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RURAL SUSTAINABILITY RESEARCH
51(346), 2024
ISSN – 2256-0939

Received: 23 January 2024 Revised: 24 March 2024 Accepted: 29 April 2024

# Possibility of Renewable Energy Solutions Usage in Rural Areas of Western Balkans: Fuzzy-Rough Approach

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**Abstract.** Energy production, supply and consumption are global issue with many economic, environmental and social implications. Mentioned issue is even more expressed in remote rural areas, in particular in developing countries, as are the countries of the Western Balkans (WB). Renewable energy sources (RES) could represent optimal energy alternative for sustainable performing of agricultural and other activities, as well as for improving the current state of living conditions in rural communities. The main goal of research is to mark the most suitable RES alternative (six alternatives) for wider implementation in rural space of WB. The applied methodology framework implies experts' opinion (engagement of eight experts) and the use of multi-criteria decision-making methods (MCDM), (specifically fuzzy-rough LMWA and fuzzy-rough CRADIS methods) under the predefined criteria (nine criteria). Derived results show that the implementation of the solar energy plants could play an optimal solution, while as the relatively unsuitable alternative could be marked the use of energy potential of watercourses. Gained final result, i.e. ranking order of the considered alternatives is additionally verified by the appliance of other MCDM methods, while the sensitivity analysis was also performed.
**Key words:** rural areas, RES, Western Balkan, multi-criteria, decision-making.

## Introduction

The growing concern for the future of the planet Earth shifts the focus to available natural resources and the possible impacts of their consumption on the environment. In order to decrease the negative impact, this research considers the possibilities of wider RES usage in rural areas. The general sense of RES implementation in rural areas and communities is to improve the quality of life, protect natural environment and facilitate the realization of certain agricultural activities (Morris & Bowen, 2020). So, basically, energy gained from the implemented RES alternatives could be used for various purposes (Harlan, 2018), supporting the farm functioning in such a way as to decrease overall production costs, secure existential life conditions, or reduce and even eliminate negative impacts to the environment. Besides, in line with principles of sustainability there is a need to implement certain innovations in energy production and consumption (Trofymenko *et al.,* 2022) especially in systems of sustainable agriculture and rural communities, initiating the decrease in various impacts of usually used conventional energy sources.

Non-renewable energy sources (NRES) are available in nature in quite a limited volume, while their permanent use affects decrease in to humane accessible reserves. Consequently, there are strong beliefs that humanity will lack some of these sources of energy in close future. They mostly involve fossil fuels (such are coal, oil, natural gas) and nuclear energy (Shankar, 2017; Kilci, 2022). Besides significant contribution to GHGs emission (e.g. through fossil fuels combustion), their use could initiate other negative impacts on environment (e.g. disposed nuclear waste shines radioactivity for dozen years, requiring the special storing treatment), (Sherman, 2012). The positive side of RES use is much effective generation of certain volume of energy than that could be gained by renewable energy sources (RES) exploitation (Guney, 2019).

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DOI: 10.2478/plua-2024-0001

RESs are available in nature. They are abundant and all-around. They are constantly or in short cycles completely or partially renewed, while they are later consumed at rate lower than the rate of their creation (Sorensen, 2004). RESs are mainly exploited towards the completely environmentally friendly production of energy in its various forms (Rahman *et al.*, 2022). RESs usually involve (Subic *et al.,* 2017): bioenergy (e.g. biogas, biofuel, or biomass), solar and wind energy (Gonzalez Sanchez & Camaraza Medina, 2022), or water (hydropower, or ocean energy) and geothermal energy. So, renewable energy represents the energy emerged from natural sources (RESs) that are naturally re-filled up and have not run out. In general, it is used for electricity generation, heating or cooling, and transportation.

Nowadays, raise in energy demand and strictness in environmental requirements of contemporary civilization initiates the rapid growth in RESs use. Renewable energy utilization increases for over 3% in 2020 compared to previous period, mostly as a consequence of decrease in demand for fossil fuels. Simultaneously it initiates for 7% higher rate of electricity generation from RESs, what is supported by stable production and supply contracts, primacy in entry to power grid, and permanent establishment of new powerplants. Therefore, RESs appliance in overall electricity generation worldwide increase to 29% in 2020. Even more, in 2021 their use grew up for over 8% (solar and wind energy use cover almost 66% of RESs growth). China assumes about 50% of worldwide increase in renewable electricity in previous years, tracked by USA, EU, and India (Basit *et al.,* 2020; Hannan *et al.,* 2020; IEA, 2021). Mentioned is in focus of global trends in last few decades that observes sustainability throughout the climate and ecological issues underlining “triple E”, i.e. energy security, economic development and environmental protection (Stoian, 2021).

Renewables could be used in many economic and non-economic activities, e.g. in agriculture and food-processing industry (Eswara & Ramakrishnarao, 2013; Jelocnik & Subic, 2021), transportation (Garcia Olivares *et al.,* 2018), electricity production (Barragán Escandón *et al.,* 2018), building industries (Mekhilef *et al.,* 2011), tourism industry and food services (Monforti Ferrario *et al.,* 2015; Asvanyi *et al.,* 2017), mining, mineral and metal industry (McLellan *et al.,* 2012; Votteler & Brent, 2016), trade, retail and logistic (Tassou *et al.,* 2011; Byrnes *et al.,* 2013; Khan *et al.,* 2020), textile industry and fashion (Choudhury, 2013; Pal, 2017), sport industry (Chard & Mallen, 2013), health and medical services (Haghighi Bardineh *et al.,* 2018), education and culture (Jones, 2014; Ocetkiewicz *et al.,* 2017), entertainment industry (Pal & Mukhopadhyay, 2023), etc.

Worldwide, both in urban and rural space, concept of renewables and the use of natural materials in households or business facilities greening have been become for decades the way of living and working for many families and legal entities that are aware of environmental issues and that are behaving in accordance with natural principles (Todorović, 2012; Claudy *et al.,* 2013; Kriström & Kiran, 2014; Yi, 2014; Tien *et al.,* 2020; Loaiza Ramírez *et al.,* 2022). Even more there are several countries, such are Finland, Sweden, Denmark, Switzerland, Slovenia, Austria, or Montenegro (Stritih *et al.,* 2007; Koch & Fritz, 2014; Djurisic *et al.,* 2020; Destek & Sinha, 2020), that recognize the renewables as instrument which leaves less shallow ecological footprint implementing them in national policies as a part of mission of further development.

In line to requirements of resilient and circular economy, it is noted that economic capacity of certain society plays significant role in facing the environmental and climate change issues. Rich countries are much easier adopting and implementing the available technologies towards the renewables use than the underdeveloped countries (Gabriel, 2016; Ilić *et al.,* 2019). Now it becomes already an economic axiom that the wider use of renewables affects the further development of economy (Kazar & Kazar 2014).

Several studies have been already showed that there is high correlation between the use of green energy (renewables), by them advanced household characteristics and derived conditions of living, and gained level of human happiness and well-being (Krekel, 2020; Mohamad *et al.,* 2020; Holechek *et al.,* 2022).

Nowadays, the appliance of renewables become the most common in urban territories (Littlefair *et al.,* 2000; Walker, 2022), but their use is not so rare in rural space too (Kaya *et al.,* 2019; Rudolph & Kirkegaard, 2019; Scott *et al.,* 2019).

Generally rural, and sometimes peri urban areas characterize lack of or weak physical infrastructure (power grid, water supply, sewerage system, roads, etc.), (Gaal & Afrah, 2017; Manggat *et al.,* 2018), affecting the increase in poverty, limiting the agricultural production, forcing the migrations, or hampering the qualitative growth of wellbeing elements of local rural population. This is even more pronounced for remote farms, or hamlets (Matous *et al.,* 2011; Wang *et al.,* 2020).

In line with that use of renewables could be highly suitable solution for rural space, not only for daily living and survival, while also for organization and sustainable realization of many farm businesses (Morris & Bowen, 2020). It could enable access to water for irrigation, livestock feeding and utilities (Harlan 2018), fishponds aeration and fish feeding (Hu *et al.,* 2022), crop production and agro-food products logistic (Katuwal & Bohara, 2009; Ji & Huang, 2009), solar drying or other forms of food processing (Karekezi & Kithyoma, 2002; Pirasteh *et al.,* 2014), practicing agritourism services (Giurea *et al.,* 2017), etc.

What is happened in Serbian and BiH rural space? As the most of Western Balkans (WB) countries, Serbia (Jelocnik *et al.,* 2018) and BiH (Žurovec *et al.,* 2017) are dominantly rural countries. They have in common that the state of living, i.e. access to physical infrastructure and social contents in rural areas is quite alarming, while they are inhabited by 55-60% of overall population (Vujicic *et al.,* 2012; Trbic *et al.,* 2021). Besides their survival is endangered by expressed rural-urban migratory processes, especially of young population, to local cities and abroad (Dimova & Wolff, 2015; Šantić *et al.,* 2017), and negative natural increase (Pašalić *et al.,* 2017; Drobnjaković *et al.,* 2022).

