1 MCDM Approach

MCA is an integrated system evaluation method that facilitates decision-making in the presence of multiple conflicting goals and diverse data and interests from various stakeholders [29, 30]. This approach is particularly effective for addressing complex problems in energy management and sustainable development. Unlike the traditional single-criteria method, which primarily focuses on minimizing costs, MCA introduces multidimensionality and allows for the simultaneous consideration of economic, environmental, technical, and social aspects.

Energy is a fundamental prerequisite for the advancement of modern economies and societies. Sustainable energy sources are increasingly important and gaining traction within the energy systems of many countries. However, assessing and selecting between different RES necessitates analyzing numerous criteria, constraints, legal regulations, and similar factors. Consequently, MCDM methods are frequently utilized in both literature and practice to evaluate renewable energy system projects and technologies.

The development of decision-making concepts has become particularly evident since the 1980s, when rising environmental awareness prompted a paradigm shift, leading to the acceptance of a broader range of criteria, with an emphasis on global environmental protection and the rational use of resources. Contemporary energy systems increasingly depend on MCA as a means of integrating RES and planning sustainable energy projects. The MCA process consists of four primary phases. The first phase involves defining alternative solutions and identifying relevant criteria for evaluation. The second phase focuses on determining the weights of these criteria, thereby highlighting their relative importance [31]. This is followed by the evaluation of alternatives against the selected criteria. The final phase entails aggregating the results and selecting the best option. If the various MCA methods yield consistent results, the process is considered complete; otherwise, the analysis is repeated to achieve consistency. Each step aims to ensure transparency, systematicity, and objectivity in decision-making while considering all relevant sustainability aspects.

The value of MCA lies in its ability to provide compromise solutions [32]. Since there is no absolute best alternative that can satisfy all criteria simultaneously, MCA seeks to identify the option that best balances various interests and goals. In doing so, the emphasis is on integrating the preferences of all stakeholders in the decision-making process. Currently, many countries are implementing policies to develop RES, leading to an increase in applications for these resources. Renewable energy is expected to play a crucial role in the future global energy supply. However, there are several challenges associated with the development of RES. Some of the key issues include prioritizing resources, selecting appropriate options, and determining the location and capacity of plants. Growing environmental concerns, depletion of reserves, and high energy prices are driving the search for RES. These sources are either non-polluting or cause minimal harm to the environment. Additionally, they are widely distributed and well-suited for local development and use. Unlike the potential depletion of fossil fuels, RES are inherently recyclable.

In Europe, the production of electricity from renewable sources has been supported for many years through subsidized electricity sales prices, tax breaks, and other incentives. As a result, numerous facilities have been established, and in some countries, the natural hydro potential has been nearly fully utilized. Specifically, regarding the Republic of Serbia, considering the geomorphological and hydrological characteristics of the terrain, the hydropower potential is estimated to be around 31,000 GWh per year [33].

3.2 Alternatives and Criteria

Decision makers must consider both qualitative and quantitative factors (indicators, criteria), as well as environmental aspects, to use RES safely, sustainably, and efficiently.

For this purpose, relevant MCDM methods have been developed to help solve complex problems [34–36]. These methods, based on operations research, address decision problems when there are different competing goals, such as conflicts between criteria, different parameters, and challenges in designing and selecting alternatives.

The Republic of Serbia's alternative energy resources include utilizing secondary raw materials such as biogas, and energies from hydro, solar, and wind. These resources can significantly reduce the gap between energy demand and supply in the Republic of Serbia and enhance electricity generation capacity.

To ensure objective decision-making in selecting the most appropriate alternative (Table 1), the establishment of well-defined and thoughtfully developed criteria is essential. Carefully formulated selection parameters contribute to transparency and acceptance in the decision-making process.

