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Application of Fuzzy-Rough Methodology to the Selection of Electric Tractors for Small Farms in Semberija

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Abstract

The selection of electric tractors falls under the Multicriteria Decision-Making (MCDM) category and can be performed using different methods. This study used expert decision-making, with experts providing assessments in the form of linguistic values. A model was created using ten criteria and six electric tractors to determine which tractor would be most suitable for small farms in the Semberija region. The Fuzzy-Rough (FR) methodology was implemented here, combining fuzzy logic with rough set theory. The importance of each criterion was evaluated through the FR Simple Weight Calculation (SiWeC) method showing that maintenance has slightly greater importance than the other criteria. Tractor selection was performed using the FR Ranking of Alternatives with Weights of Criterion (RAWEC) method, which showcased the Solectrac e25 as the tractor that achieved the best result. These outcomes were confirmed by comparison with other FR methods and sensitivity analysis. This research's impact is represented by encouraging the usage of electric tractors to reduce environmental pollution and the development of an improved FR methodology using the bonferroni mean operator to harmonize expert ratings.

Keywords: Electric tractors, Fuzzy-rough, Small farms, Semberija, SiWeC method, RAWEC method .

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1 | Introduction

The agriculture sector faces challenges [1] in maintaining sustainability and increasing efficiency while adapting to modern technologies [2]. Agricultural production must align with dynamic market trends, among them is the modernization of farming equipment [3]. Traditionally, agricultural machinery depends on fossil fuels. However, this transition towards the greater goal of environmentally sustainable agriculture demands adopting new technologies. Among these innovations, electric tractors offer a greener option than traditionally fossil fuel-powered tractors.

In the last ten years, the production of vehicles has seen a change towards greener solutions. In such a context, electric tractors represent one of the sustainable alternatives for the future, reducing $CO2$ emissions and operational costs for agriculture [4]. The modern trends form part of the global goals of carbon emission reduction. However, choosing an electric tractor is not easy for small farms; many factors need to be considered. These are put in terms of criteria the tractor must satisfy to be appropriate for a particular farm's needs. Because of this, the limitations many farmers face result in many farmers having a proper tractor that should be selected with these criteria in mind to have successful operations. With many factors, Multicriteria Decision-Making (MCDM) methods guide the selection process. The literature reveals that MCDM methods are necessary to improve work processes, particularly in smaller organizations like farms [5].

Different methods may be used in the selection of an electric tractor. Conventional decision-making methods have rigid structures that led to the development of flexible approaches [6], [7], with fuzzy, rough, and gray approaches better serving incomplete and uncertain information data [8], [9]. This research uses the Fuzzy-Rough (FR) approach, combining the strengths of both fuzzy and rough methods. The fuzzy approach allows for decisions based on subjective expert evaluations expressed through linguistic values, addressing situations where information is imprecise [10], [11]. This is useful when not all the necessary information to make a decision is available [12] and can hardly be obtained [13]; fuzzy logic was developed to deal with this uncertainty. On the other hand, the rough approach tries to reduce subjectivity by dealing with the uncertainty directly within the decision process. The combination of both approaches exploits the advantages of each to ensure more reliable decisions [14], improving agricultural production for small farms in the Semberija region.

This combined approach gives a strong and flexible decision-making tool, fitting the complexity of farmers' experience in choosing an electric tractor. Including a range of criteria solves problems of uncertainty and complexity most often encountered in real-life situations. It results in a structured guide for agricultural producers to make informed decisions and ensures they pick the most appropriate electric tractor to improve their farm's production. This approach is also flexible, so it can be modified to suit particular situations, thus making decision-making more efficient.

The motivation for this research is based on the need to develop agriculture in developing countries, such as Bosnia and Herzegovina (BiH), especially in small-scale farms with limited machinery investment funds. Also, introducing electric tractors to BiH aligns with the sustainability criteria of the European Union (EU), as BiH is currently an EU membership candidate. Electric tractors will contribute to the reduction in $CO2$ emissions, enhance energy efficiency in agriculture, and lower working costs. However, they come with some challenges, especially for small farms, since they require electricity for charging, which may need to be accompanied by changes such as installing fast-charging stations. Choosing an electric tractor involves complexities, so all relevant criteria must be considered. The FR approach provides a useful tool for solving this decision-making process under conditions of uncertainty and incomplete information. Another key motivation for this study is the need for a systematic and reliable method to help farmers in Semberija select electric tractors that support sustainable farming practices. Based on this, the specific objectives are set to:

I. Develop a methodology using the FR approach for selecting electric tractors suited to small farms, considering complex criteria such as technical specifications, economic factors, and environmental impact.