Additionally, some surveys for Serbia show that in previous decade over the 25% of villages is dying out, while almost 10% are up to 10 inhabitants, or without young population (Jeločnik *et al.,* 2020; Subić & Jeločnik, 2021). Similar statistic is characteristic for Bosnian villages too (Henig, 2012; Nurković, 2018), or even in all WB. It's obvious that shortage in infrastructural contents in rural space (including access to electricity) drives mostly the young population to urban areas in search for better conditions of living and business.

The main goal of the article is to evaluate the suitability of renewables as a factor that could offer better living and business environment for rural population. Estimation is done according to deep expertise and personal opinions (based on previously developed structured questionnaire and results derived from multi-criteria analysis) of relevant represents from academic and professional community of Serbia and Bosnia and Herzegovina active in the field of renewable energy utilization, that could be later implied to all WB countries.

The articles' contribution could be considered in the following:

- Supported by expert decision-making, it will be determined the most suitable type of RES for rural communities in the WB;
- Applying the fuzzy-rough methodology will enable a decrease in subjectivity in decision-making, while it will support independence in the decision-making process;
- The propagation of the f RESs' use in rural areas will be made in order to decrease the overall dependence on fossil fuels; and
- It will enable the performance of further research according to the use of the fuzzy-rough approach.

## Research Design and Methodology

In Figure 1 is showed the used mechanism in research performing. The first step is selection of experts who will be engaged in this research (Table 1).

When conducting this research, the first thing to do is to select an expert (Figure 1). Then, together with

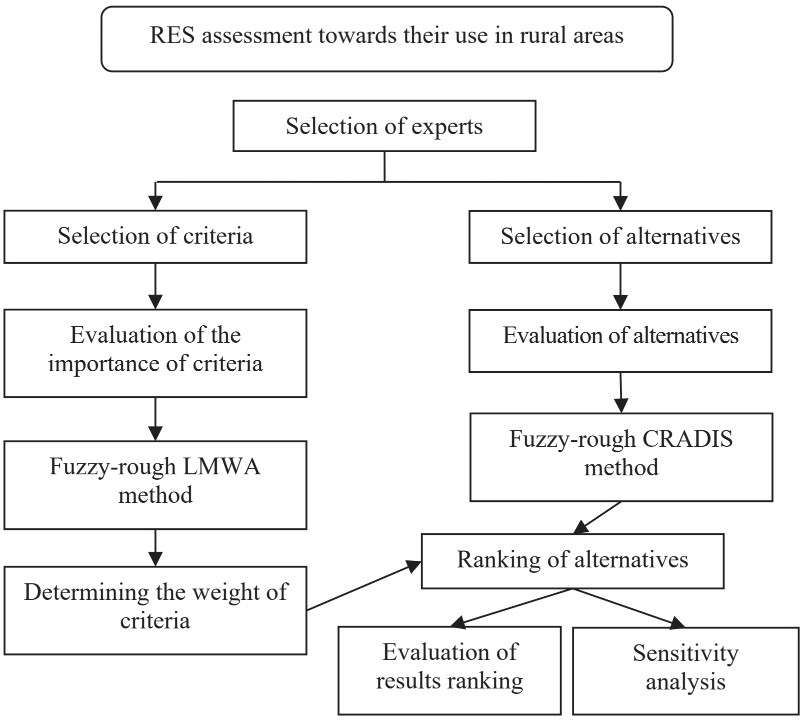


Figure 1. Research methodology.

Table 1

**Information related to engaged experts**

| Expert | Experts' title | Institution |
|---|---|---|
| Expert 1 | Principal Research Fellow | Institute Mihajlo Pupin, Belgrade, Serbia |
| Expert 2 | Principal Research Fellow | Institute Mihajlo Pupin, Belgrade, Serbia |
| Expert 3 | Research Associate | Institute Mihajlo Pupin, Belgrade, Serbia |
| Expert 4 | Research Assistant | Faculty of Mining and Geology, Belgrade University, Serbia |
| Expert 5 | Associate Professor | Technical Faculty "Mihajlo Pupin" - Zrenjanin, University of Novi Sad, Serbia |
| Expert 6 | Research Associate | Institute Mihajlo Pupin, Belgrade, Serbia |
| Expert 7 | Associate Professor | Technical Faculty "Mihajlo Pupin" - Zrenjanin, University of Novi Sad, Serbia |
| Expert 8 | Associate Professor | Technical Faculty "Mihajlo Pupin" - Zrenjanin, University of Novi Sad, Serbia |

these experts, criteria and alternatives are chosen based on the set goals. The goal was set in cooperation with experts. The experts then determined the importance of the criteria and evaluated the alternatives using them. Using the fuzzy-rough LMWA method, the weight of the criteria was determined, while the fuzzy-rough CRADIS method was used to rank the alternatives, because it is necessary to use the value of the weight of the criteria. After that, the alternatives are ranked with other MCDM methods through the evaluation of the results of the alternatives, and a sensitivity analysis is performed by changing the weight of the criteria.

A total of eight experts from a total of 3 institutions were selected. The reason why these institutions were chosen is that most of the countries of the Western Balkans belong to the countries of the former Yugoslavia. The largest agricultural research centers in the former Yugoslavia are located in the vicinity of the former capital of Yugoslavia, i.e. Belgrade, and these three institutions have the greatest tradition in the Western Balkans.

These experts together with researchers are determining which criteria (Table 2) and alternatives will be considered. In order to find out which of six available alternatives (solar energy (A1), wind energy (A2), biomass (A3), biogas (A4), geo and hydro-thermal energy (A5), energy potential of watercourses (A6)) is the best solution for the use as the sustainable source of energy in rural areas, initially there is a need to define the importance of selected criteria (nine criteria) by determining their weights. For this activity the fuzzy-rough LMWA method should be used. Afterwards, the ranking of the alternatives is determined, while mentioned activity will be done using the fuzzy-rough CRADIS method. Ensuring the correctness of the final decision requires validation of derived results, as well as carrying out the sensitivity analysis.

When using the criteria (Table 2), care was taken to ensure that these criteria are general so that it can be seen globally how a particular RES can be applied in practice. The research was not conducted in a specific locality where these alternatives would be observed, but rather the entire area of the Western Balkans was observed as a whole. The goal is to present a global picture of which RES alternatives are the most suitable for the entire territory, but this does not mean that some other alternatives will not be better in a particular area.

*Fuzzy-rough approach*

There are many approaches for selecting the best alternative by the use of multi-criteria decision analysis (MCDM) methods (Tešić *et al.,* 2023). One of the most applied is the use of fuzzy numbers, which allow utilization of incomplete and imprecise information in decision-making process. Research implies, the assessment of criteria and alternatives is in the form of linguistic values that have to be considered in order to answer the question which alternative for renewable energy sources (RES) is the best option for the rural areas in the WB. Linguistic values are a useful tool in solving too complex situations, or situations that are incompletely defined to be quantitatively evaluated. On that occasion, the decision is made under the subjective influence of experts, as through the use of mentioned values they are evaluating the importance of observed criteria, as well as they assess the available alternatives. In order to mitigate subjectivity and include uncertainty in decision making, besides fuzzy numbers the rough numbers have been also used. So, this research combines the fuzzy and rough approach in selecting optimal RES alternative for the rural areas. Initially, the linguistic values are transformed into the

Table 2

**Criteria used in RES assessment**

| Id | Criteria | Definition |
|---|---|---|
| C1 | Price of RES plant implementation | Sum of financial assets required for purchasing, building, installing, putting into the operation, administering, and etc. of all parts linked to certain RES plant. |
| C2 | Ecological impact of RES plant use | Depth of eco-footprint made by RES plant use, i.e. level of damages within the available natural environment and value of externalities affected by the RES plant use in defined rural area. |
| C3 | Sustainability of implemented RES plant use | Longevity of specific parts or overall implemented RES plant, profitability and efficiency of certain RES plant use, appearance of certain social impacts, etc. |
| C4 | Period required for RES plant implementation | Time-period required for performing all necessary activities toward starting using certain RES plant (assuming turn-key system). |
| C5 | Ergonomics of RES plant use | Level of knowledge and skills required for RES usage, level of risks linked to human health that arise from direct use of RES plant, level of user friendly, etc. |
| C6 | Availability of RES at certain micro-locality level | In general, level of availability and specificities of availability of certain RES over the year at some rural territory. |
| C7 | Different opportunities of RES use | Number of different (non)agricultural activities that could be performed at farm property or generally in rural space, and which could be based on the use of RES. |
| C8 | Costs of RES plant maintaining | Frequency, complexity and level of costs linked to regular maintenance activities of certain RES plant in use. |
| C9 | Possibilities for joint use of implemented RES plant | Possibility of certain RES plant use at single farm, cooperative or even overall rural community level. |

fuzzy numbers using the membership function, while later the lower and upper limits of individual fuzzy numbers are determined by the use of rough approach. In this way, subjectivity in decision-making process is reduced, simultaneously with inclusion of uncertainty (Pamučar *et al.*, 2018). Because of these advantages, the fuzzy-rough approach was chosen. Based on this approach, it is possible to make decisions when there is no precise information, which is the case when qualitative values are used instead of quantitative ones. Then it is possible to include uncertainty in decision-making, which achieves greater certainty in decision-making.