Table 1. The renewable energy alternatives

Alternative	No.
Mini hydropower plant	A_1
Wind power plant	A_2
Solar power plant	A_3
Biogas power plant	A_4

A_1 - Mini hydropower plants operate on the principle of converting the potential energy of water into mechanical energy using turbines, which are then transformed into electrical energy through a generator. Key components of the system include the inlet channel or pipeline, the turbine, and the generator, as well as the flow regulation and system control infrastructure. Different types of turbines are employed depending on the available water flow and head, with the most common being Francis, Pelton, and Kaplan turbines. One of the main advantages of mini hydropower plants is their relatively low environmental disruption compared to large hydropower projects. They occupy less space and do not require the creation of large storage lakes, which minimizes negative impacts on biodiversity, local communities, and microclimates.

Additionally, mini-hydroelectric plants enable local energy production, thereby contributing to energy security and reducing losses in transmission networks. Another significant advantage is the stability of electricity production, since, unlike solar and wind power plants; mini hydropower plants are less susceptible to weather variations. Their longevity and low operating costs further justify the initial investment, especially in regions with favorable hydrological conditions. Although they are more environmentally friendly than large hydroelectric plants, mini hydropower plants have their drawbacks. Inadequate planning and construction can disrupt the natural flow of rivers, diminish biological diversity, degrade aquatic habitats, and alter sedimentary regimes.

Mini hydropower plants represent significant potential for sustainably increasing the share of RES in the overall energy balance. However, their construction and operation require careful planning, thorough environmental impact assessments, and active stakeholder involvement to ensure their contribution to the energy transition is economically viable, socially acceptable, and environmentally sustainable.

The cost (construction + installation) of a small hydroelectric power plant with a capacity of 1 MW is worth \$ 2-5 million. If we assume \$ 3 million investment [37], the profit from it is about 400000 dollars a year, and the payback period of capital investments is 7 years. For the operation of a mini hydropower plant, with a nominal electrical power capacity of the system of 1 MW, the head of the water flow should be H = 120 - 125 [m], with a water supply of Q(v) = 1 [m^3/s] or similar (H = 250 [m], with Q(v) = 0.5 m^3/s). The cost of electricity generated by the mini hydropower plant is about 0.045 - 0.05 [\$/kWh].

A_2 - Wind power plant. The main component of the wind farm is the wind turbine, consisting of a rotor with blades, a nacelle containing the generator and transmission mechanisms, and a support column. Wind turbines in modern wind farms have capacities ranging from several hundred kilowatts to several megawatts per unit. Wind farms can be built on land (onshore) or at sea (offshore). One of the key advantages of wind power plants is that wind energy is a renewable and practically inexhaustible source of energy, with minimal greenhouse gas emissions during operation. Therefore, wind farms positively impact the reduction of total carbon dioxide emissions, aligning with SDGs and international climate change agreements.

Additionally, the development of wind farms contributes to the diversification of energy sources and enhances energy security. The construction of wind farms also brings about a positive socio-economic effect by creating jobs in the design, construction, maintenance, and management phases of the facilities.

However, despite numerous advantages, developing wind farms faces certain challenges. First, electricity production from wind depends on variable meteorological conditions, which can affect the stability of the power system. Effective integration of wind farms with the existing transmission network and the development of energy balancing and storage systems are essential. Environmental challenges include potential negative impacts on birds and bats, landscape changes, and low-frequency sound emissions.

In the context of the global energy transition, the intensive development of wind farms is expected to continue, alongside improvements in the efficiency of wind turbines and reductions in investment costs. Contemporary trends include applying digital technologies to optimize wind farm operations, enhance predictive maintenance, and develop hybrid systems in combination with batteries or other renewable sources.

Wind farms play a crucial role in modernizing the energy sector and achieving climate neutrality goals. Their further development must be accompanied by careful planning, environmental assessments, and local community involvement, along with continuous technological advancements to address system stability and environmental protection challenges. The cost of a small wind power plant with a capacity of 1 MW is approximately \$ 1.3 million [38]. The annual operational and maintenance costs range between 42000 and 48000 dollars. A 1 MW wind power plant generates about 2000 MWh of electricity annually, with a payback period for capital investments of 5 to 6 years.

