

Article

New Frontiers in Determining Criteria and Strategies in Rural Area Sustainable Development in Serbia: Fuzzy AHP Approach

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Abstract

Rural area sustainable development represents one of the main aspects of prosperity, enabling countries to strengthen their economy, improve living conditions, and create new opportunities for growth. Different criteria from the areas of economic sustainability, infrastructure and access to services, community participation and resource management, geographical location, and social sustainability were determined, and three appropriate multi-criteria decision-making methods were applied; the most significant sub-criteria for rural area development were diversification of the economy, connection with urban areas, and innovations in agriculture and tourism. Also, rankings of sub-criteria were performed, and the similarity of the rankings was checked, making the fuzzy AHP algorithms suitable for estimating the influence of factors on rural areas development. Based on the results obtained, some strategies of underdeveloped area economic growth and sustainable development were presented.

Keywords: rural areas; economy; economics; economic development; sustainable development; Serbia; management; Fuzzy AHP; triangular fuzzy number; spherical fuzzy set



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1. Introduction

Urban areas are characterized by a concentration of people in smaller spaces; well-developed infrastructure with networks of roads and public transportation; a diverse economy featuring industry and commerce; as well as excellent access to healthcare, education, and recreational spaces [1,2]. In contrast, rural areas are geographical regions located outside urban centers, such as cities and towns, generally with low population density and large open spaces. These areas are typically composed of settlements surrounded by forests and agricultural estates, often rich in tradition and cultural heritage, playing a significant role in society, the economy, and sustainable development. Comprising dispersed villages with limited access to various services such as public transportation, healthcare, and educational institutions, rural areas face numerous challenges in the fields of infrastructure, social welfare, and development [2]. Rural areas are primarily dependent on agriculture, livestock farming, and forestry, which form the foundation of their economy. The inhabitants of

these areas utilize land for the production of food and resources that are essential for the broader regions and cities. Therefore, the sustainability of agricultural production and the preservation of natural resources are critical for the survival of rural communities. However, rural areas face numerous challenges, such as poverty, population migration, inadequate infrastructure, insufficient education, and a lack of employment opportunities [3]. Educational and employment levels in rural areas are lower compared to urban areas, and many people lack access to modern services. Young individuals often migrate to cities in search of better living conditions, leading to a decline in the population of rural areas and exacerbating their demographic and economic issues. This population aging process becomes even more pronounced as older individuals remain in rural areas, while younger people move to urban centers. In rural regions, healthcare services are often insufficiently accessible, as hospitals and medical centers are typically located at a considerable distance, which can lead to delays in treatment and worsening health conditions. Furthermore, educational institutions may be remote, and the quality of education is often not on par with that found in urban areas [4,5]. One of the challenges faced by rural areas is rapid urbanization, which reduces agricultural land, destroys natural habitats, and creates issues with cultural and demographic resources [6]. In many parts of the world, rural areas are susceptible to urban expansion, leading to a decrease in food production and disruption of ecological balance. Sustainable rural development has become crucial for preserving natural resources and improving the quality of life within these communities. To achieve sustainable development, it is necessary to promote environmentally friendly agriculture, invest in infrastructure as well as educational and healthcare systems, and create new employment opportunities. In contemporary society, the development of rural areas, where life is centered around preserving values and traditions, has become a significant topic in government policies and international organizations' projects. Continuous efforts are being made to improve education, healthcare, and road quality and promote sustainable agricultural development. Rural development encompasses various sectors, including agriculture, forestry, tourism, industry, and digitalization. The adoption of new technologies, such as precision agriculture, can enhance food production efficiency and reduce its negative environmental impact. Additionally, the development of tourism can assist rural areas in diversifying their economies, creating new jobs, and attracting investments [7–9].

Although rural areas face numerous challenges, they possess significant potential for future development. With appropriate investments, innovation, and careful planning, they can become centers of sustainable development, providing a high quality of life for their residents while simultaneously preserving natural resources and cultural heritage. By developing sustainable practices, strengthening the local economy, and improving living conditions, rural areas can reduce migration to urban centers, revitalize communities, and create new opportunities for growth. In this process, the key role lies in the collaboration between government institutions, international organizations, and local communities as well as maintaining a balance between development and environmental protection.

Serbia, a country located in the Balkans, is predominantly rural, with approximately 85% of its total territory classified as rural according to OECD data [10]. After World War II, there was a division of settlements into urban, mixed, and rural, which proved useful in the process of developing and urbanizing villages. However, this approach was soon abandoned [11]. As there is currently no standardized methodology for classifying rural areas and the decision to define urban and “other” areas has been left to local authorities, a vague picture of the division between urban and rural settlements emerges [12]. As a result, both large, urbanized settlements near major cities and remote mountain villages with only a few residents fall under the same category. There are alternative methods of classifying areas within the Republic of Serbia. For instance, according to the NUTS 3

system (Nomenclature of Territorial Units for Statistics, level 3), based on a combination of OECD criteria, structural characteristics, development opportunities, and population density, there are three types of rural areas. Using PCA analysis and 41 variables, rural municipalities in Serbia have been classified into four types [7]. Similarly, in [13], four primary factors based on 15 variables are defined, which can be used to classify rural areas. In the paper [14], also using 15 variables, the authors define five types of rural and urban municipalities.

Rural areas around the world, including Serbia, are of significant importance for the economy, cultural heritage, and the preservation of natural resources. Although global urbanization is advancing rapidly, rural areas continue to play a crucial role in food production, the preservation of traditions, environmental protection, and supporting the development of local communities. In Serbia, where agriculture is a major sector, over 40% of the population lives in rural areas; however, these regions face numerous challenges.

Depopulation, particularly among the youth, is one of the most significant issues faced by rural areas. Many young people leave rural areas in search of better access to education, employment, and social opportunities in cities. As a result, elderly individuals make up the majority of the population in rural settlements, and the number of families is declining. These changes have long-term consequences on the demographic composition, economy, and quality of life in these areas. To combat depopulation, it is crucial to develop policies that encourage young people to stay in or return to rural communities, which includes improving economic opportunities, education, and social and healthcare infrastructure [7,15].

Agriculture has a long tradition in the rural areas of Serbia and remains a key component of the country's economy. Although agriculture is being modernized in many parts of the world, Serbia still has a large number of small farms that use traditional production methods. To achieve sustainable development in these areas, it is necessary to invest in the modernization of agriculture, including the adoption of ecological practices and new technologies. Sustainable agriculture encompasses techniques that reduce the negative environmental impact, preserve resources, and improve soil fertility while also enabling higher productivity [16]. Serbia has significant potential for organic farming, which can make its products more competitive in both domestic and international markets. Additionally, the use of technologies such as precision agriculture, automated irrigation systems, and drones for crop monitoring can significantly increase efficiency and reduce costs. By supporting these innovations, farmers can achieve higher yields, reduce the risk of diseases and pests, and decrease pesticide use, thus contributing to the preservation of ecological balance. Furthermore, it is essential to invest in the training of farmers, as education on sustainable practices can enhance productivity and preserve natural resources.

Another challenge faced by rural areas in Serbia is their dependence on agriculture. Economic diversification is crucial, and investments are needed in other sectors such as tourism, small businesses, craftsmanship, renewable energy, and even the IT sector. Tourism, based on natural beauty, cultural heritage, and tradition, can contribute to the development of rural areas. Ecotourism, rural households, and estates can attract visitors and create new jobs. Additionally, craftsmanship and local food production can generate additional income and preserve the tradition and identity of these areas, thereby contributing to both the economy and culture [17].

Developed infrastructure is vital for the sustainable development of rural areas. Many rural communities in Serbia face challenges such as poor roads, lack of water supply and sewage systems, energy supply issues, and weak digital connectivity, which hinder market access, increase the cost of living, and limit entrepreneurial opportunities. Enhancing market access for agricultural products and services from rural areas can improve com-

petitiveness. Rural communities should have better access to markets and easier access to financial resources, such as favorable loans and subsidies, which they can use to modernize their farms and businesses. Investments in infrastructure, such as improving roads, internet connectivity, and energy efficiency, can improve rural area life quality and help them become more competitive [18]. Furthermore, improving transportation links with urban areas facilitates the easier movement of people and products, which is crucial for economic stability.

Access to education and healthcare services in rural areas of Serbia remains a significant challenge. These key areas, along with social protection, are crucial for the creation of sustainable and prosperous rural communities. In many rural areas, schools and healthcare institutions face a lack of resources and qualified personnel. Therefore, it is essential to invest in educational and healthcare systems as well as in the provision of adequate social services, which can significantly improve the quality of life in these areas. Improving the educational system in rural areas as well as providing training for acquiring new skills are vital for preparing the population for market and technological changes [19,20]. Additionally, it is necessary to enhance access to healthcare services, as many rural communities lack well-developed healthcare systems and the distance to the nearest hospitals often prevents timely medical assistance.