Assume that universe A is covered with the elements of the set $\theta^e$, i.e. $\theta^e = (\tilde{X}_1, \tilde{X}_2, \ldots \tilde{X}_n)$. In this universe are also fuzzy values $\tilde{X}_i$ that could be presented with $\tilde{X}_i = \left(x_i^l, x_i^m, x_i^u\right), (i = 1,2,\ldots,n)$, or basically all elements are presented with triangular fuzzy number. If it is assumed that $\theta^e = \{x_1^e, x_2^e, \ldots, x_n^e\}$ $(e = l, m, n)$ occur as fuzzy numbers, then the lower and upper limits of element $\tilde{X}_i$ could be defined by the rough approach in following way (Zhu *et al.,* 2022):

$$\underline{Lim}(c_i^e) = \frac{1}{N^e}\sum_{i=1}^{N^e} \varphi \epsilon \underline{Apr}(c_i^e), \quad (1)$$

$$\overline{Lim}(c_i^e) = \frac{1}{N^e}\sum_{i=1}^{\overline{N}^e} \varphi \epsilon \overline{Apr}(c_i^e) \quad (2)$$

Based on these values is forming the fuzzy-rough number $\tilde{X}_i$ that could be expressed as (Pamučar *et al.,* 2018):

$$FR\left(\bar{\bar{X}}_i\right) = \left(\left[x_i^{lL}, x_i^{lU}\right], \left[x_i^{mL}, x_i^{mU}\right], \left[x_i^{uL}, x_i^{uU}\right]\right) = \left(\left[\underline{Lim}(x_i^l), \overline{Lim}(x_i^l)\right], \left[\underline{Lim}(x_i^m), \overline{Lim}(x_i^m)\right], \left[\underline{Lim}(x_i^u), \overline{Lim}(x_i^u)\right]\right) \quad (3)$$

Where the labels *l, m, u* indicate individual fuzzy numbers, while the values L and U indicate the lower and upper limits of the rough number, while the label FR indicates the fuzzy-rough set.

If there are two universes A and B, then the following operations can be performed with the elements of fuzzy-rough numbers set in these universes:

Addition:

$$FR(\bar{a}) + FR(\bar{b}) = ([a^{lL}, a^{lU}], [a^{mL}, a^{mU}], [a^{uL}, a^{uU}]) + ([b^{lL}, b^{lU}], [b^{mL}, b^{mU}], [b^{uL}, b^{uU}]) = [a^{lL} + b^{lL}, a^{lU} + b^{lU}], [a^{mL} + b^{mL}, a^{mU} + b^{mU}], [a^{uL} + b^{uL}, a^{uU} + b^{uU}] \tag{4}$$

Subtraction:

$$FR(\bar{a}) - FR(\bar{b}) = ([a^{lL}, a^{lU}], [a^{mL}, a^{mU}], [a^{uL}, a^{uU}]) + ([b^{lL}, b^{lU}], [b^{mL}, b^{mU}], [b^{uL}, b^{uU}]) = [a^{lL} - b^{uU}, a^{lU} - b^{uL}], [a^{mL} - b^{mU}, a^{mU} - b^{mL}], [a^{uL} - b^{lU}, a^{uU} - b^{lL}] \tag{5}$$

Multiplication:

$$FR(\bar{a}) \times FR(\bar{b}) = ([a^{lL}, a^{lU}], [a^{mL}, a^{mU}], [a^{uL}, a^{uU}]) + ([b^{lL}, b^{lU}], [b^{mL}, b^{mU}], [b^{uL}, b^{uU}]) = [a^{lL} \times b^{lL}, a^{lU} \times b^{lU}], [a^{mL} \times b^{mL}, a^{mU} \times b^{mU}], [a^{uL} \times b^{uL}, a^{uU} \times b^{uU}] \tag{6}$$

Division:

$$FR(\bar{a}) \div FR(\bar{b}) = ([a^{lL}, a^{lU}], [a^{mL}, a^{mU}], [a^{uL}, a^{uU}]) + ([b^{lL}, b^{lU}], [b^{mL}, b^{mU}], [b^{uL}, b^{uU}]) = [a^{lL} \div b^{uU}, a^{lU} \div b^{uL}], [a^{mL} \div b^{mU}, a^{mU} \div b^{mL}], [a^{uL} \div b^{lU}, a^{uU} \div b^{lL}] \tag{7}$$

Scalar multiplication:

$$c \times FR(\bar{a}) = c \times ([a^{lL}, a^{lU}], [a^{mL}, a^{mU}], [a^{uL}, \alpha^{uU}]) = ([c \times a^{lL}, c \times a^{lU}], [c \times a^{mL}, c \times a^{mU}], [c \times a^{uL}, c \times a^{uU}]) \tag{8}$$

Scalar division:

$$\frac{RF(\bar{a})}{c} = \frac{[a^{lL}, a^{lU}], [a^{mL}, a^{mU}], [a^{uL}, a^{uU}]}{c} = \left(\left[\frac{a^{lL}}{c}, \frac{a^{lU}}{c}\right], \left[\frac{a^{mL}}{c}, \frac{a^{mU}}{c}\right], \left[\frac{a^{uL}}{c}, \frac{a^{uU}}{c}\right]\right) \tag{9}$$

*Fuzzy-rough LMWA method*

By the fuzzy-rough approach is making the transformation of LMWA method, as it is used in solving certain problems.

It implies following steps (Štilić *et al.,* 2023):

Step 1. Formation of the initial decision matrix. Forming of matrix is based on evaluation of certain criteria according to predefined linguistic values (Table 3).

Table 3

**Linguistic values with membership function used in criteria assessment**

| Linguistic values | Fuzzy numbers |
|---|---|
| Absolutely low (AL) | (1, 1, 1) |
| Very low (VL) | (1, 2, 3) |
| Low (L) | (2, 3, 4) |
| Medium low (ML) | (3, 4, 5) |
| Equal (E) | (4, 5, 6) |
| Medium high (MH) | (5, 6, 7) |
| High (H) | (6, 7, 8) |
| Very high (EH) | (7, 8, 9) |
| Absolutely high (AH) | (8, 9, 10) |
| Perfect (P) | (9, 10, 10) |

Source: Pamučar *et al.,* 2023

Step 2. Linguistic values transferring into the fuzzy numbers, while performing this activity by the use of utility function (Table 3).

Step 3. Defining the lower and upper limits of rough number for each fuzzy number, i.e. forming the fuzzy-rough number $\bar{\bar{\gamma}}_{Cn}^{e}$.

$$\bar{\bar{\gamma}}_{Cn}^{e} = ([\alpha^{lL}, \alpha^{lU}], [\alpha^{mL}, \alpha^{mU}], [\alpha^{uL}, \alpha^{uU}]) \tag{10}$$

Step 4. Defining the absolute anti-ideal point ($\bar{\bar{\gamma}}_{AIP}$), where mentioned value is lower than the lowest value of the fuzzy-rough numbers $\bar{\bar{\gamma}}_{Cn}^{e}$.

Step 5. Defining the ratio vector, i.e. dividing the fuzzy-rough numbers $\bar{\bar{\gamma}}_{Cn}^{e}$ with anti-ideal point ($\bar{\bar{\gamma}}_{AIP}$).

$$\bar{\bar{\mu}}_{Cn}^{e} = \left(\frac{\bar{\bar{\gamma}}_{Cn}^{e}}{\bar{\bar{\gamma}}_{AIP}}\right) = \left(\left[\frac{\alpha^{lL}}{\gamma_{AIP}} \cdot \frac{\alpha^{lU}}{\gamma_{AIP}}\right] \cdot \left[\frac{\alpha^{mL}}{\gamma_{AIP}} \cdot \frac{\alpha^{mU}}{\gamma_{AIP}}\right] \cdot \left[\frac{\alpha^{uL}}{\gamma_{AIP}} \cdot \frac{\alpha^{uU}}{\gamma_{AIP}}\right]\right) \tag{11}$$

Step 6. Determination of the weight coefficients' vector for each expert.

$$\bar{\bar{\omega}}_{j}^{e} = \left(\frac{\ln(\bar{\bar{\mu}}_{Cn}^{LU})}{\ln(\prod_{j=1}^{n} \bar{\bar{\mu}}_{Cn}^{LU})}\right) = \left(\left[\frac{\ln(\mu_{Cn}^{lL})}{\ln(\prod_{j=1}^{n} \mu_{Cn}^{uU})}; \frac{\ln(\mu_{Cn}^{lU})}{\ln(\prod_{j=1}^{n} \mu_{Cn}^{uL})}\right] \cdot \left[\frac{\ln(\mu_{Cn}^{mL})}{\ln(\prod_{j=1}^{n} \mu_{Cn}^{mU})}; \frac{\ln(\mu_{Cn}^{mU})}{\ln(\prod_{j=1}^{n} \mu_{Cn}^{mL})}\right] \cdot \left[\frac{\ln(\mu_{Cn}^{uL})}{\ln(\prod_{j=1}^{n} \mu_{Cn}^{lU})}; \frac{\ln(\mu_{Cn}^{uU})}{\ln(\prod_{j=1}^{n} \mu_{Cn}^{lL})}\right]\right) \tag{12}$$

Step 7. Calculation of the aggregated vectors of weight coefficients using the Bonferroni aggregator.

$$\overline{\overline{\omega}}_j = \left(\frac{1}{k(k-1)}\sum_{\substack{i.j=1\\ i\neq j}}^{k} \overline{\overline{\omega}}_i^{(UL)p}\,\overline{\overline{\omega}}_i^{(UL)q}\right)^{\frac{1}{p+q}} \tag{13}$$

Gained values for weights will be furtherly used in fuzzy-rough CRADIS method.