A_3 - Solar power plants operate based on the PV effect, where solar panels, made of semiconductor materials (most often silicon), convert solar radiation into electrical energy. The basic elements of a solar power plant include PV modules, inverters (which convert direct current into alternating current), production monitoring systems, and energy storage systems (batteries).

There are two main categories of solar power plants: decentralized (small, often placed on the roofs of buildings and households) and centralized (large solar farms connected to transmission networks). In light of high electricity demands and decarbonization efforts, large-capacity centralized solar power plants are becoming increasingly important.

One of the key advantages of solar power plants is the inexhaustibility of solar energy, along with its universal availability. They do not emit greenhouse gases during operation, thereby contributing directly to reducing carbon dioxide emissions and combating climate change. Furthermore, solar power plants have low operating and maintenance costs, as well as a long service life for PV panels (averaging 25 to 30 years). Their modularity allows for easy adaptation to varying requirements, from small autonomous systems to large commercial plants.

Despite their numerous advantages, the application of solar power plants faces certain limitations. The primary challenge is the intermittency of production, as electricity generation is directly dependent on weather conditions and day/night cycles. This necessitates the development of energy balancing and storage systems to ensure the stability of the power system.

Additional challenges include high initial investment costs, although there has been a downward trend in technology prices in recent years. Establishing large solar farms can also require significant land areas, which may lead to land use conflicts, particularly in agriculturally developed or environmentally sensitive areas.

In the context of global climate policies and technological advancements, solar power plants are becoming central in plans for transitioning to sustainable energy systems. Future technology development aims to increase solar cell efficiency, reduce production costs, and enhance energy storage capacity.

Solar power plants offer a sustainable solution for increasing electricity production from renewable sources, with minimal environmental impact. Their broader implementation necessitates further investments in infrastructure, storage, and system digitization, but the potential they present for energy transition and climate neutrality makes them a crucial component of future energy strategies.

The cost of a solar power plant with a capacity of 1 MW ranges from $ 0.8 million to $ 1 million [39]. If we use 200-watt solar panels, that requires at least 5,000 panels for 1 MW. For 4 hours of sunshine a day, this amounts to 1,440 hours per year, resulting in 1,200 to 1,500 MWh of electricity per year. The payback period for capital investments is estimated at 5 to 6 years.

A_4 - Biogas power plants function on the principle of anaerobic digestion, the process of decomposition of organic matter without the presence of oxygen, whereby microorganisms produce biogas - a mixture of carbon dioxide (CO_2) and methane (CH_4), whereby methane has a high energy value. Various types of biomass are used as raw materials for the production of biogas: agricultural waste, manure, residue from the food industry, municipal biowaste, and even certain types of energy crops.

The produced biogas is most often used to drive gas engines that drive generators for the production of electricity. Additionally, waste heat from the process can be used for heating, thus increasing the overall efficiency of the system (cogeneration). Purified biogas can also be used as biomethane, the equivalent of natural gas, for use in transport or distribution through the gas pipeline network.

Biogas power plants offer multiple advantages. First of all, they enable the production of energy from locally available resources, thereby contributing to energy independence and diversification of sources. One of the key environmental advantages is reflected in the reduction of methane emissions, which would otherwise be released by the decomposition of waste in landfills, and the reduction of carbon dioxide emissions through the use of renewable fuel.

In addition, digestate - a by-product of anaerobic digestion - is a high-quality organic fertilizer that can replace chemical fertilizers, thereby contributing to sustainable agriculture. Biogas power plants also create local jobs and encourage the development of rural areas, especially in agriculturally developed regions.

Despite the mentioned advantages, the development of biogas power plants faces certain challenges. One of the key problems is the high initial investment, which includes the costs of building digesters, gas engines, gas purification systems, and infrastructure connections. Additionally, the successful operation of a biogas plant depends on a continuous and reliable supply of raw materials, which can be challenging due to seasonal variations or insufficiently developed waste collection chains.