The protection of natural resources; the preservation of land, forests, water, and biodiversity; as well as the reduction in pollution are essential for the long-term sustainable development of rural areas. Agriculture in rural areas can have a significant impact on ecosystems, and it is important to develop sustainable agricultural practices that reduce the use of chemicals and enable long-term soil fertility preservation. Sustainable resource use can create a balance between economic and ecological goals. Furthermore, the development of renewable energy sources, such as solar, wind, and biomass, can significantly contribute to reducing the negative environmental impact and increasing the energy efficiency of rural communities.

Multi-criteria decision-making (MCDM) has been widely used during recent years in research across various fields of science, particularly when there is a need to reorganize a multi-criteria problem. This process culminates in the selection of the most optimal or an alternative solution. MCDM provides a formal framework for modeling complex, multidimensional decision-making problems, particularly for situations requiring some analysis of systems, the examination of the complexity of the decision, the assessment of the consequences, and ensuring accountability for decisions made. By incorporating fuzzy MCDM (F-MCDM), an effective approach is available for evaluating multiple criteria. This method supports managers, experts, and other decision-makers by helping them balance and measure different factors, ultimately simplifying and clarifying the decision-making process.

In this paper, we explore the factors critical for rural area development using the fuzzy analytical hierarchy process (FAHP) based on triangular and spherical fuzzy numbers [21]. In many scenarios from the real-world, relying solely on human judgment for decision-making can be insufficient and unreliable. Therefore, triangular and spherical fuzzy numbers offer a viable alternative for evaluating qualitative factors and their relative importance. Other alternatives, such as trapezoidal fuzzy numbers, Pythagorean fuzzy numbers, and z-numbers, can also be considered in the application of the FAHP method. This paper begins with a literature review, followed by the selection of key factors and sub-factors for prioritization.

The purpose of this study is to develop and apply a robust MCDM framework to support decision-making in the context of sustainable rural development, considering complex, interrelated, and often imprecise or colliding criteria. To accomplish this, this

study proposes the integration of the fuzzy AHP with triangular and spherical fuzzy numbers to better model uncertainty and subjective expert evaluations. The main steps of the research are identifying and structuring key criteria relevant to sustainable rural development, developing the MCDM model incorporating fuzzy AHP with both triangular and spherical fuzzy numbers, demonstrating the effectiveness and applicability of the given model, and comparing the results obtained using different types of fuzzy numbers and their advantages in the context of decision-maker uncertainty.

The main advances of this paper can be summarized as follows:

- We introduced new sub-criteria influencing rural development.
- We applied the AHP (crisp) and FAHP method with triangular and spherical fuzzy numbers.
- We conducted and discussed the ranking similarities, estimation, and analysis in all methods.

As far as the authors are aware, there is a limited number of scientific papers published in international journals that focus on determining and ranking the criteria that affect the improvement of the quality of life in rural areas and their economic sustainability. The objective of this paper is to select, based on expert opinions, groups of criteria that influence the development of rural areas in the Republic of Serbia, identify the sub-criteria belonging to these groups, and rank their importance using multi-criteria decision-making methods.

Sustainable development of rural areas today faces a number of economic and social challenges. As many factors are interrelated, making decisions about advancing development can often be difficult. That is why multi-criteria decision-making, which has proven to be a useful tool when it comes to incorporating expertise and considering different and sometimes conflicting criteria, can be used to determine the sustainable development goals. The application of fuzzy logic makes it possible to make imprecise and often subjective assessments of experts, expressed through linguistic concepts of quantitative processing, more realistic and reduce errors in reasoning.

According to this goal, we formulated the following research questions:

RQ1: Does a highly influencing sub-factor(s) regarding rural area sustainability exist?

RQ2: How do socio-economic factors influence the effectiveness of rural development in Serbia?

RQ3: Can this paper's results help local and state governments of the Western Balkans region?

RQ4: What are the key strategies for overcoming barriers to rural development management in Serbia?

The rest of this paper has four more sections, and it is organized as follows. In Section 2, we present the criteria for rural area development, divided into factors and sub-factors. In Section 3, we deal with methodology, based on a spherical fuzzy set and an algorithm. Finally, in Section 4, we give the results, while in Section 5, we present the concluding remarks.

2. The Rural Area Development Criteria

In this Section, we first give an overview of the literature regarding MCDM application. Afterwards, the main criteria and sub-criteria for the rural areas' development are identified.

2.1. Literature Overview

The application of MCDM and similar approaches in the evaluation process of rural-area-related tasks has led to several published works. In the past three decades, these approaches have usually included but are not limited to Analytical Network Process

(ANP) [22], Fuzzy DEMATEL [23], Full Consistency Method (FUCOM) [24], Analytical hierarchy process (AHP) [25], Fuzzy AHP [26], Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [27], Multi-criteria optimization and Compromise Solution (VIšekriterijumska optimizacija i KOmpromisno Rešenje (in Serbian)—VIKOR) [28,29], and Preference Ranking Organization METHod for Enrichment Evaluation (PROMETHEE) [30,31]. Also, there are other methods applied in rural development sustainability. For example, authors in [23,24,32,33] consider the possibilities of tourism and ecotourism, while the possibility of agriculture development, investigating important factors, and non-grain productivity is the main concern in papers [34,35]. Some criteria were given for green agriculture in [36] and organic agriculture in [37]. The number of schools; the condition of basic equipment; the number of teachers; and the proportion of school areas in elementary, middle, and high schools were determined as the most influential criteria affecting the differences between urban and rural area education quality [38]. In [39], the authors define and rank criteria affecting the low use of ICT in the teaching process, since it has been recognized as important for improving the quality of education. Healthcare plays an important role in the development of rural areas, and there are many scientific papers on this topic. Some of them deal with success factors for better healthcare [40], the language model evaluation criteria framework in healthcare [41], appropriate healthcare for elderly patients [42,43], and smart technology for enhancement of healthcare [44–46]. Similar investigations on risk measures and service quality for public healthcare have been discussed by Khambhati et al. [47] and Singh and Prasher [48]. However, there are other very relevant papers with some different viewpoints. For example, Azizkhani et al. [49] deal with healthcare waste management, Parvin et al. [50] have determined the site suitability for healthcare services, and Boyacı and Şişman [51] have focused on hospital site selection based on Pythagorean fuzzy sets. Appropriate infrastructure is also one of the basic criteria for rural area development [52]. According to [25,53], enlargement of a road infrastructure leads to easier transportation of all rural area goods, following similar conclusions as in [54,55].

2.2. Main Criteria for Development of Rural Areas

The starting factors and sub-factors influencing the rural area development in Serbia were obtained from the literature overview that is given in Section 2.1, followed by an expert discussion. The debate and consultation among the 10 experts/decision-makers from the areas of economics, rural development, construction, agriculture, and education, based on their life and more than 10 years of working experience, led to the selection of 21 sub-criteria, classified into five groups: economic sustainability (E), infrastructure and access to services (I), community participation and resource management (C), geographical location (G), and social sustainability (S).

The selection of the experts was conducted to represent a broad and balanced range of perspectives, including individuals from academia, the public sector, and industry. Particular attention was given to ensuring that no single institution dominated the panel, although a few participants were affiliated with related organizations, as can be seen in Table 1. Furthermore, all participants were asked to declare any potential conflicts of interest prior to their involvement in this study.

The selection of the 21 sub-criteria is based on a detailed analysis of the relevant literature and preliminary consultations with experts in the field of sustainable rural development. The expertise involved in this process included academic researchers, practitioners from the rural development sector, and decision-makers, thus providing a multidisciplinary perspective. The assessment and selection of sub-criteria were carried out through several rounds of the evaluation process. During this procedure, experts assessed the relevance and significance of individual sub-criterion according to pre-defined criteria, such as rele-

vance for sustainable development, measurability, and applicability in the local context. Based on the analysis and consensus of experts, those sub-criteria that received the highest importance rating were selected. The sub-criteria are grouped into five categories in order to provide a clear hierarchical structure that reflects the different aspects of sustainable development and facilitates their further analysis in the framework of multi-criteria decision-making. This division follows widely accepted frameworks and models of sustainable development, which enables both comparability with other research and practical application in different contexts.

Table 1. The basic information on the experts.

ID	Area of Expertise	Years of Experience	Institution/Organization
Expert 1	Macroeconomics	16	Regional development agency
Expert 2	Microeconomics	19	Faculty of Economics
Expert 3	Rural development	16	Ministry of rural affairs
Expert 4	Environmental protection	15	Regional development agency
Expert 5	Civil engineering	13	Faculty of Architecture
Expert 6	Infrastructure and EU funds	18	Office for European integration
Expert 7	Agriculture	11	Faculty of Agriculture
Expert 8	Sustainable tourism	11	Faculty of Tourism and hotel management
Expert 9	Digital infrastructure	16	Digitization council/IT sector
Expert 10	Education	19	Faculty of Education

The schedule of criteria and sub-criteria is given in Table 2 and Figure 1, while the detailed description of each is given below.