*Fuzzy-rough CRADIS method*

The fuzzy-rough CRADIS method will be used to rank the alternative. This method was chosen for the following reasons:

- The CRADIS method determines deviations based on the largest and smallest ideal and anti-ideal values. Unlike other similar methods that determine these values for individual criteria, in this way all criteria are approached equally and the weights of the criteria are taken into account;
- The CRADIS method, in addition to calculating deviations from these values, also calculates the utility function in relation to optimal alternatives;
- Through its steps, the CRADIS method modifies the steps of other methods, and in this way, by applying this method; certain essential steps of other methods that characterize those methods are also applied;
- By using the CRADIS method, the affirmation of new MCDM methods is carried out.

In order to use the CRADIS method for solving certain issue, there is a need for its modification into the fuzzy-rough CRADIS method. So, method implies combining the fuzzy CRADIS and rough CRADIS methods. Up today, in previous works, steps that characterize mentioned method have not been defined yet.

Table 4

**Linguistic values with membership function at assessment of alternatives**

| Linguistic values | Fuzzy numbers |
|---|---|
| Very bed (VB) | (1, 1, 2) |
| Bed (B) | (1, 2, 4) |
| Medium bed (MB) | (2, 4, 6) |
| Medium (M) | (3, 5, 7) |
| Medium good (MG) | (5, 7, 9) |
| Good (G) | (7, 9, 10) |
| Very good (VG) | (9, 10, 10) |

Source: Puška *et al.,* 2023

Step 1. Forming the decision matrix, i.e. previous to exercising the steps of the CRADIS method, it is necessary to form the initial fuzzy-rough matrix. Firstly, a linguistic decision matrix is formed according to expert's evaluation of selected alternatives by the use of predefined criteria. Then, linguistic values are transforming into the fuzzy numbers (Table 4) applying the membership function, while later the lower and upper limits of individual fuzzy numbers have been determined, i.e. way of forming the fuzzy-rough decision matrix.

Once the fuzzy-rough decision matrix is established, the steps of the CRADIS method are applying.

Step 2. Normalization of fuzzy-rough decision matrix. It implies previous determination of the type of criteria, whether they are benefit or cost type, while later according to set criteria type certain normalization formula are used:

$$\overline{\overline{n}}_{ij} = \left(\left[\frac{\alpha^{lL}}{max_i\alpha_i^{uU}}\cdot\frac{\alpha^{lU}}{max_i\alpha_i^{uL}}\right]\cdot\left[\frac{\alpha^{mL}}{max_i\alpha_i^{mU}}\cdot\frac{\alpha^{mU}}{max_i\alpha_i^{mL}}\right]\cdot\right.$$
$$\left.\cdot\left[\frac{\alpha^{uL}}{max_i\alpha_i^{lU}}\cdot\frac{\alpha^{uU}}{max_i\alpha_i^{lL}}\right]\right) \text{ for benefit criteria} \tag{14}$$

$$\overline{\overline{n}}_{ij} = \left(\left[\frac{\min x_j^{lL}}{x_{ij}^{uU}},\frac{\min x_j^{lU}}{x_{ij}^{uL}}\right],\left[\frac{\min x_j^{mL}}{x_{ij}^{mU}},\frac{\min x_j^{mU}}{x_{ij}^{mL}}\right],\right.$$
$$\left.\left[\frac{\min x_{ij}^{uL}}{x_{ij}^{lU}},\frac{\min x_j^{uU}}{x_{ij}^{lL}}\right]\right) \text{ for cost criteria} \tag{15}$$

Step 3. Weighting the normalized fuzzy-rough decision matrix. Step considers multiplication of normalized fuzzy-rough decision matrix with determined weights.

$$\overline{\overline{v}}_{ij} = \overline{\overline{w}}_j \cdot \overline{\overline{n}}_{ij} \tag{16}$$

Step 4. Determining the ideal and anti-ideal values. The highest value among all elements within the weighted decision matrix ($\overline{\overline{v}}_{ij}$) represents the ideal value, or contrary to that the lowest value ($\overline{\overline{v}}_{ij}$) is identified as the anti-ideal value.

$$\overline{\overline{t}}_i = \max \overline{\overline{v}}_{ij},$$
$$\text{where } \overline{\overline{v}}_{ij} = ([v^{lL},v^{lU}],[v^{mL},v^{mU}],[v^{uL},v^{uU}]) \tag{17}$$

$$\overline{\overline{t}}_{ai} = \min \overline{\overline{v}}_{ij},$$
$$\text{where } \overline{\overline{v}}_{ij} = ([v^{lL},v^{lU}],[v^{mL},v^{mU}],[v^{uL},v^{uU}]) \tag{18}$$

Step 5. Determining the deviation from ideal and anti-ideal value, i.e. calculating the deviation from ideal and anti-ideal values for individual elements of weighted decision matrix $\overline{\overline{v}}_{ij}$.

$$\overline{\overline{d}}^{+} = \overline{\overline{t}}_i - \overline{\overline{v}}_{ij} \tag{19}$$

$$\overline{\overline{d}}^{-} = \overline{\overline{v}}_{ij} - \overline{\overline{t}}_{ai} \tag{20}$$

Step 6. Forming the optimal alternatives. At deviation from the ideal value, optimal alternative represents one that has the lowest values for all criteria and alternatives. Contrary to that, at deviation from the anti-ideal value, optimal alternative represents one that has the highest values for each observed criteria and alternatives.

Step 7. Determining the cumulative deviation of alternative from ideal and anti-ideal values.

$$\bar{\bar{s}}_i^+ = \sum_{j=1}^{n} \bar{\bar{d}}^+ \quad (21)$$

$$\bar{\bar{s}}_i^- = \sum_{j=1}^{n} \bar{\bar{d}}^- \quad (22)$$

Step 8. Calculating the utility function, where the utility function is calculating in line to the both optimal alternatives.

$$\bar{\bar{K}}_i^+ = \frac{\bar{\bar{s}}_0^+}{\bar{\bar{s}}_i^+} = \left(\left[\frac{s_0^{+lL}}{s_i^{+uU}}, \frac{s_0^{+lU}}{s_i^{+uL}}\right], \left[\frac{s_0^{+mL}}{s_i^{+mU}}, \frac{s_0^{+mU}}{s_i^{+mL}}\right], \left[\frac{s_0^{+uL}}{s_i^{+lU}}, \frac{s_0^{+uU}}{s_i^{+lL}}\right]\right) \quad (23)$$

$$\bar{\bar{K}}_i^- = \frac{\bar{\bar{s}}_i^-}{\bar{\bar{s}}_0^-} = \left(\left[\frac{s_i^{-lL}}{s_0^{-uU}}, \frac{s_i^{-lU}}{s_0^{-uL}}\right], \left[\frac{s_i^{-mL}}{s_0^{-mU}}, \frac{s_i^{-mU}}{s_0^{-mL}}\right], \left[\frac{s_i^{-uL}}{s_0^{+lU}}, \frac{s_i^{-uU}}{s_0^{+lL}}\right]\right) \quad (24)$$

Where $\bar{\bar{s}}_0^+$ represents the optimal ideal alternative, while $\bar{\bar{s}}_0^-$ represents optimal anti-ideal alternative.

Step 9. Ranking the alternatives according to average value of utility function.

$$\bar{\bar{Q}}_i = \frac{\bar{\bar{K}}_i^+ + \bar{\bar{K}}_i^+}{2} \quad (26)$$

Step 10. Definig the final value of the fuzzy-rough CRADIS method.

$$R_i = \frac{Q_i^{lL} + Q_i^{lU} + Q_i^{mL} + Q_i^{mU} + Q_i^{uL} + Q_i^{uU}}{6} \quad (27)$$

As the best (optimal) alternative could be considered one with the highest value, or contrary to that the worst one has the lowest value of the fuzzy-rough CRADIS number.