The cost of a biogas power plant with a capacity of 1 MW is worth $ 4.5 million [40]. Biogas power plant of 1 MW gives about 8000 MWh electricity per year, but can also give additional big amount of heat energy. Biogas plant employs from 10 to 15 workers, and has an additional operating cost for workers. The payback period of capital investments is 5-6 years. By the purification of biogas (instead of production electricity), biomethane is produced which can be pumped into the gas network (natural gas pipelines network).

This research employs seven distinct criteria (Table 2), encompassing economic, technical, and environmental aspects, to assess the performance of the available alternatives.

When defining the decision-making matrix, one often encounters a situation in which the criteria values for each alternative are expressed qualitatively. In such cases, the challenge arises of how to compare the qualitative with the quantitative values of the criteria. In order to overcome this problem, the process of quantification of qualitative criteria is applied, that is, their transformation into numerical values.

There are different methods for converting qualitative attributes into quantitative ones:

• Ordinal scale – enables the ranking of alternatives without considering the relative differences between individual ranks;

• Interval scale - ensures equal distances between criteria values and enables measurement of differences or deviations to a previously defined reference level;

• Ratio scale – allows for equal spacing between criteria, where differences are measured from a certain reference level that is not set in advance.

Given that the interval scale is most often used in practice, in this research this method is applied for the conversion of qualitative values into quantitative ones. The range of values within the scale ranges from 1 to 9, while the values 0 and 10 are not included, since the minimum and maximum values of the observed criterion are not explicitly defined (Table 3) [41].

Table 2. Criteria for RES

Criteria	No.	Criteria Unit
Cost (construction and installation)	f_1	kW, thous.
Payback (period of capital investments)	f_2	year
Energy output per MW annually	f_3	MWh
Environmental impact	f_4	-
Continuous 24 h operation	f_5	-
Annual production stability	f_6	-
Capability to generate alternative energy forms	f_7	-

Table 3. Saaty's scale

Qualitative Value	Poor	Low	Average	High	Very High	Criteria Type
Quantitative value	1	3	5	7	9	Max
	9	7	5	3	1	Min

The values of criteria f_4, f_5, f_6, and f_7 for the adopted alternatives were derived from the author's assessment, as well as from data and information from studies [9–14, 37–40](Table 4).

Table 4. The starting matrix utilized for determining the renewable energy source

	f_1	f_2	f_3	f_4	f_5	f_6	f_7
	min	min	max	max	max	max	max
A_1	3.5	7.5	3500	1	8	7	1
A_2	1.3	6	2000	5	6	6	2
A_3	1	5.5	1350	6	5	5	4
A_4	4.5	6.5	8000	8	9	8	8

4 Implementation of the Approach and Analysis of Findings

4.1 FANMA Method

The FANMA method calculates criteria weighting coefficients by utilizing the principle of distance from an ideal point, a process known as early weight normalization. This methodology relies on the concept of ideal point proximity and weighted normalized values. Initially, all values undergo normalization to ensure comparability. Each element within the decision matrix is adjusted to fit within a standardized range from 0 to 1, ensuring that all criteria share a consistent scale.

Normalization for maxim criteria [42, 43]:

$$x_{ij} = \frac{\mathrm{a}_{ij} - a_j^{\min}}{a_j^{\max} - a_j^{\min}}, i = 1, 2, \ldots, n; j = 1, 2, \ldots, m; \tag{1}$$

Normalization for minimizing criteria [43, 44]:

$$x_{ij} = \frac{a_j^{\max} - \mathrm{a}_{ij}}{a_j^{\max} - a_j^{\min}}, i = 1, 2, \ldots, n; j = 1, 2, \ldots, m; \tag{2}$$

where, $a_j^{\max} = \max\{a_{1j}, a_{2j}, \ldots, a_{nj}\}; a_j^{\min} = \min\{a_{1j}, a_{2j}, \ldots, a_{nj}\}$

Through this normalization process, the decision matrix is transformed into a weighted matrix. The ideal solution is represented as a hypothetical alternative that embodies the most favorable criteria values. The squared distance serves as a measure of each alternative's deviation from the ideal point [42, 43].