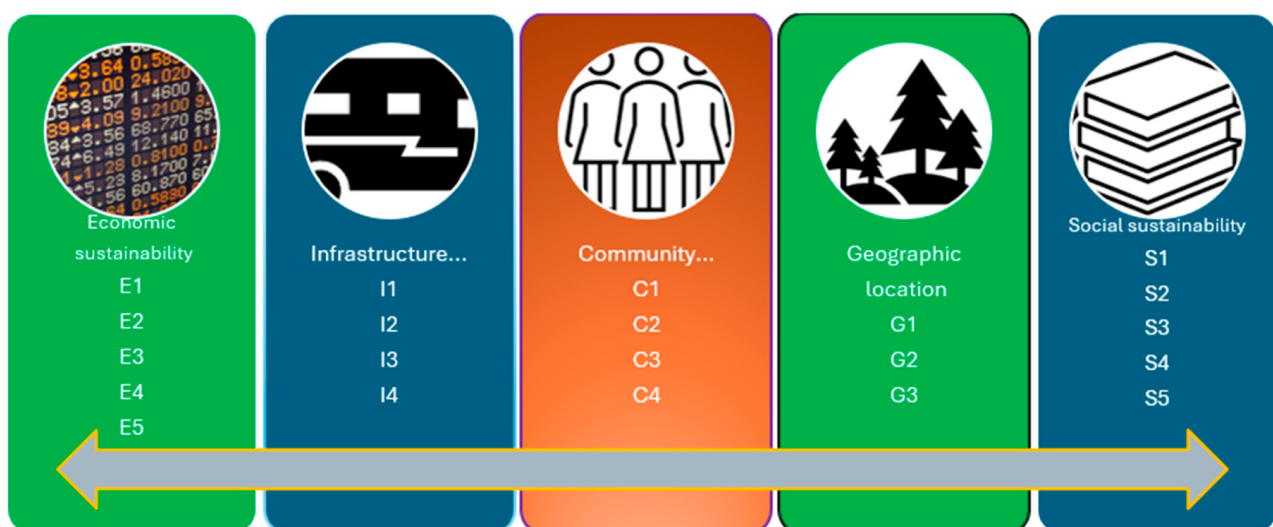


Figure 1. The schedule of factors and sub-factors for rural area development in Serbia.

Table 2. The adopted criteria and sub-criteria for rural area development in Serbia.

Economic sustainability (E)	E1—Diversification of the economy E2—Innovations in agriculture and tourism E3—Access to markets and finance E4—Reduction in the cost of living E5—Development of small- and medium-sized enterprises
Infrastructure and access to services (I)	I1—Connection with urban areas I2—Development of infrastructure from EU funds I3—Digital connectivity I4—Pollution reduction and waste management
Community participation and resource management (C)	C1—Active participation of the local community C2—Encouraging entrepreneurship and startups C3—Ensuring public utility services C4—Preservation of tradition and cultural heritage
Geographical location (G)	G1—Proximity to highways G2—Proximity to the city and business center G3—Natural beauty of the landscape and preservation of nature
Social sustainability (S)	S1—Access to quality education S2—Political stability S3—Tighter regulations in the field of environmental protection S4—Support for marginalized groups S5—Healthcare

2.2.1. Economic Sustainability

The economic sustainability of rural areas refers to their ability to develop and maintain economic activities that can endure over the long term without depleting the resources they rely on. Economic sustainability in rural areas is crucial, as it enables long-term prosperity, poverty reduction, and improved quality of life for their residents [22]. While economic diversification plays a key role, agriculture remains the primary source of income in many rural areas. Sustainable agriculture, which employs ecological practices and modern technologies, can improve productivity and long-term soil fertility while reducing negative environmental impacts. Access to markets allows rural entrepreneurs to sell their products, whether agricultural goods, crafts, or tourism services [23]. Connecting to both domestic and international markets is essential for increasing income and maintaining competitiveness. Good market access can help reduce market uncertainty and provide stable income sources for rural communities, offering security, stability, and a more resilient economy for small- and medium-sized enterprises [56,57].

2.2.2. Infrastructure and Access to Services

Infrastructure as well as basic services access are critical elements in the development of rural areas. While rural communities often possess the necessary components for development, the lack of modern infrastructure coupled with limited access to essential services can hinder their progress, both economically and socially. Investment in infrastructure and improvements in service access lay the foundation for sustainable development, enhanced living standards, and reduced migration to urban centers [25]. Infrastructure includes both physical and organizational components, such as road, water supply, and sewage systems; energy networks; and internet connectivity, which enable the efficient functioning of society and economic advancement. Well-developed transportation infrastructure in rural areas facilitates better connectivity with urban centers, markets, and other rural regions, making it a strong argument for competing for international funding [34]. Quality of life is also improved through access to clean water, the absence of pollution, and well-managed waste disposal (recycling and proper waste management). Access to the internet and modern tech-

nologies facilitates the acquisition of information, while using digital platforms simplifies product sales and business expansion [58,59].

2.2.3. Community Participation and Resource Management

Community participation involves engaging citizens in decision-making processes, planning, and implementing projects. Some ways to achieve this include meetings, forums, or surveys where the community can gain better insight into the situation and have a direct influence on project selection and entrepreneurship development [56]. Water supply, sewage systems, and energy provision are essential for the basic comfort and health of the population; however, there are still rural areas where there is a significant shortage of these fundamental services [22]. Preserving tradition and cultural heritage contributes to strengthening local customs, language, crafts, arts, and folk traditions, which can maintain the balance and stability of the area while also enhancing the local economy [60].

2.2.4. Geographical Location

Geographical location affects access to markets and resources and plays a significant role in attracting investments. Proximity to major centers and cities can facilitate the marketing of agricultural products. Rural areas with good roads and transportation links can more easily access education, healthcare, and energy resources [61]. Demographic development is also influenced by geographic location, as remote areas often face depopulation issues. Climatic conditions and changes as well as terrain relief impact the development of the area, particularly agriculture and the selection of crops to be cultivated [60]. Natural beauties, such as rivers, mountains, and forests, along with the diversity of the area can strengthen the economy of rural regions through tourism offerings [62].

2.2.5. Social Sustainability

If quality education was more accessible in rural areas, young people would have the opportunity to acquire the necessary skills and knowledge for the labor market, which would lead to a reduction in migration to cities and create a foundation for economic development [63]. Schools in rural areas often have limited access to resources and qualified staff, so investing in educational institutions can have long-term positive effects [38,39]. Access to adequate healthcare services is essential for the well-being of the population [41]. Rural areas often suffer from a lack of healthcare centers, equipment, and professional staff, which is why investing in healthcare infrastructure is important [40]. Proximity to healthcare services increases the chances of timely diagnosis and treatment while reducing mortality from preventable diseases. Ensuring social protection, including support for the elderly, disabled people, and marginalized groups, is key to the sustainable development of rural communities [42,43]. Access to social services improves the quality of life and reduces social exclusion. Trust in institutions as well as political stability contribute to making sound decisions, implementing development programs, and increasing investments, which enhances resource management and planning, providing a secure environment for economic development [60,64].

Each sub-criterion, obtained from relevant literature or discussion with experts, is classified to a corresponding dimension and evaluated based on the direction of its impact. This means that an increase in the sub-criteria can have either a positive (contributes to) or negative (hinders) effect on sustainable development. In this paper, all selected sub-criteria are positively oriented, meaning that higher values are interpreted as beneficial for sustainability.

3. Methodology

The application of the analytic hierarchy process (AHP) has been in practice since the 1980s, following its development by Thomas L. Saaty [65]. Since its inception, AHP has proven to be an effective method for representing comparison estimates using precise values, specifically natural numbers. A key characteristic of this versatile approach is its ability to determine the optimal evaluation for conflicting criteria, sub-criteria, and alternatives. This is achieved through a balance of logical reasoning and intuition, allowing complex problems to be systematically decomposed into a multi-tiered hierarchy. At the top of this hierarchy is the primary objective of the decision-maker, followed by criteria and sub-criteria in a top-down structure. This framework facilitates comparisons between elements at the same level of the hierarchy while considering their influence on higher levels. The theory of fuzzy sets has been a foundational concept for over fifty years, introduced by Lotfi Zadeh in 1965. Since its inception, it has been utilized to address fuzzy decision-making problems. Initially developed for linguistic purposes, fuzzy set theory has proven indispensable in representing uncertainty and imprecision in decision-making processes [66,67]. This framework enables the characterization of sets in a deterministic manner, serving as an extension of traditional set theory. As a result, decision-makers can incorporate incomplete or partially unknown information into their models. Unlike conventional set theory, where an element either belongs or does not belong to a set, fuzzy sets assign membership to elements as numerical values within the interval $[0, 1]$. Each element within a fuzzy set can be associated with a membership function (MF), denoted as μ , and a fuzzy set can possess multiple distinct MFs.

3.1. Spherical Fuzzy Sets: Preliminaries

Unification of Neutrosophic and Pythagorean fuzzy set theories, where the squared sum of membership, non-membership, and hesitancy functions is at most equal to 1, has led to the definition of spherical fuzzy sets. Mahmood et al. [68] as well as Kutlu and Kahraman [69,70] introduced the spherical fuzzy sets, their characteristics, and geometrical representation.