On a practical example, each of these steps will be explained in detail because the CRADIS method has not been used in fuzzy-rough form so far, so it is necessary to explain in detail how the calculation of this method is performed.

## Results

Principally, before determining which RES could optimally fit the rural area's needs, it is necessary to define the importance of used criteria by which alternatives are evaluated. So, firstly are defined the significance of each criteria by computing their weights, i.e. initial step in criteria weighting is valuation of criteria importance. This implies expert rating of criteria importance by the linguistic values (Table 5), or forming the linguistic decision matrix, basic tool in criteria weights determination.

Next step in determining weights is the transformation of linguistic values into the fuzzy numbers (Table 3) by applying the fuzzy number membership function. Then, by applying the principles for rough numbers, the lower and upper limits of individual fuzzy numbers are calculated, while later the initial fuzzy-rough decision matrix has been formed.

On the example of criterion C1 the used mechanism looks like: the linguistic value Absolutely high (AH) is transformed into a fuzzy number (8, 9, 10), while the linguistic value Perfect (P) is transformed into a fuzzy number (9, 10, 10). After that, the lower and upper limits for this criterion are determined. So statement of the Expert 1 could be considered like this $\alpha^{lL} = \frac{9+8+9+9+8+9+9+9}{8} = 8.75; \alpha^{lU} = \frac{9+9+9+9+9+9}{6} =$ $= 9.00; \alpha^{mL} = \frac{10+9+10+10+9+10+10+10}{8} = 9.75;\ \alpha^{mU} =$ $\frac{10+10+10+10+10+10}{6} = 10; \alpha^{uL} =$ $= \frac{10+10+10+10+10+10+10+10}{8} = 10.00; \alpha^{uU} =$ $\frac{10+10+10+10+10+10+10+10}{8} = 10.00$

Table 5

**Linguistic decision matrix for criteria**

| Experts | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
|---|---|---|---|---|---|---|---|---|---|
| Expert 1 | P | P | P | E | H | EH | MH | EH | EH |
| Expert 2 | AH | AH | AH | EH | EH | EH | EH | AH | AH |
| Expert 3 | P | P | P | AH | AH | P | EH | P | AH |
| Expert 4 | P | P | P | EH | H | H | H | P | P |
| Expert 5 | AH | P | AH | EH | H | MH | H | P | P |
| Expert 6 | P | P | EH | EH | H | H | H | P | P |
| Expert 7 | P | EH | AH | H | H | H | MH | P | P |
| Expert 8 | P | E | EH | E | L | AH | H | MH | ML |

Table 6

**Determing the fuzzy-rough decision matrix**

| Experts | C1 | C2 | ... | C9 |
|---|---|---|---|---|
| Expert 1 | ([8.8, 9.0][9.0, 10][10, 10]) | ([8.0, 9.0][9.0, 10][10, 10]) | ... | ([5.0, 8.4][8.4, 9.4][9.4, 9.9]) |
| Expert 2 | ([8.0, 8.8][8.8, 9.8] [9.8, 10]) | ([6.3, 8.8][8.8, 9.8][9.8, 10]) | ... | ([6.5, 8.7][8.7, 9.7][9.7, 10]) |
| Expert 3 | ([8.8, 9.0][9.0, 10][10, 10]) | ([8.0, 9.0][9.0, 10][10, 10]) | ... | ([6.5, 8.7][8.7, 9.7][9.7, 10]) |
| Expert 4 | ([8.8, 9.0][9.0, 10][10, 10]) | ([8.0, 9.0][9.0, 10][10, 10]) | ... | ([7.8, 9.0][9.0, 10][10, 10]) |
| Expert 5 | ([8.0, 8.8][8.8, 9.8][9.8, 10]) | ([8.0, 9.0][9.0, 10][10, 10]) | ... | ([7.8, 9.0][9.0, 10][10, 10]) |
| Expert 6 | ([8.8, 9.0][9.0, 10][10, 10]) | ([8.0, 9.0][9.0, 10][10, 10]) | ... | ([7.8, 9.0][9.0, 10][10, 10]) |
| Expert 7 | ([8.8, 9.0][9.0, 10][10, 10]) | ([5.5, 8.6][8.6, 9.6][9.6, 9.9]) | ... | ([7.8, 9.0][9.0, 10][10, 10]) |
| Expert 8 | ([8.8, 9.0][9.0, 10][10, 10]) | ([4.0, 8.0][8.0, 9.0][9.0, 9.4]) | ... | ([3.0, 7.8][7.8, 8.8][8.8, 9.3]) |

In this way, the lower and upper limits of fuzzy-rough numbers are created. When determining the lower limit of a certain fuzzy-rough number, the fuzzy number of each individual expert is observed, while all values of other experts are considered if they are the same or less than the value of an expert in a focus. Contrary to that, in case of upper limit, the same or higher values obtained from other experts are taken into the consideration. By applying mentioned principle, a fuzzy-rough decision matrix is established (Table 6). In process of decision matrix creation, it is necessary to take care that the upper limit of the first fuzzy-rough number is less than or the same as the lower limit of the second fuzzy-rough number, or, the upper limit of the second fuzzy-rough number has to be less than or the same as the lower limit of the third fuzzy-rough number, etc. This is why the matrix is being corrected. Due to the fact that there were many requirements for a change, it is necessary to set the upper limit of the first fuzzy-rough number as the lower limit of the second fuzzy-rough number, while the upper limit of the second fuzzy-rough number should be the lower limit of the third fuzzy-rough number, etc., in order to give the same treatment to all observed criteria and engaged experts. If only a few limits were changed, those limits would be possibly lower or higher than other unchanged limits. So, in this way, all lower and upper limits of fuzzy-rough numbers are treated in the same way.

Next step is determining the absolute anti-ideal point ($\tilde{\gamma}_{AIP}$). As the lowest value in the fuzzy-rough decision matrix is 2.00, $\tilde{\gamma}_{AIP}$ takes the value of 1.90, i.e. the value that is lower than the lowest value within the fuzzy-rough decision matrix. Then all the values in fuzzy-rough decision matrix are divided by this value, e.g. in case of the first Expert for the first criterion C1 mentioned mechanism looks like:

$$\bar{\bar{\mu}}_{11}^{1} = \left(\left[\frac{8.8}{1.9} = 4.6, \frac{9.0}{1.9} = 4.7\right].\left[\frac{9.0}{1.9} = 4.7, \frac{10.0}{1.9} = 5.3\right].\left[\frac{10.0}{1.9} = 5.3, \frac{10.0}{1.9} = 5.3\right]\right).$$

In same way are computing other elements of fuzzy rough matrix. Then the vector of weight coefficients for individual experts is determined. In this step is calculated the value of natural logarithm from the individual values of the fuzzy-rough matrix multiplying with the natural logarithm of all criteria values for individual experts, e.g. in case of the first Expert for the first criterion C1 the applied mechanism looks like: $\bar{\bar{\omega}}_{1}^{1} = \left(\left[\frac{1.5}{14.3} = 0.11, \frac{1.6}{13.7} = 0.11\right].\left[\frac{1.6}{13.7} = 0.11, \frac{1.7}{12.6} = 0.13\right].\left[\frac{1.7}{12.6} = 0.13, \frac{1.7}{10.5} = 0.16\right]\right)$. So, on that way are computing the values of vectors of weight coefficients for each expert for all criteria. At the end are used the aggregated vectors of weight coefficients, gained by the Bonferroni aggregator, while the final weights of criteria are formed (Table 7). According to derived results the highest weight is linked with the criterion C1 (price of RES plant implementation), while the lowest weight is linked to the criterion C5 (ergonomics of RES plant use).