$$g_i = \sum_{j=1}^{m} w_j^2 \left(x_j^* - x_{ij}\right)^2, i = 1, 2, \ldots, n \tag{3}$$

After performing the necessary calculations, the final vector is derived, which is then used to establish the weighting coefficients [42, 43].

$$w_j^* = \frac{1}{\left[\sum_{i=1}^{n} \left(x_j^* - x_{ij}\right)^2\right] \left[\sum_{j=1}^{m} \frac{1}{\left[\sum_{i=1}^{n} \left(x_j^* - x_{ij}\right)^2\right]}\right]} \tag{4}$$

4.2 WASPAS Method

The WASPAS method uses a hybrid approach, which includes a weighted sum and a weighted product to rank alternatives. The algorithm consists of the following steps [44]:

Step 1: Formation of the decision matrix

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{5}$$

where, x_{ij} is the value of alternative i according to criterion j.

Step 2: Matrix normalization

The values in the decision matrix are normalized depending on the type of criteria:

• maximizing criteria (bigger is better):

$$r_{ij} = \frac{\mathrm{x}_{ij}}{\max x_{ij}} \tag{6}$$

• minimizing criteria (less is better):

$$r_{ij} = \frac{\min \mathrm{x}_{ij}}{x_{ij}} \tag{7}$$

Step 3: Calculation of Q_i value

$$Q_i = 0.5 \sum_{j=1}^{n} w_j \cdot r_{ij} + 0.5 \prod_{j=1}^{n} r_{ij}^{w_j} \tag{8}$$

The first member represents the Weighted Sum Model (WSM), which calculates the weighted sum of the alternatives' values. The second member represents the Weighted Product Model (WPM), which calculates the weighted product of the alternatives' values. By combining these methods, WASPAS enhances decision accuracy and minimizes subjective errors. The alternatives are ranked according to the resulting Q_i values, with a higher value indicating a better alternative.

4.3 Implementation of the MCDM Approach and Results

After forming the initial decision matrix and using Eqs. (1) and (2), Table 5 is obtained, i.e., the normalized matrix of the FANMA method.

Following the implementation of the FANMA method and the use of Eqs. (3) and (4), the values of square distance and weighting coefficients are obtained (Table 6).

The calculation results of weighting coefficients, using the FANMA method based on Eqs. (1)-(4), were obtained through the MS Excel software, that the f_2 - Payback (period of capital investments) (0.336) is the most important criterion in the evaluation system. After that comes a criterion: f_4 - Environmental impact (0.178), f_5 - Continuous 24h operation (0.153), f_1 - Cost (construction and installation) (0.148), f_6 - Annual production stability (0.126), and f_7 - Capability to generate alternative energy forms (0.039). Criterion f_3 - Energy output per MW annually has the smallest weighting coefficient (0.020), showing that this indicator has a minor impact on the evaluation process.

Table 5. The normalized matrix in the FANMA method

	f_1	f_2	f_3	f_4	f_5	f_6	f_7
	min	min	max	max	max	max	max
A_1	0.400	0.000	1.000	0.000	1.000	1.000	0.000
A_2	1.280	0.750	0.302	0.800	0.333	0.500	0.333
A_3	1.400	1.000	0.000	1.000	0.000	0.000	1.000
A_4	0.000	0.500	3.093	1.400	1.333	1.500	2.333

Table 6. Weight coefficients by the FANMA method

	f_1	f_2	f_3	f_4	f_5	f_6	f_7
g_i	2.974	1.313	21.736	2.480	2.889	3.500	11.222
w_j	0.148	0.336	0.020	0.178	0.153	0.126	0.039

Table 7. The normalized matrix in the WASPAS method

	f_1	f_2	f_3	f_4	f_5	f_6	f_7
	min	min	max	max	max	max	max
A_1	0.29	0.73	0.44	0.13	0.89	0.88	0.13
A_2	0.77	0.92	0.25	0.63	0.67	0.75	0.25
A_3	1.00	1.00	0.17	0.75	0.56	0.63	0.50
A_4	0.22	0.85	1.00	1.00	1.00	1.00	1.00

Creating the initial decision matrix by Eq. (5) and calculating the criteria weighting coefficients (Table 6) is the basis for using the WASPAS method. Using Eqs. (6) and (7), a normalized decision matrix was obtained (Table 7).