In this part, some basic definitions regarding the spherical fuzzy sets will be given [68–70]:

Definition 1. Let X be a non-empty universe of discourse. A spherical fuzzy set $\tilde{A}_s$ of the non-empty universe of discourse X is defined as

$$\tilde{A}_s = \left\{ x, (\mu_{\tilde{A}_s}(x), \nu_{\tilde{A}_s}(x), \pi_{\tilde{A}_s}(x), x \in X) \right\}, \quad (1)$$

where $\mu_{\tilde{A}_s}(x): X \rightarrow [0, 1]$, $\nu_{\tilde{A}_s}(x): X \rightarrow [0, 1]$, and $\pi_{\tilde{A}_s}(x): X \rightarrow [0, 1]$ are the membership, non-membership, and hesitancy functions, satisfying the condition

$$\mu_{\tilde{A}_s}^2 + \nu_{\tilde{A}_s}^2 + \pi_{\tilde{A}_s}^2 \in [0, 1] \quad (2)$$

Definition 2. Let $\tilde{A}_s = (\mu_{\tilde{A}_s}, \nu_{\tilde{A}_s}, \pi_{\tilde{A}_s})$ and $\tilde{B}_s = (\mu_{\tilde{B}_s}, \nu_{\tilde{B}_s}, \pi_{\tilde{B}_s})$ be two spherical fuzzy sets defined on the non-empty universal set X and k scalar. The basic unary and binary operations are defined as

$$\text{Intersection: } \tilde{A}_s \cap \tilde{B}_s = \left(\mu_{\tilde{A}_s}, \nu_{\tilde{A}_s}, \pi_{\tilde{A}_s} \right) \cap \left(\mu_{\tilde{B}_s}, \nu_{\tilde{B}_s}, \pi_{\tilde{B}_s} \right) = \left\{ \begin{array}{c} \min \left\{ \mu_{\tilde{A}_s}, \mu_{\tilde{B}_s} \right\}, \\ \max \left\{ \nu_{\tilde{A}_s}, \nu_{\tilde{B}_s} \right\}, \\ \max \left\{ \sqrt{1 - \left(\min \left\{ \mu_{\tilde{A}_s}, \mu_{\tilde{B}_s} \right\} \right)^2 - \left(\max \left\{ \nu_{\tilde{A}_s}, \nu_{\tilde{B}_s} \right\} \right)^2}, \min \left\{ \pi_{\tilde{A}_s}, \pi_{\tilde{B}_s} \right\} \right\} \end{array} \right\}^T \quad (3)$$

$$\text{Union: } \tilde{A}_s \cup \tilde{B}_s = \left(\mu_{\tilde{A}_s}, \nu_{\tilde{A}_s}, \pi_{\tilde{A}_s} \right) \cup \left(\mu_{\tilde{B}_s}, \nu_{\tilde{B}_s}, \pi_{\tilde{B}_s} \right) = \left\{ \begin{array}{c} \max \left\{ \mu_{\tilde{A}_s}, \mu_{\tilde{B}_s} \right\}, \\ \min \left\{ \nu_{\tilde{A}_s}, \nu_{\tilde{B}_s} \right\}, \\ \min \left\{ \sqrt{1 - \left(\max \left\{ \mu_{\tilde{A}_s}, \mu_{\tilde{B}_s} \right\} \right)^2 - \left(\min \left\{ \nu_{\tilde{A}_s}, \nu_{\tilde{B}_s} \right\} \right)^2}, \max \left\{ \pi_{\tilde{A}_s}, \pi_{\tilde{B}_s} \right\} \right\} \end{array} \right\}^T \quad (4)$$

$$\text{Addition: } \tilde{A}_s \oplus \tilde{B}_s = \left(\mu_{\tilde{A}_s}, \nu_{\tilde{A}_s}, \pi_{\tilde{A}_s} \right) \oplus \left(\mu_{\tilde{B}_s}, \nu_{\tilde{B}_s}, \pi_{\tilde{B}_s} \right) = \left\{ \begin{array}{c} \sqrt{\mu_{\tilde{A}_s}^2 + \mu_{\tilde{B}_s}^2 - \mu_{\tilde{A}_s}^2 \mu_{\tilde{B}_s}^2}, \\ \nu_{\tilde{A}_s} \nu_{\tilde{B}_s}, \\ \sqrt{\pi_{\tilde{A}_s}^2 \left(1 - \mu_{\tilde{B}_s}^2 \right) + \pi_{\tilde{B}_s}^2 \left(1 - \mu_{\tilde{A}_s}^2 \right) - \pi_{\tilde{A}_s}^2 \pi_{\tilde{B}_s}^2} \end{array} \right\}^T \quad (5)$$

$$\text{Multiplication: } \tilde{A}_s \odot \tilde{B}_s = \left(\mu_{\tilde{A}_s}, \nu_{\tilde{A}_s}, \pi_{\tilde{A}_s} \right) \odot \left(\mu_{\tilde{B}_s}, \nu_{\tilde{B}_s}, \pi_{\tilde{B}_s} \right) = \left\{ \begin{array}{c} \mu_{\tilde{A}_s} \mu_{\tilde{B}_s}, \\ \sqrt{\nu_{\tilde{A}_s}^2 + \nu_{\tilde{B}_s}^2 - \nu_{\tilde{A}_s}^2 \nu_{\tilde{B}_s}^2}, \\ \sqrt{\pi_{\tilde{A}_s}^2 \left(1 - \nu_{\tilde{B}_s}^2 \right) + \pi_{\tilde{B}_s}^2 \left(1 - \nu_{\tilde{A}_s}^2 \right) - \pi_{\tilde{A}_s}^2 \pi_{\tilde{B}_s}^2} \end{array} \right\}^T \quad (6)$$

$$\text{Multiplication by a scalar } k: k \times \tilde{A}_s = k \times \left(\mu_{\tilde{A}_s}, \nu_{\tilde{A}_s}, \pi_{\tilde{A}_s} \right) = \left\{ \begin{array}{c} \sqrt{1 - \left(1 - \mu_{\tilde{A}_s}^2 \right)^k}, \\ \nu_{\tilde{A}_s}^k, \\ \sqrt{\left(1 - \mu_{\tilde{A}_s}^2 \right)^k - \left(1 - \mu_{\tilde{A}_s}^2 - \pi_{\tilde{A}_s}^2 \right)^k} \end{array} \right\}^T \quad (7)$$

$$\text{Power: } \tilde{A}_s^k = \left(\mu_{\tilde{A}_s}, \nu_{\tilde{A}_s}, \pi_{\tilde{A}_s} \right)^k = \left\{ \begin{array}{c} \mu_{\tilde{A}_s}^k, \\ \sqrt{1 - \left(1 - \nu_{\tilde{A}_s}^2 \right)^k}, \\ \sqrt{\left(1 - \nu_{\tilde{A}_s}^2 \right)^k - \left(1 - \nu_{\tilde{A}_s}^2 - \pi_{\tilde{A}_s}^2 \right)^k} \end{array} \right\}^T \quad (8)$$

Definition 3. Let $\tilde{A}_s = (\mu_{\tilde{A}_s}, \nu_{\tilde{A}_s}, \pi_{\tilde{A}_s})$ and $\tilde{B}_s = (\mu_{\tilde{B}_s}, \nu_{\tilde{B}_s}, \pi_{\tilde{B}_s})$ be two spherical fuzzy sets defined on the non-empty universal set X , and k, k_1 , and k_2 are positive scalars. Then, the following characteristics are valid:

1. $\tilde{A}_s \oplus \tilde{B}_s = \tilde{B}_s \oplus \tilde{A}_s$
2. $\tilde{A}_s \odot \tilde{B}_s = \tilde{B}_s \odot \tilde{A}_s$
3. $k \left(\tilde{A}_s \oplus \tilde{B}_s \right) = k\tilde{A}_s \oplus k\tilde{B}_s$
4. $(k_1 + k_2)\tilde{A}_s = k_1\tilde{A}_s + k_2\tilde{A}_s$
5. $\left(\tilde{A}_s \odot \tilde{B}_s \right)^k = \tilde{A}_s^k \odot \tilde{B}_s^k$
6. $\tilde{A}_s^{k_1+k_2} = \tilde{A}_s^{k_1} \odot \tilde{A}_s^{k_2}$

Definition 4. Let $\tilde{A}_s = (\mu_{\tilde{A}_s}, \nu_{\tilde{A}_s}, \pi_{\tilde{A}_s})$ and $\tilde{B}_s = (\mu_{\tilde{B}_s}, \nu_{\tilde{B}_s}, \pi_{\tilde{B}_s})$ be two spherical fuzzy sets defined on the non-empty universal set X . To compare these fuzzy sets, the score function (SC) and accuracy function (AC) are defined as

$$SC1\left(\tilde{A}_s\right) = \sqrt{100 \left| \left(\left(3\mu_{\tilde{A}_s} - \frac{\pi_{\tilde{A}_s}}{2} \right)^2 - \left(\frac{\nu_{\tilde{A}_s}}{2} - \pi_{\tilde{A}_s} \right)^2 \right) \right|} \quad (9)$$

$$SC2\left(\tilde{A}_s\right) = \frac{\mu_{\tilde{A}_s} + 2\left(1 - \nu_{\tilde{A}_s}\right) - \pi_{\tilde{A}_s}}{3} \quad (10)$$

$$AC\left(\tilde{A}_s\right) = \mu_{\tilde{A}_s}^2 + \nu_{\tilde{A}_s}^2 + \pi_{\tilde{A}_s}^2 \quad (11)$$

After calculating the SC and AC functions, the comparison rules are as follows:

If $SC(\tilde{A}_s) > SC(\tilde{B}_s)$, then $\tilde{A}_s > \tilde{B}_s$;

If $SC(\tilde{A}_s) = SC(\tilde{B}_s)$, and $AC(\tilde{A}_s) > AC(\tilde{B}_s)$, then $\tilde{A}_s > \tilde{B}_s$;

If $SC(\tilde{A}_s) = SC(\tilde{B}_s)$, and $AC(\tilde{A}_s) = AC(\tilde{B}_s)$, then $\tilde{A}_s = \tilde{B}_s$;

If $SC(\tilde{A}_s) = SC(\tilde{B}_s)$, and $AC(\tilde{A}_s) < AC(\tilde{B}_s)$, then $\tilde{A}_s < \tilde{B}_s$.