Table 7

**Final weights of criteria**

| Criteria | Weights |
|---|---|
| C1 | [(0.10, 0.11) (0.11, 0.13) (0.13, 0.15)] |
| C2 | [(0.09, 0.11) (0.11, 0.13) (0.13, 0.15)] |
| C3 | [(0.10, 0.11) (0.11, 0.13) (0.13, 0.15)] |
| C4 | [(0.07, 0.09) (0.09, 0.11) (0.11, 0.14)] |
| C5 | [(0.05, 0.09) (0.09, 0.11) (0.11, 0.14)] |
| C6 | [(0.08, 0.10) (0.10, 0.12) (0.12, 0.15)] |
| C7 | [(0.07, 0.09) (0.09, 0.11) (0.11, 0.14)] |
| C8 | [(0.09, 0.11) (0.11, 0.13) (0.13, 0.15)] |
| C9 | [(0.08, 0.11) (0.11, 0.13) (0.13, 0.15)] |

Table 8

**Initial linguistic decision matrix**

| Expert 1 | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
|---|---|---|---|---|---|---|---|---|---|
| A1 | M | VG | G | G | G | VG | VG | B | VG |
| A2 | MB | G | G | VG | G | MB | MB | VB | MG |
| A3 | B | B | MG | VG | VG | M | MG | MB | VG |
| A4 | M | MB | M | MB | M | B | MG | MG | MB |
| A5 | MB | VG | VG | M | G | VB | MB | VB | G |
| A6 | M | VG | VG | MG | G | VB | MB | MB | G |
| Expert 2 | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
| A1 | MG | MG | G | VG | MG | M | G | B | VG |
| A2 | MG | M | G | MG | MG | M | G | MB | G |
| A3 | M | MB | M | MB | M | MB | MG | M | MG |
| A4 | M | MB | M | MB | M | MB | MG | M | MG |
| A5 | M | MB | MB | MB | M | MB | MG | M | MG |
| A6 | MB | MB | MG | MG | M | M | MG | MB | G |
| Expert 3 | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
| A1 | VG | VG | VG | G | G | VG | MG | VG | M |
| A2 | VG | VG | VG | G | G | VG | MG | VG | VG |
| A3 | VG | VG | VG | G | G | VG | MG | VG | MG |
| A4 | VG | VG | VG | G | G | VG | MG | VG | MG |
| A5 | VG | VG | VG | G | G | VG | MG | VG | VG |
| A6 | VG | VG | VG | G | G | VG | MG | VG | VG |
| Expert 4 | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
| A1 | MG | VG | MG | VG | VG | VG | VG | G | VG |
| A2 | MB | VG | MG | M | MG | MG | VG | B | VG |
| A3 | G | MG | G | MG | MG | VG | VG | MG | VG |
| A4 | MG | MG | G | MG | MG | MG | VG | M | VG |
| A5 | VG | MG | G | MG | M | M | VG | M | VG |
| A6 | VG | MG | G | MG | M | M | VG | M | VG |
| Expert 5 | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
| A1 | M | G | MG | G | MG | VG | VG | G | VG |
| A2 | MG | G | G | M | G | G | G | MG | MG |
| A3 | MG | MG | MG | G | G | G | VG | MG | VG |
| A4 | M | M | MG | MG | MG | G | VG | MB | VG |
| A5 | VG | M | MG | G | G | M | VG | M | VG |
| A6 | MG | MG | G | MG | M | MG | VG | M | VG |
| Expert 6 | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
| A1 | M | G | MG | G | MG | VG | VG | G | VG |
| A2 | G | G | G | M | G | G | G | MG | MG |
| A3 | G | G | VG | G | G | VG | G | VG | G |
| A4 | M | M | VG | VG | MG | G | VG | MB | VG |
| A5 | VG | M | MG | G | G | MB | VG | M | VG |
| A6 | MG | MG | G | MG | M | MG | VG | M | G |
| Expert 7 | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
| A1 | MG | G | MG | G | M | VG | VG | G | VG |
| A2 | VG | G | G | MG | VG | G | G | G | VG |
| A3 | G | G | VG | G | G | MG | G | VG | G |
| A4 | VG | MG | M | G | MG | G | G | G | VG |
| A5 | VG | M | MG | G | G | MG | VG | MG | VG |
| A6 | MG | MG | G | MG | G | VG | VG | M | G |
| Expert 8 | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
| A1 | MG | G | G | VG | G | G | VG | G | VG |
| A2 | M | G | G | G | G | MG | M | G | VG |
| A3 | M | MB | MG | MG | M | M | VG | MG | VG |
| A4 | MG | MG | M | MG | MG | VG | VG | MG | VG |
| A5 | MB | M | M | M | G | MB | VG | M | M |
| A6 | VB | B | G | B | MB | VB | M | MB | B |

Table 9

**Determining the initial fuzzy-rough decision matrix**

| A/C | C1 | C2 | … | C9 |
|---|---|---|---|---|
| A1 | ([3.8, 5.8][5.8, 7.5][7.5, 9.0]) | ([6.7, 8.2][8.2, 9.6][9.6, 10]) | … | ([7.6, 8.9][8.9, 9.9][9.9, 10]) |
| A2 | ([3.5, 7.1][7.1, 8.6] [8.6, 9.4]) | ([6.1, 7.9][7.9, 9.4][9.4, 10]) | ... | ([6.2, 8.3][8.3, 9.5][9.5, 9.9]) |
| A3 | ([3.5, 6.9][6.9, 8.6][8.6, 9.5]) | ([2.9, 6.6][6.6, 8.3][8.3, 10]) | ... | ([6.5, 8.5][8.5, 9.7][9.7, 9.9]) |
| A4 | ([3.7, 6.5][6.5, 8.0][8.0, 9.0]) | ([3.0, 5.7][5.7, 7.4][7.4, 8.8]) | ... | ([5.7, 8.5][8.5, 9.6][9.6, 9.8]) |
| A5 | ([4.9, 8.3][8.3, 9.4][9.4, 9.6]) | ([3.2, 6.3][6.3, 7.8][7.8, 8.8]) | ... | ([6.2, 8.7][8.7, 9.8][9.8, 9.9]) |
| A6 | ([3.1, 6.8][6.8, 8.2][8.2, 9.2]) | ([3.5, 6.8][6.8, 8.3][8.3, 9.4]) | ... | ([5.7, 8.2][8.2, 9.5][9.5, 9.9]) |
| *max* | ([4.9, 8.3][8.3, 9.4][9.4, 9.6]) | ([6.7, 8.2][8.2, 9.6][9.6, 10]) | ... | ([7.8, 8.9][8.9, 9.9][9.9, 10]) |

Determination of criteria weights is followed by the ranking of the available alternatives using the fuzzy-rough CRADIS method. According to this method, the initial step is to determine the starting linguistic decision matrix (Table 8). This matrix is obtained after the experts have been evaluated the observed alternatives with selected criteria.

In order to operate with mentioned decision matrix, the same steps as the steps at the fuzzy-rough LMWA method are performed, such are transformation of linguistic values into the fuzzy numbers (Table 4), or determination of lower and upper limits for fuzzy-rough numbers. By applying the same principles, the initial fuzzy-rough decision matrix is established (Table 9).

Next step is normalization of previously formed fuzzy-rough decision matrix. Due to fact that the linguistic values are in the form from very bad to very good, it is not necessary to determine the type of criteria, so all criteria are considered as benefit criteria.

Therefore, firstly it is necessary to determine the maximal values for each criterion, and then it is required to divide the individual values by maximal values, e.g. for alternative A1 and criterion C1 mechanism looks like: $\bar{\bar{n}}_{11} = \left(\left[\frac{3.8}{9.6} = 0.39, \frac{5.8}{9.4} = 0.62\right].\left[\frac{5.8}{9.4} = 0.62, \frac{7.5}{8.3} = 0.91\right].\left[\frac{7.5}{8.3} = 0.91, \frac{9.0}{4.9} = 1.85\right]\right)$

Similarly, but only with the use of maximal values for observed criterion, the normalized fuzzy-rough decision matrix is calculated. Then comes to multiplying of obtained decision matrix with the calculated weights of criteria (Table 7), i.e. getting the weighted decision matrix. In case of alternative A1 and criterion C1, it looks like: $\bar{\bar{v}}_{11} = ([0.39 \times 0.10 = 0.04, 0.62 \times 0.11 = 0.07][0.62 \times 0.11 = 0.07, 0.91 \times 0.13 = 0.12][0.91 \times 0.13 = 0.12, 1.85 \times 0.15 = 0.29])$.

Then the minimal and maximal values of weighted decision matrix are extracting, what represents the ideal ([0.06, 0.10][0.10, 0.15][0.15, 0.34]) and anti-ideal values ([0.02, 0.05][0.05, 0.08][0.09, 0.17]). Further, the deviation of values of weighted decision matrix from previously mentioned values are calculated, while two matrices are formed, i.e. one matrix represents the deviation from the ideal value, and other matrix represents the deviation from the anti-ideal value. After that, optimal alternatives are established. At deviation from the ideal value, the optimal alternative is the one with the smallest deviations of the alternative from the ideal value, or contrary to that at deviation from the anti-ideal value; the optimal value is the one with the largest deviation of the alternative from the anti-ideal value. Then, cumulative deviation from the ideal and anti-ideal values are formed, which represent the cumulative values of deviations by certain alternative (Table 10).