Using calculations according to Eqs. (5)-(8), the values of Q_i are obtained based on the WSM and WPM members (Table 8). The alternatives are ranked based on the obtained Q_i values, where a higher value indicates a more favorable option. This ranking method ensures a clear identification of the most suitable alternative according to the defined criteria (Table 8).

Table 8. Ranking by the WASPAS method

	WSM	**WPM**	$\mathbf{Q_i}$	**Rank**
A_1	0.571	0.453	0.5116	**4**
A_2	0.744	0.717	0.7307	**3**
A_3	0.804	0.768	0.7862	**2**
A_4	0.833	0.757	0.7948	**1**

According to the results (Table 8) derived from the WASPAS method for ranking RES in the Republic of Serbia, in MS Excel, the best alternative identified is A_4 - biogas power plant, the second place is reserved for A_3 - solar power plant, the third place is A_2 - wind power plant and the worst alternative identified is A_1 - mini hydropower plant.

Biogas power plants represent a sustainable solution that simultaneously responds to the energy, environmental and economic challenges of modern society. Their wider implementation requires a strategic approach that includes infrastructure development, stimulating investment, educating actors and establishing a regulatory framework that encourages the sustainable use of biomass for energy needs. Regulatory challenges include requirements related to waste management, emission standards and the certification of generated energy. On the ecological side, inadequate management of digestate can cause soil and water pollution. Also, local communities sometimes express concerns about possible unpleasant odors or impacts on the landscape. Global trends indicate the increasing potential of biogas power plants, especially in the context of decarbonization of agriculture, improvement of waste management and development of a circular economy. Innovations in the field of digestion, such as two-stage systems or combining them with municipal wastewater treatment, further improve the efficiency and sustainability of biogas plants. The introduction of incentive measures, guaranteed purchase prices and subsidies contributes to the economic profitability of these systems.

5 Conclusions

Although the role of energy policy is essential in addressing challenges, the creation of renewable energy strategies varies among countries, as both needs and objectives are specific to each nation. Despite the numerous implementations of policy measures aimed at promoting the use of renewable sources across sectors, significant geographical and local differences in the distribution of these resources persist. Therefore, the sub-national level is increasingly recognized as a crucial step in the development of RES and has become a significant issue in the context of regional development, as these resources are seen as solutions to environmental challenges and as means to accelerate economic progress at the local level.

In this context, this research aims to provide a comprehensive framework for decision-making, enabling governments and experts to identify RES and thereby support the achievement of SDGs at the subnational level.

With a growing population and ongoing industrial development, the Republic of Serbia will encounter increased energy demands. To meet these needs, there is interest in expanding electricity capacity for future demand. RES represent significant options that governments can explore when developing sustainable energy strategies. Prioritizing energy sources for the country's sustainable development necessitates a structured decision-making process.

This study aims to evaluate and rank RES in the Republic of Serbia based on multiple criteria, including investment costs, payback period, energy output per MW, environmental impact, and operational continuity. The analysis employs the FANMA and WASPAS methods to ensure a holistic assessment. The findings are crucial for prioritizing renewable energy investments and formulating policies in Serbia and other developing nations. Key alternative energy sources considered include biogas, hydropower, solar, and wind energy, all of which have the potential to enhance electricity generation and bridge the energy supply-demand gap.

It is recommended that the government develop a favorable policy and regulatory framework that includes tax incentives and subsidies to encourage investments in biomass, and also establish regulations that set standards for production, transport, and distribution. Investments in infrastructure development are essential, including processing plants and transmission lines, along with launching a public campaign to raise awareness of the benefits of biomass for sustainable development. The participation of private and public sectors in renewable energy technologies can become economically viable with state support and infrastructure development. Additionally, financing capacity building can stimulate the growth of solar and wind power in the Republic of Serbia.

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Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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