Definition 5. Let $\tilde{A}_s = (\mu_{\tilde{A}_s}, \nu_{\tilde{A}_s}, \pi_{\tilde{A}_s})$ be a spherical fuzzy set. The score indices (SI) corresponding to a set $\tilde{A}_s$ are defined as follows:

$$SI = \begin{cases} \sqrt{100 \cdot \left(\mu_{\tilde{A}_s}^2 - 2\pi_{\tilde{A}_s} \left(\mu_{\tilde{A}_s} - \nu_{\tilde{A}_s} \right) - \nu_{\tilde{A}_s}^2 \right)}, & \text{for E, AS, ES, VS, FS,} \\ \frac{1}{\sqrt{100 \cdot \left(\mu_{\tilde{A}_s}^2 - 2\pi_{\tilde{A}_s} \left(\mu_{\tilde{A}_s} - \nu_{\tilde{A}_s} \right) - \nu_{\tilde{A}_s}^2 \right)}}, & \text{for AW, EW, VW, FW,} \end{cases} \quad (12)$$

where E, AS, ES, VS, FS, W, EW, VW, FW are explained in Table 3.

Table 3. Linguistic measures of importance of criteria and spherical fuzzy sets.

LM	Meaning of LM	(μ, v, π)	Score Index
E	Equal importance	(0.5, 0.4, 0.4)	1
AW	Absolutely weak dominance	(0.1, 0.9, 0.1)	1/9
EW	Extremely weak dominance	(0.2, 0.8, 0.1)	1/7
VW	Very weak dominance	(0.3, 0.7, 0.2)	1/5
FW	Fairly weak dominance	(0.4, 0.6, 0.3)	1/3
FS	Fairly strong dominance	(0.6, 0.4, 0.3)	3
VS	Very strong dominance	(0.7, 0.3, 0.2)	5
ES	Extremely strong dominance	(0.8, 0.2, 0.1)	7
AS	Absolutely strong dominance	(0.9, 0.1, 0.1)	9

Definition 6. Spherical fuzzy weighted arithmetic mean (SFAM) with respect to $\omega = (\omega_1, \omega_2, \omega_3, \dots, \omega_n)$, $\omega_i \in [0, 1]$, and $\sum_{i=1}^n \omega_i = 1$ is the value calculated as follows:

$$\begin{aligned}
 \text{SWAM}_{\omega}(\tilde{A}_{s1}, \dots, \tilde{A}_{sn}) &= \omega_1 \tilde{A}_{s1} + \omega_2 \tilde{A}_{s2} + \omega_3 \tilde{A}_{s3} + \dots + \omega_n \tilde{A}_{sn} \\
 &= \left\{ \begin{array}{c} \sqrt{1 - \prod_{j=1}^n \left(1 - \mu_{\tilde{A}_s}^2\right)^{\omega_j}}, \\ \prod_{i=1}^n \nu_{\tilde{A}_s}^{\omega_i}, \\ \sqrt{\left(1 - \mu_{\tilde{A}_s}^2\right)^{\omega_i} - \left(1 - \mu_{\tilde{A}_s}^2 - \pi_{\tilde{A}_s}^2\right)^{\omega_i}} \end{array} \right\}^T
 \end{aligned} \quad (13)$$

3.2. Algorithm

In the sequel, the steps of the spherical fuzzy AHP method are presented [21,71,72].

Step 1: Establishing the hierarchical structure and construction of evaluation matrices.

The vertically constituted hierarchical structure with few levels of organization, with the most significant component (goal) at level 1, contributing criteria, sub-criteria, and sub-sub-criteria at the following levels and, eventually, alternatives at the last level, is built. The evaluation matrices $\tilde{D} = (\tilde{d}_{ij})_{n \times n}$ with pairwise comparisons are conducted for all considered preference criteria and sub-criteria, where $\tilde{d}_{ij} = (\mu, v, \pi)$. Corresponding score indices, linguistic measures, their meaning, and spherical fuzzy sets are presented in Table 2. The linguistic measure E corresponding to $\tilde{d}_{ii}$ is equal (0.5, 0.5, 0.5). The aggregation of k different experts' opinions is calculated by the averaging method, based on the corresponding linguistic assessments of (μ_i, v_i, π_i) , $i = 1, \dots, k$, rounding to the nearest integer.

Step 2: Matrices consistency examination.

The matrix consistency index $CI = \frac{\lambda_{\max} - n}{n-1}$ and consistency index $CR = \frac{CI}{RI}$ for the greatest eigenvalue $\lambda_{\max}$ of the matrix $\tilde{D}$ and random index RI depending on the number of criteria are used for each pairwise comparison matrix consistency evaluation. The value of consistency index $CR < 0.1$ is acceptable; otherwise, the experts should revise their evaluation to make the comparison matrix consistent.

Step 3: Calculation of fuzzy weights and global fuzzy weights of criteria.

Using the spherical fuzzy weighted arithmetic mean, the fuzzy weights for criteria and sub-criteria are calculated.

Step 4: The defuzzification process is conducted.

Applying score function formulas, the weights w_i for all criteria and sub-criteria were obtained. Crisp numbers were calculated in two different ways.

Step 5: Normalization of weight vector is calculated.

Using the formula $w_i^* = \frac{w_i}{\sum_{i=1}^n w_i}$, the normalization of the vector is performed.

These steps, in a detailed manner and in an algorithm form, are given below in the next Algorithm 1 [73,74].

Algorithm 1. Steps in the Process of Spherical Fuzzy AHP

Establishing the main goal	
Identifying the E, I, C, G, S	Criteria
Identifying the E_i, I_i, C_i, G_i, S_i	Sub-criteria
Construction of $\tilde{D}$, using Table 2	Fuzzy correlation matrix
Calculate CR	
if $CR > 0.1$, then	
Adjust values and go to 4	
else	
Fuzzification, applying the Equation (13)	SFAM
Defuzzification, applying the Equation (9)	
applying the Equation (10)	
Calculate w_i^*	Normalization vector
Ranking of E_i, I_i, C_i, G_i, S_i	Sub-criteria ranking
end if	

Triangular fuzzy numbers are an effective way to quantify uncertain estimates because they allow you to easily model expert estimates through the smallest, most probable, and highest values. They are intuitive, numerically stable, and often used in applied research precisely because of their ease of application and interpretation. Spherical fuzzy numbers, on the other hand, were introduced in the analysis with the aim of further expanding the model and better expressing uncertainty, since they allow a more flexible representation of uncertainty thanks to their geometric approach. They provide greater accuracy in cases where expert assessments contain a high degree of cognitive uncertainty and are difficult to fit into traditional fuzzy forms. By combining these two approaches within the fuzzy AHP method as well as the two variants of defuzzification, it is possible to create a more robust and realistic decision model, which better reflects the complexity of the criteria and interdependencies within the analysis.

4. Results and Discussion

In this section, the outlined algorithm has been applied. Also, the FAHP [73,75] with five degrees of optimism, pessimistic ($\lambda = 0$), semi-pessimistic ($\lambda = 0.25$), balanced ($\lambda = 0.5$), semi-optimistic ($\lambda = 0.75$), and optimistic ($\lambda = 1$), as well as crisp AHP methods are used to compare the obtained results and sub-criteria ranking. A group of experts from the areas of rural development, construction, economics, agriculture, and education selected groups of criteria and sub-criteria and expressed their opinion based on the meaning of linguistic measures and spherical fuzzy sets presented in Table 3. The assessments the experts gave were aggregated based on the first step of the presented algorithm.