Table 10

**Cumulative deviation of alternatives and utility function**

| A | $\bar{\bar{s}}_i^+$ | $\bar{\bar{s}}_i^-$ | $\bar{\bar{K}}_i^+$ | $\bar{\bar{K}}_i^-$ |
|---|---|---|---|---|
| A1 | ([1.3, 1.9][2.0, 2.3][2.3, 2.4]) | ([0.3, 0.6][0.6, 1.0][1.1, 1.9]) | ([0.4, 0.8][0.8, 1.2][1.2, 2.1]) | ([0.1, 0.5][0.6, 1.6][1.6, 6.1]) |
| A2 | ([1.3, 2.0][2.0, 2.3][2.3, 2.5]) | ([0.2, 0.6][0.6, 1.0][1.0, 1.9]) | ([0.4, 0.8][0.8, 1.2][1.2, 2.1]) | ([0.1, 0.5][0.5, 1.6][1.6, 6.0]) |
| A3 | ([1.3, 2.0][2.0, 2.3][2.3, 2.5]) | ([0.2, 0.6][0.6, 1.0][1.0, 1.9]) | ([0.4, 0.8][0.8, 1.2][1.2, 2.1]) | ([0.1, 0.5][0.5, 1.6][1.6, 6.0]) |
| A4 | ([1.3, 2.0][2.1, 2.4][2.4, 2.6]) | ([0.2, 0.5][0.5, 0.9][1.0, 1.9]) | ([0.4, 0.8][0.8, 1.1][1.1, 2.0]) | ([0.1, 0.5][0.5, 1.4][1.5, 5.8]) |
| A5 | ([1.4, 2.0][2.1, 2.4][2.4, 2.5]) | ([0.2, 0.5][0.5, 0.9][1.0, 1.8]) | ([0.4, 0.8][0.8, 1.1][1.1, 1.9]) | ([0.1, 0.5][0.5, 1.5][1.5, 5.7]) |
| A6 | ([1.4, 2.1][2.1, 2.4][2.4, 2.5]) | ([0.1, 0.5][0.5, 0.9][0.9, 1.8]) | ([0.4, 0.8][0.8, 1.1][1.1, 1.9]) | ([0.1, 0.4][0.5, 1.4][1.4, 5.6]) |
| $A_0$ | ([1.0, 1.8][1.9, 2.3][2.3, 2.6]) | ([0.3, 0.6][0.6, 1.1][1.1, 2.0]) | | |

Table 11

**Ranking of alternatives according to fuzzy-rough CRADIS method**

| A | $\bar{\bar{Q}}_i$ | $R_i$ | RANK |
|---|---|---|---|
| A1 | ([0.3, 0.7][0.7, 1.4][1.4, 4.1]) | 1.4207 | 1 |
| A2 | ([0.2, 0.6][0.7, 1.4][1.4, 4.0]) | 1.3876 | 3 |
| A3 | ([0.2, 0.7][0.7, 1.4][1.4, 4.1]) | 1.3962 | 2 |
| A4 | ([0.2, 0.6][0.6, 1.3][1.3, 3.9]) | 1.3201 | 4 |
| A5 | ([0.2, 0.6][0.6, 1.3][1.3, 3.8]) | 1.3142 | 5 |
| A6 | ([0.2, 0.6][0.6, 1.3][1.3, 3.8]) | 1.2897 | 6 |

According to gained values, utility functions have been also formed, e.g. in case of alternative A1 it looks like: $\bar{\bar{K}}_i^+ = \left(\left[\frac{1.0}{2.4} = 0.4, \frac{1.8}{2.3} = 0.8\right].\left[\frac{1.9}{2.3} = 0.8, \frac{2.3}{2.0} = 1.2\right].\left[\frac{2.3}{1.9} = 1.2, \frac{2.6}{1.3} = 2.1\right]\right)$, $\bar{\bar{K}}_i^- = \left(\left[\frac{0.3}{2.0} = 0.1, \frac{0.6}{1.1} = 0.5\right].\left[\frac{0.6}{1.1} = 0.6, \frac{1.0}{0.6} = 1.6\right].\left[\frac{1.1}{0.6} = 1.6, \frac{1.9}{0.3} = 6.1\right]\right)$. It could be noticed certain incorrectness of presented results, as in tables are shown the rounded values.

After the calculation of utility functions, the average utility ($\bar{\bar{Q}}_i$) is computing, while then it is approaching to the calculation of all results linked to the fuzzy-rough CRADIS method. According to derived results, the solar energy (A1) is marked as the best ranked RES alternative that could be used in rural areas, followed by biomass (A3), while as the worst RES alternative is ranked the energy potential of watercourses (A6), (Table 11).

Verification of gained results requires their validation, as well as performing of sensitivity analysis. Validation of results is common practice linked to use methods of multi-criteria decision making. In performed analysis (verification), the same initial decision matrix and the same criteria weights are used, while the ranking is done by the use of some other selected methods, such are: fuzzy-rough SAW (Simple Additive Weighting), fuzzy-rough ARAS (Additive Ratio Assessment), fuzzy rough MABAC (Multi-Attributive Border Approximation area Comparison) and fuzzy-rough WPM (Weighted Product Method) method (Figure 2). Comparing the results gained by mentioned methods with the results obtained by fuzzy-rough CRADIS method, there are certain level of deviation at two methods, fuzzy-rough SAW and fuzzy rough MABAC method, as well as at alternatives A4 and A5. At other alternatives and methods, the ranking is the same. So, the results obtained by the fuzzy-rough CRADIS method could be considered acceptable.

After validation, sensitivity analysis (Figure 3) is performed in order to examine the impact of individual criteria on the final ranking of alternatives. Mentioned is done through the gradually changing of the weights of individual criteria for 15% (Stojanović *et al.*, 2022), e.g. step by step decrease of the weights of individual criteria for 15% implies their value to

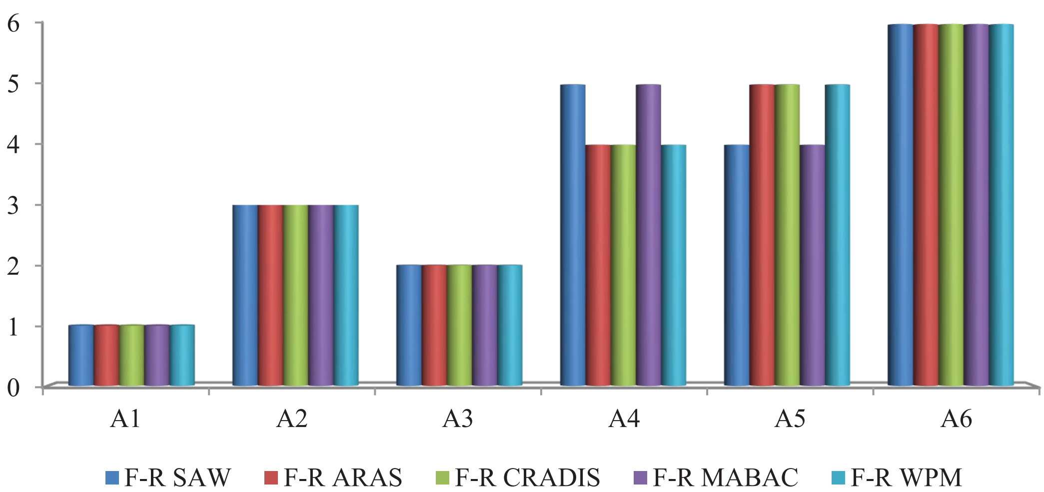


Figure 2. Validation of derived research results.

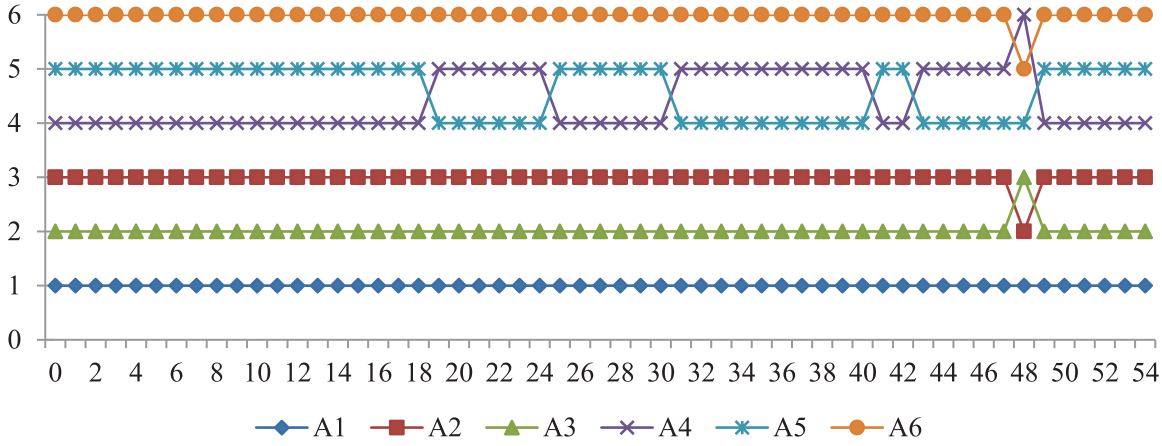


Figure 3. Sensitivity analysis.

85%, 70%, 55%, 40%, 25% or 10% of overall criterion value. Since there were operating with nine criteria, while the weight of individual criteria was changed for six times, in total 54 scenarios were created. The derived results after applied sensitive analysis show that the ranking of alternatives have not changed for alternative A1, as it was ranked as the first in all scenarios. In one scenario, alternative A2 was better ranked than the alternative A3, due to the fact that the costs of plant maintenance are higher at alternative A2, so by reducing the weight of this criterion, its impact on final ranking has been also reduced, making the alternative better. The biggest changes in ranking were for alternatives A5 and A4, what affects different ranking order in operating the fuzzy-rough SAW and fuzzy-rough MABAC methods.