Firstly, the main criteria group ranking was determined. According to the aggregated experts' opinions, the most important group is economic sustainability, denoted by E, followed by infrastructure and access to services (I) and community participation and resource management (C). At the end, there are geographic location (G) and social sustainability (S), with the same rank. The matrix corresponding to the main group of criteria is consistent, with $CI = 0.034$ and $CR = 0.031$, calculated as follows:

$$\lambda_{max} = \frac{5.31163956 + 5.238586457 + 5.041396039 + 5.046665539 + 5.046665539}{5} = 5.136990627$$

$$CI = \frac{5.137 - 5}{5 - 1} = 0.0342, \quad CR = \frac{0.0342}{1.12} = 0.0305.$$

The weights in the AHP case are $w(E) = 0.505$, $w(I) = 0.259$, $w(C) = 0.127$, and $w(G) = w(S) = 0.055$, respectively. In the optimistic FAHP case, the leading criterion has weight $w(E) = 0.433$, having 1.51 times higher weight than criteria I and 2.66 and 6.287 times more importance than criteria C and G, respectively. Considering the pessimistic case, the quotients mentioned are 1.668, 3.387, and 7.638. Applying the SFAHP algorithm, for both SC1 and SC2, at the top of the ladder is economic sustainability, with corresponding weights 0.286 and 0.301, followed by infrastructure and access to services, with weights 0.237 and 0.24. At the end, social sustainability has the weights 0.138 and 0.131 apiece. This algorithm provides significantly smaller quotients ranging from 1.21 to 2.08 in the SC1 case and 1.25 to 2.3 for SC2. The average weights of the main group of criteria in all algorithms are $w(E) = 0.415$, $w(I) = 0.269$, $w(C) = 0.156$, $w(S) = 0.084$, and $w(G) = 0.073$.

The sub-criteria ranking is carried out in the same manner and similar to the main criteria ranking, and fuzzy comparison matrices and the corresponding weights are given in Tables 4–9 and Figures 2–8 below.

According to the results, all matrices are consistent. Like the comparison of the main criteria, the AHP method yields equal ranking in the case of sub-criteria from group E, as can be seen in Table 4. Among the five sub-criteria, we have equal rankings in two pairs: innovations in agriculture and tourism (E2) and access to markets and finance (E3) as well as reduction in the cost of living (E4) and development of small- and medium-sized enterprises (E5), all being led by the most important sub-criteria, diversification of the economy (E1). Their weights in the AHP case are, respectfully, $w(E1) = 0.462$, $w(E2) = 0.195 = w(E3)$, $w(E4) = 0.074 = w(E5)$, while in the balanced FAHP, the weights are $w(E1) = 0.409$, $w(E2) = 0.224$, $w(E3) = 0.205$, $w(E4) = 0.091$, and $w(E5) = 0.071$. Using the second formula for the defuzzification in the SFAHP method, the first and fifth sub-criteria weights are $w(E1) = 0.268$ and $w(E5) = 0.151$, as can be seen in Table 5.

The sub-criteria belonging to the group infrastructure and access to services are ranked in the following way. Connection with urban areas (I1) is at the top, followed by pollution reduction and waste management (I4), development of infrastructure from EU funds (I2), and digital connectivity (I3), as can be seen in Table 6. Considering both defuzzification formulas in the SFAHP algorithm, the average weights of these sub-criteria are $w(I1) = 0.279$, $w(I4) = 0.27$, $w(I2) = 0.232$, and $w(I3) = 0.219$. In the balanced FAHP case, the sub-criterion I1 has 1.66 times greater influence than I4 and 3.3 and 8.81 times greater than I2 and I3. The triangular fuzzy numbers obtained for the criteria from group I can be seen in Figure 2. Comparing the results in the semi-pessimistic and semi-optimistic points of view (FAHP), $w(I1) = 0.502$ and $w(I1) = 0.491$, while digital connectivity has weights $w(I3) = 0.058$ and $w(I3) = 0.055$, being 8.71 and 8.88 times less important than I1.

Table 4. The matrix of fuzzy comparison for sub-criteria from group E (CI = 0.014, CR = 0.013).

E	E1	E2	E3	E4	E5
E1	1	FS	FS	VS	VS
E2	1/FS	1	E	FS	FS
E3	1/FS	1/E	1	FS	FS
E4	1/VS	1/FS	1/FS	1	E
E5	1/VS	1/FS	1/FS	1/E	1

Table 5. The weights for the sub-criteria from group E in the AHP, FAHP, and SFAHP case.

E	AHP	FAHP					SFAHP	
		$\lambda = 0$	$\lambda = 0.25$	$\lambda = 0.5$	$\lambda = 0.75$	$\lambda = 1$	SC1	SC2
E1	0.462385	0.429979	0.416140	0.409238	0.405106	0.4023467	0.261925	0.268289
E2	0.195154	0.208277	0.218953	0.224277	0.227466	0.2295929	0.211129	0.213250
E3	0.195154	0.200417	0.203220	0.204619	0.205455	0.2060133	0.204095	0.203551
E4	0.073653	0.084593	0.088710	0.090763	0.091997	0.0928133	0.166397	0.163545
E5	0.073653	0.076733	0.072977	0.071104	0.069981	0.0692337	0.156460	0.151368

Table 6. The matrix of fuzzy comparison for sub-criteria from group I (CI = 0.039, CR = 0.044).

I	I1	I4	I2	I3
I1	1	FS	VS	ES
I4	1/FS	1	FS	VS
I2	1/VS	1/FS	1	FS
I3	1/ES	1/VS	1/FS	1

Table 7. The matrix of fuzzy comparison for sub-criteria from group C (CI = 0, CR = 0).

C	C1	C2	C3	C4
C1	1	E	FS	FS
C2	1/E	1	FS	FS
C3	1/FS	1/FS	1	E
C4	1/FS	1/FS	1/E	1

Table 8. The matrix of fuzzy comparison for sub-criteria from group G (CI = 0.019, CR = 0.033).

G	G1	G2	G3
G1	1	FS	VS
G2	1/FS	1	FS
G3	1/VS	1/FS	1

Table 9. The matrix of fuzzy comparison for sub-criteria from group S (CI = 0.018, CR = 0.016).

S	S2	S1	S5	S4	S3
S2	1	E	E	FS	ES
S1	1/E	1	E	FS	ES
S5	1/E	1/E	1	FS	ES
S4	1/FS	1/FS	1/FS	1	VS
S3	1/ES	1/ES	1/ES	1/VS	1

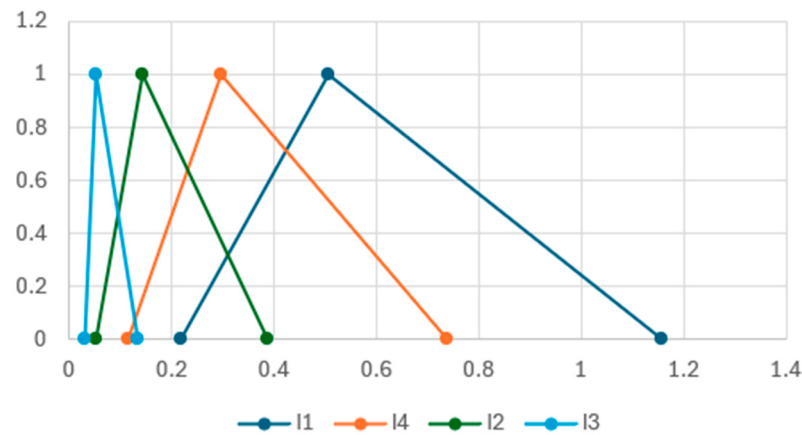


Figure 2. Triangular fuzzy numbers for the sub-criteria related to group I.

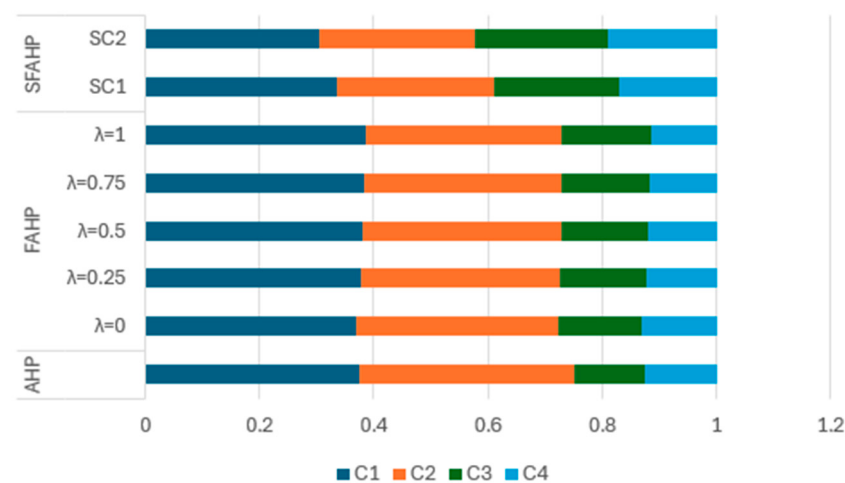


Figure 3. Weights for the sub-criteria belonging to group C in the AHP, FAHP, and SFAHP case.