The derived results for these alternatives were approximately the same, so extra small change in weights of individual criteria affects the change in the final rank of the alternatives. In 16 scenarios, alternative A5 was better than the alternative A4. In one scenario, after changing the weights of the criteria costs of plant maintenance alternative A6 was better ranked than alternative A4 for the same reason as was occurred in previously mentioned change in ranking of alternatives A2 and A3.

There were come to similar changes in research performed by Puška *et al.,* (2023), where also was a change in ranking of two alternatives. In this way, it was proved that performed steps of different methods could affect the final ranking of alternatives, but not that much to refute the results obtained by the fuzzy-rough CRADIS method.

## Discussion

Supplying and permanent availability of energy in rural areas is one of the imperatives of their development or even survival. On the other hand, negative implications of fossil fuels, mostly economic and environmental, are rapidly shifting the focus to renewable energy sources (RES) utilization. In order to examine which of the observed RES is the most suitable for the use in rural communities of the Western Balkans (WB), expert opinion was performed. As a result, eight experts were selected to evaluate the predefined criteria and alternatives. The general problem with expert opinion is that final decision could be under the significant subjective influence of the decision maker (Hicham *et al.,* 2023). Trying to reduce the occurred subjectivity a combination of certain fuzzy-rough approaches was used. Used combination firstly allows decision making contrary to available incomplete and imprecise information by the use of linguistic values under applied fuzzy approach.

Derived results of performed multi-criteria decision analysis have been showed that some of observed criteria have similar weights. However, the criterion price of RES plant implementation has a slightly higher importance than the criterion sustainability of implemented RES plant use. The main reason for this should be found in usually large initial assets required for implementation of mentioned energetic technologies. Basically, it is necessary to purchase and implement one of available alternatives and then in their further use to wait for the return on made investment according to reduction of energy costs.

Therefore, according to experts' opinion, the price plays a major role in RES implementation. In addition, derived results show that it is not necessary to adjust observed alternatives to the final user, but the final user must be adapted to them. However, considering just the criteria weights, it can be seen that there are differences only at the lower limit of the first rough number, while those differences are minimal at the upper limit of the third rough number. According to that, it can be concluded that all selected criteria significantly affect the final ranking of alternatives.

Performed research provides the basics of how the CRADIS method can be used in the fuzzy-rough approach. Applying mentioned method, gained results show that the best alternative for RES implementation in rural space is the solar energy, followed by the biomass, while as the relatively unsuitable is energy potential of watercourses. Main explanation could be that solar energy is available to any household, so everyone can use its benefits, while the benefit of watercourses mainly could realize just households that have the access to certain watercourses. On the other side, countries of the WB have already overused the possibility of producing electricity from larger watercourses, so the additional building of new dams would lead to further jeopardizing of the local environment, flora and fauna, or landscape.

The obtained results have been also confirmed using other fuzzy-rough methods. However, the verification by certain methods showed that there is not the same ranking order of observed alternatives, specifically alternatives A4 and A5. This is caused as these two alternatives have got the closest results compared to the other alternatives. So small changes in the steps of the fuzzy-rough SAW method, or small changes in normalization or weighting process in the fuzzy-rough MABAC method could affect changing in ranking of these two alternatives.

Derived results could be concerned as general guidelines, methodologically verified with the scientific arguments, for farms and rural communities in WB toward the implementation of available RES alternatives. Derived research results especially have high importance in remote rural areas, where the availability of public power supply is still restricted or even impossible. So, in the bottom line, the proper decision related to the use of adequate RES could represent the flywheel for sustainability, or even survival for local rural population.

Future research should focus on the size of solar panels that provide the best results for individual households in rural communities. It is necessary to establish how many solar panels are needed, how much electricity they should produce and where they should be installed. In addition, it is necessary in future research to carry out individual alternatives within preselected alternatives. The methodology presented in this paper has shown great flexibility and should be used in future similar research in other fields of rural development.

It should be noted that this decision problem could be solved by using only crips, fuzzy and rough numbers. Applying Crips numbers would use classical versions of MCDM methods. Applying this approach, it is then necessary to be sure of the evaluation of criteria or alternatives. Is that criterion important to get a grade of 5 and not 6 or to get a grade of 4. Sometimes it is difficult to determine the exact grade of a certain criterion or alternative, so linguistic values are used. In order to use linguistic values, it is necessary to apply the fuzzy approach. With this approach, uncertainty cannot be included in decision-making, and decision-making is heavily influenced by the decision-maker. The rough approach is used to include uncertainty in decision-making and to reduce subjectivity in decision-making. This approach must use crips numbers which must be precise. Therefore, in this research, a fuzzy-rough approach was taken in order to use imprecise evaluations in the form of linguistic values, and in addition to include uncertainty in decision-making and reduce subjectivity in making the final decision. However, perhaps this result could be obtained by applying only these other approaches, but then all advantages of individual accesses could not be included in a single fuzzy-rough approach.

## Conclusions

This paper was aimed at examining which RES alternative is the most suitable for rural settlements. For this purpose, a multi-criteria analysis based on the application of fuzzy and rough numbers was used. The task of this approach was to include information that is not precise in the expert decision-making process and to include uncertainty in decision-making. The results were based on the application of the fuzzy-rough LMAW and CRADIS methods. When determining the weights of the criteria, criterion C1 received the highest value (price of RES plant implementation) (w = [(0.10, 0.11) (0.11, 0.13) (0.13, 0.15)]), while criterion C5 received the least weight (ergonomics of RES plant use) (w = [(0.05, 0.09) (0.09, 0.11) (0.11, 0.14)]). The obtained results showed that the best-ranked RES alternative is solar energy ($R_i$ = 1.4207) followed by biomass ($R_i$ = 1.3962), and the worst results were achieved by the energy potential of watercourses ($R_i$ = 1.2897). Based on these results obtained on the basis of experts' opinions, agricultural households should use solar energy the most as a choice of RES. Another choice is the use of biomass. The reason for this is that agricultural production also produces side products that can be used as biomass. It can be straw, corn stalks, hay, branches of fruit trees and forest trees, etc. In order to use the full potential of agricultural households, it would be best to have a combination of these two alternatives. The reason for this should be found in the fact that solar panels cannot produce electricity at night, so it is necessary to have alternatives. Whether the excess electricity produced will be stored in batteries or other alternatives will be used, but that is then a matter of choice for individual households. RES of using the energy potential of watercourses is ranked last, and that is because not all households have access to running water in order to use that potential for generating electricity. In addition, the construction of the mini-hydroelectric power plant changes the course of the river itself. This affects the animals and plants that are found in those waters as well as on the banks of those waters. However, it is necessary to conduct similar research in certain micro-localities where the characteristics of those localities would influence this choice. These results were confirmed by conducting validation and sensitivity analysis.

With all of them, including this research, there are certain limits that were not considered in this research. The conducted research is based on expert opinion and not on real data. For this reason, in future research it is necessary to use real research in rural settlements on the basis of experiments and to measure how well individual RES alternatives give results. In addition to this limit, when applying multi-criteria methods, one always encounters limits as to why certain methods were used and others were not. However, each of the methods of multi-criteria analysis has its own characteristics, which can be good and sometimes bad sides of those methods. This was the reason to conduct the 1st validation evaluation that confirmed the obtained results. The mentioned approach also has limitations regarding the complicated application of the mentioned methodology and methods, so farmers could have problems using similar approaches when making decisions. However, the conducted research gives general guidelines which RES alternatives should be used in agricultural households. In addition, the problem of these alternatives is the finances available to certain agricultural producers, that is, whether they are able to use these same alternatives. That is why manufacturers, for example, of solar panels must work to make these panels more affordable in order to be used as much as possible in practice. The same is the case with other alternatives. It is necessary to invest certain funds which are the limiting factor in order to acquire these alternatives. In future research, it is necessary to investigate whether there is a need for RES alternatives and how much people in rural areas are interested in it. Also, it is necessary to see how many people have the knowledge and skills to apply RES alternatives and to what extent they are ready for it. Would it be used more often if users had incentives from state institutions, as well as various other questions that this research opens up? Due to the complex approach of applying the fuzzy-rough methodology, it is necessary to examine in future research whether individual approaches give the same order of alternatives as the fuzzy-rough approach. This would answer whether the fuzzy-rough approach must be applied or whether it is possible to obtain the same order only with the fuzzy approach or the crips approach.

The use of fuzzy-rough, which was used in this research, showed a great deal of flexibility, so it can be used in similar research. The methods used are simple and give the same results as other methods and can be used in future research. In addition, the results of this research showed that in rural settlements it is necessary to use sustainable energy sources as much as possible, and solar panels showed the best results, and this is recommended to be used as much as possible in rural research.

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## Acknowledgement

Paper is a part of research financed by the MSTDI RS, agreed in decision no. 451-03-66/2024-03/200009 from 5.2.2024.