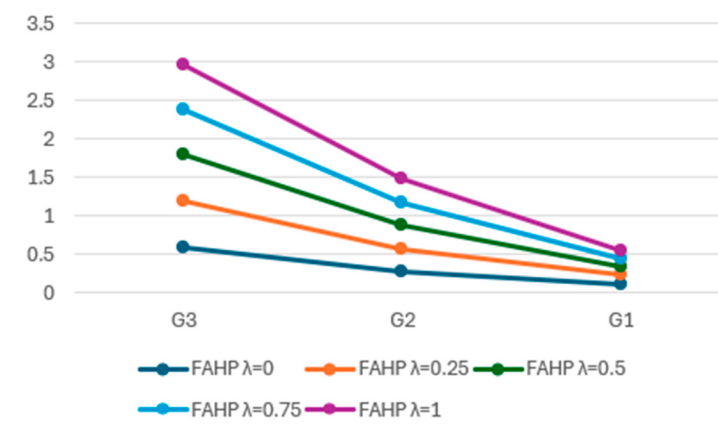


Figure 4. Weights for the sub-criteria belonging to group G corresponding to FAHP.

Speaking of community participation and resource management, the AHP algorithm yields two pairs of equally ranked sub-criteria: active participation of the local community and encouraging entrepreneurship and startups dividing the first position; and ensuring public utility services and preservation of tradition and cultural heritage on the next two positions (see Table 7). In the rest of the cases, there are no equally ranked sub-criteria. All five FAHP cases favor C1, with the average weight $w(C1) = 0.379$ and greatest value of 0.386 obtained for $\lambda = 1$ and smallest value of 0.369 obtained for $\lambda = 0$, as can be seen in Figure 3. The weights for the second-ranked sub-criteria C2 in the optimistic and

pessimistic FAHP case are 0.343 and 0.355, respectively, while for the lowest-ranked sub-criteria, the corresponding weights are 0.114 and 0.131. A similar conclusion can be also made in the case of the SFAHP algorithm, where the average values of the sub-criteria are, respectively, $w(C1) = 0.321$, $w(C2) = 0.273$, $w(C3) = 0.227$, and $w(C4) = 0.18$.

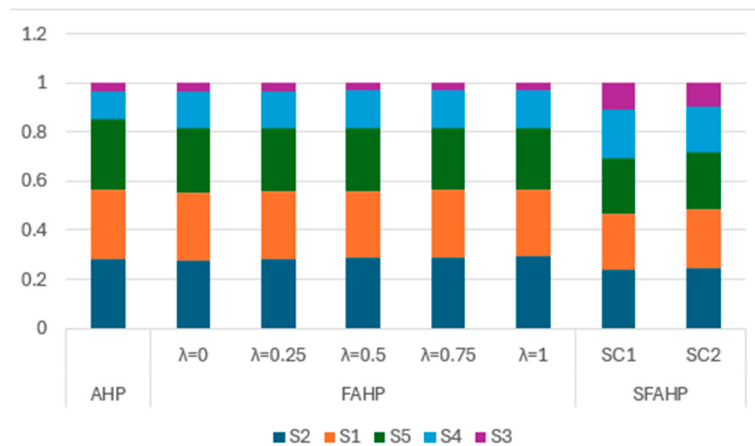


Figure 5. Weights for the sub-criteria belonging to group S corresponding to AHP, FAHP, and FAHP.

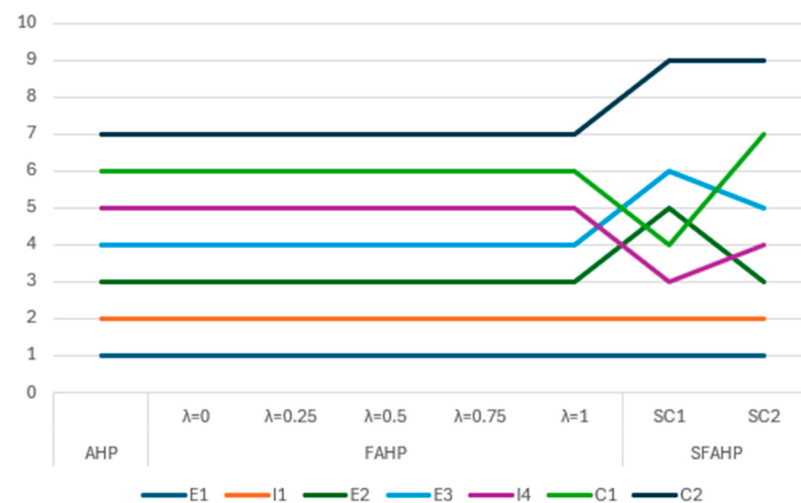


Figure 6. Ranking of first seven sub-criteria in AHP, FAHP, and SFAHP case.

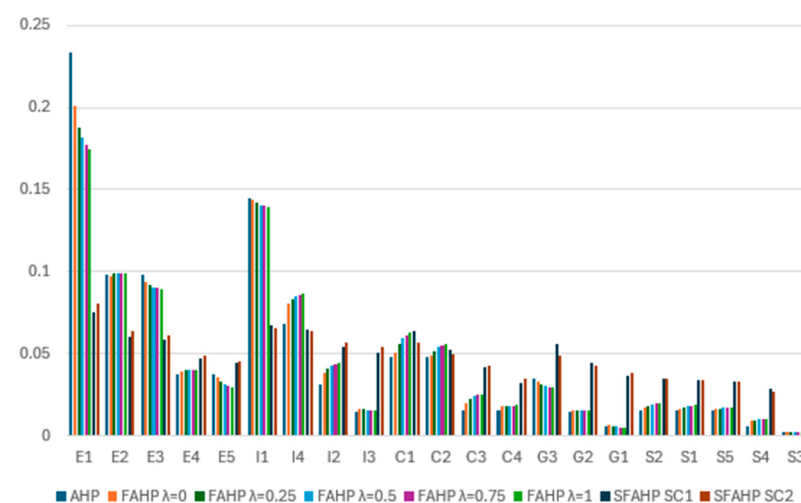


Figure 7. Final ranking of all sub-criteria.

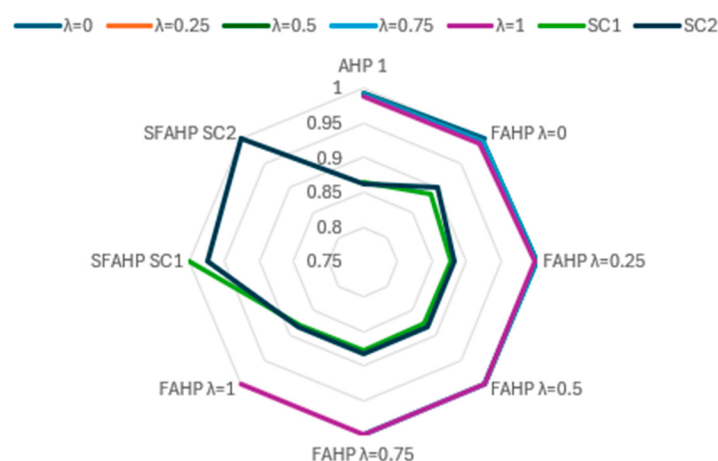


Figure 8. The sub-criteria ranking similarity (AHP, five FAHP, and two SFAHP cases).

The three sub-criteria from the geographic location group concern natural beauty of the landscape and preservation of nature (G3), proximity to the city and business center (G2), and proximity to highways (G1), ranked in the given order, presented in Table 8. Their weights for both cases of SFAHP are, respectfully, $w(G3) = 0.407$, $w(G2) = 0.324$, $w(G1) = 0.268$, and $w(G3) = 0.377$, $w(G2) = 0.326$, $w(G1) = 0.296$, while the corresponding fuzzy numbers are (0.612, 0.391, 0.346), (0.511, 0.464, 0.409), and (0.437, 0.5, 0.442). In the crisp AHP case, the weights are significantly higher, making the leading sub-criteria $w(G3) = 0.633$, 2.43 and 5.97 times more important than G2 and G1. Figure 4 presents the sub-criteria weights in all five cases of the FAHP.

The last group of criteria referring to social sustainability, as can be seen in Table 9, has three equally ranked sub-criteria. The weight 0.283 in the AHP case refers to political stability (S2), access to quality education (S1), and healthcare (S5). Support for marginalized groups (S4) and tighter regulations in the field of environmental protection (S3) are 2.48 and 7.87 times less important than the leading sub-criteria. In the pessimistic FAHP case, $w(S2) = 0.278$, being higher than S1 and S5 just for 0.007 and 0.013, respectively. Same differences in the balanced point of view are 0.016 and 0.031, and for $\lambda = 1$, they are 0.02 and 0.04. The SFAHP yields average results for the sub-criteria $w(S2) = 0.241$, $w(S1) = 0.234$, $w(S5) = 0.229$, $w(S4) = 0.19$, and $w(S5) = 0.104$. All the weights are shown in Figure 5.

Now, using the eight different ways, we performed the sub-criteria final ranking. It can be observed that, while the sub-criterion named E1 is still ranked highest, all the remaining sub-criteria from E (economic sustainability), E2, E3, E4, and E5 are ranked third, fourth, eighth, and ninth, respectively, in the AHP and the majority of the FAHP cases, with a small difference in ranking order for the SFAHP. Diversification of economy, followed by connection with urban areas, innovations in agriculture and tourism, access to markets and finance, and pollution reduction and waste management represent the five most influential sub-criteria in rural area development. This confirms the existence of the most important criteria, answering RQ1. Furthermore, active participation of the local community and encouraging entrepreneurship and startups also play an important role in making the strategies in rural areas progress. The sub-criterion natural beauty of the landscape and preservation of nature from the geographic location group is in the middle of the ladder, having solid influence, with approximately seven times smaller weight than the leading E1. The ranking of the seven most influential sub-criteria is presented in Figure 6, making a solid base for local authorities, management offices, and governments in creating a healthy and inspiring environment for better conditions in rural areas, providing the answer for RQ3.

Smaller global weights belong to the sub-criteria from group S, tighter regulations in the field of environmental protection and support for marginalized groups, with sub-criteria S3 being least important in all cases, while S4 is replaced with proximity to highways (G1) on the twentieth place in all cases but SFAHP. The best rank for the social sustainability group is political stability, ranking thirteenth in the FAHP ($\lambda = 0.25$, $\lambda = 0.5$, $\lambda = 0.75$, $\lambda = 1$) and sixteenth in both SFAHP. The ranking of all sub-criteria can be seen in Figure 7.

In Serbia, socio-economic differences between rural and urban areas greatly impact the success in rural development efforts. To overcome these challenges, we need policies that focus on specific locations. These policies should invest in infrastructure and economic support while also improving education, governance, and social inclusion. If we do not address the underlying socio-economic issues, rural development initiatives may end up being short-term or ineffective (RQ2).

There is also a recently introduced surface fuzzy AHP [76] applicable in similar situations, using a given surface instead of a sphere, allowing the decision-makers to have a higher degree of freedom. Also, more information on the possible use of tensor calculus and geodesic mappings in decision-making can be seen in [77–79].

The development of rural areas depends on a series of interconnected factors that shape the quality of life, economic opportunities, and sustainability of communities in those regions. In many countries, including the Western Balkans, rural area development is of key importance in preventing regional inequalities and depopulation and maintaining natural resources. Also, important social factors positively affecting the quality of life, like access to quality education and healthcare, present a way of avoiding the basic obstacles of inhabitants staying or even settling down in rural areas. Although the economic factors play a crucial role in underdeveloped areas' sustainability achievements, social factors definitely have their place in rural areas' successful progress. Regarding the sub-criteria mentioned and described in this paper, some of the strategies in overcoming rural areas' difficulties might be focused on improvement of infrastructure (group I), support for education and professional development (group S), encouraging entrepreneurship and access to finance (groups E and S), and decentralization and strengthening of local administration (group C). Rural development management in Serbia faces numerous barriers, including limited institutional capacity, socio-economic disparities, infrastructure gaps, and low civic participation. To address these challenges, a combination of policy-, institutional-, and community-based strategies is essential. The key strategies, as RQ4 stated, include strengthening local governance and institutional capacity, investing in infrastructure and connectivity, economic diversification and support for SMEs, enhancing human capital, encouraging civic participation and social inclusion, and improving access to funding and EU support. In this manner, barriers in rural development in Serbia may be overcome, and success may be visible.

Previous sub-criteria ranking can lead to some differences, discrepancy, or debate. To inspect the possibilities of inconsistencies, estimation, and analysis of ranking similarities applying three algorithms (crisp AHP, five degrees of optimism FAHP, and two ways of defuzzification SFAHP) to all sub-criteria influencing rural area development in Serbia and Western Balkans, we conducted twenty-nine different rankings using the Spearman rank correlation coefficient [80]:

$$r_s = 1 - \frac{6 \sum_{i=1}^n d_i^2}{n(n^2 - 1)}, \quad d_i = R_{x_i} - R_{y_i}, \quad (14)$$

where n stands for the number of elements in ranking and R_{x_i} and R_{y_i} mean the i -th element in the rankings used for comparison. As can be seen in Figure 8, the highest similarity (100%) in ranking sub-criteria is obtained when comparing the semi-pessimistic FAHP with the balanced and semi-optimistic FAHP. The lowest value of the coefficient r_s

for the AHP is when it is compared to SFAHP (SC2) and is equal to 0.8623377, also being the minimum of all calculated values. It is worth mentioning that $r_s = 0.998701$ comparing the optimistic FAHP case with FAHP ($\lambda = 0.25$, $\lambda = 0.5$, $\lambda = 0.75$). A similar situation is when two SFAHP cases are observed, having coefficient $r_s = 0.876623$ and $r_s = 0.8831169$, compared with three less excluding cases of FAHP, respectively. Analyzing the results obtained comparing the pessimistic FAHP with three elements of the previously mentioned set, it can be seen that the coefficient has the value 0.993506. Considering only SFAHP, $r_s = 0.974026$.

5. Conclusions

In this paper, we explore the problem of rural area development and the influence of various different factors in the case of Serbia. Indicators corresponding with underdeveloped rural areas have been divided into five groups, involving economic sustainability, infrastructure and access to services, community participation and resource management, geographic location, and social sustainability. Using crisp AHP, FAHP, and SFAHP, twenty-one sub-criteria were ranked to determine the preferred ones in the process of sustainable development. The obtained results marked that the proposed methods are entirely capable of estimating the influence of all factors and sub-factors on rural area development. Considering all obtained weights for each sub-criteria, we note that all five values of λ in the FAHP case and two defuzzification ways in the SFAHP case criteria, such as diversification of the economy, connection with urban areas, innovations in agriculture and tourism, access to markets and finance, and pollution reduction and waste management, have the most significant effect on rural area development in Serbia and the Western Balkans, while proximity to highways, tighter regulations in the field of environmental protection, and support for marginalized groups seem to be least significant. In the context of Serbia, these findings reinforce the importance of aligning rural policies with broader economic and spatial planning agendas, particularly those that support small- and medium-sized enterprise rural tourism and functional integration with regional hubs. Given the similar socio-economic and infrastructural profiles across the Western Balkans, these criteria can be generalized and applied regionally. Policymakers across the region should prioritize investments in rural–urban linkages, digital and transport infrastructure, and localized economic activities, especially in areas facing demographic decline and economic stagnation. The findings could serve as a decision-support tool in the formulation or revision of national rural development strategies and can also contribute to regional cooperation frameworks supported by the EU, UNDP, or regional development agencies.

This work strives towards the fact that connections between local authorities, government, and managers on the one side and rural area inhabitants on the other should be higher and more comprehensible, applying one or more strategies to make areas more sustainable.

This study aimed to create a strong multi-criteria decision-making framework to support sustainable rural development in Serbia. It focused on combining fuzzy AHP methodology with both triangular and spherical fuzzy numbers. Expert consultation and literature review identified 21 sub-criteria, which were grouped into five main dimensions to reflect the complex nature of sustainability. By applying fuzzy AHP with both triangular and spherical fuzzy numbers, this study effectively captured the uncertainty in expert judgments, revealing the most important criteria to help local authorities in rural development strategy creation and overcome barriers. It showed that using fuzzy sets improves the strength and realism of decision-making processes. The comparative analysis found that both triangular and spherical fuzzy numbers produced consistent results, but spherical fuzzy numbers provided more flexibility in dealing with uncertainty, especially

when expert opinions varied significantly. Ranking similarities were also presented using the Spearman correlation coefficient.

The methodological innovation in this manuscript is a hybrid fuzzy AHP model that combines both triangular and spherical fuzzy numbers. This approach is not widely used in rural development decision-making. Adding spherical fuzzy sets is particularly innovative. This modern extension of classical fuzzy theory allows for better representation of uncertainty, particularly when expert opinions are very unclear or conflicting. Comparing the two types of fuzzy numbers within the same MCDM framework offers new insights into their behavior and effectiveness, which helps advance methods in fuzzy decision-making literature. The results address a gap in studies that have rarely modeled expert-based decision-making under uncertainty in sustainable rural development. Also, the findings contribute to a better understanding of how to prioritize development actions under uncertainty and provide a practical tool for policymakers to enhance evidence-based rural development planning.

While our work offers observation into several advantages of rural area development strategies, it has some limitations. Applying the top-down structure in AHP comparing criteria across different levels may create criteria that are difficult to compare. Using ANP with clusters can overcome this problem. Another limitation is the inability (costs) in time and money to survey residents of rural areas, which was the main reason for interviews with experts from different fields of expertise. Also, our research was geographically directed to Serbia and surrounding countries with similar geographic, social, and demographic conditions, representing another limitation.

This paper's findings (also limitations) may present some kind of a starting point for some other future research into rural area development. Depending on the research direction, some criteria and/sub-criteria could be added, and our focus might be to investigate the managerial aspects of our findings. Finally, there are other MCDM methods applicable in this situation, based on triangular, trapezoidal, Fermatean, Pythagorean, or Z numbers, or recently published surface FAHP.

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Abbreviations

The following abbreviations are used in this manuscript:

AHP	Analytic Hierarchy Process
FAHP	Fuzzy Analytic Hierarchy Process
SFAHP	Spherical Fuzzy Analytic Hierarchy Process
ANP	Analytic Network Process
MCDM	Multi-Criteria Decision-Making

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