II. Identify the importance of criteria for evaluating electric tractors on small farms in the Semberija region.

III. Apply an FR methodology to a specific set of electric tractors to select the one that best meets the needs of small-scale agricultural production.

IV. Harmonize group decision-making evaluations for electric tractor selection, addressing the importance of criteria and how well the tractors satisfy them, using the Bonferroni mean operator.

V. Recommend the best electric tractor for small farms and provide guidelines on how this decision-making process can be applied to other contexts.

In achieving these objectives, this research offers several key contributions:

I. Development of a new methodology based on the FR approach, incorporating innovative MCDM methods.

II. Improvement of the decision-making process in agriculture by addressing uncertainty and limited data availability.

III. Practical application of the FR methodology to select electric tractors that support sustainable agriculture for small-scale farmers.

IV. Improved knowledge of the FR decision-making process and the methods used in this process.

V. Providing guidance and support to farmers transitioning from fossil-fuel-based machinery to more environmentally friendly alternatives.

Setting guidelines for adopting sustainable technology in agricultural production in BiH, particularly in the Semberija region.

This paper is divided into six sections. The introduction presents the subject, goals, contributions, and motivation for creating this paper. Section 2 presents papers researching electric tractors first, followed by those applying MCDM methods in tractor selection and gap identification. section 3 deals with the research methodology and methods used in this study. Section 4 focuses on applying the selected methods to a concrete example from practice. Section 5 provides a more detailed explanation of the obtained results. The final section outlines the most important research findings, limitations, and future study guidelines.

2 | Literature Review

The literature review is divided into three sections. The first part focuses on research related to electric tractors, while the second part covers the application of MCDM methods in tractor selection. Finally, gaps in previous research on electric tractors are highlighted.

2.1 | Review of Papers on Electric Tractors

In their research, Malik and Kohli [15] emphasized the importance of tractors in agricultural production and introduced Indian electric tractors as a solution to reduce air pollution caused by fossil fuel-powered tractors. Topal [16] explored how agricultural practices are changing, with a growing reliance on electric systems in tractors, and provided a literature review on using electric tractors in agriculture. Bessette et al. [17] pointed out electric tractors' advantages over conventional tractors: higher efficiency, more torque, lower maintenance costs, and reduced environmental impact. Their study also investigated farmers' willingness to adopt electric tractors.

Gao and Xue [18] established the cost model to estimate the general life-cycle cost of the transition from fossil fuel-based tractors to electric tractors. Wen et al. [19] researched the application of two-motor electric tractors to raise power output and enable the completion of more demanding field tasks. Beligoj et al. [20] conducted an economic feasibility study of electric tractors by comparing electricity consumption with the fuel consumption of conventional tractors and concluded that electric tractors can reduce operational costs considerably. Li et al. [21] conducted simulations to verify the performance of electric tractors with a dual-input coupling powertrain system and developed energy management strategies for such vehicles.

Zhang et al. [22] researched the traction performance of electric tractors and looked for possible improvements. Through simulation techniques, they proposed battery placement strategies to improve the tractors' balance. Mocera et al. [23] compared a traditional orchard tractor with three hybrid electric tractors, analyzing their power and durability. Luo et al. [24] focused on energy-saving strategies for electric tractors, considering the tasks performed and the terrain configuration. Liu et al. [25] compared different types of tractors and found that hybrid tractors, combining electric and conventional power, currently offer the best practical results. Yu et al. [26] conducted simulations to investigate the mismatch between the power output of electric tractors and the demands of specific agricultural tasks.

2.2 | Application of MCDM Methods in Tractor Selection

Several studies have applied MCDM methods to tractor selection. Puška et al. [27] employed the FR approach using the Logarithm Methodology of Additive Weights (LMAW) and Simple Additive Weighting (SAW) to evaluate five large tractors. Özdağoğlu et al. [28] applied the fuzzy PIvot Pairwise RElative Criteria Importance Assessment (PIPRECIA) and fuzzy Complex Proportional Assessment (COPRAS) to select tractors for towing. García-Alcaraz et al. [29] used Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to identify key attributes in tractor sales models, analyzing six tractor alternatives to determine which best met their objectives.

Amini and Asoodar [30] investigated tractor selection in Ghaemshahr and Ahvaz using AHP. Puška et al. [31] applied five objective methods to evaluate the importance of criteria and introduced a new approach, the modified standard-deviation method, ranking tractors using Compromise Ranking of Alternatives from Distance to Ideal Solution (CRADIS). Gupta [32] used TOPSIS to determine which tractor best met the specified criteria. Mishra and Satapathy [33] focused on maintenance factors and applied Stepwise Weight Assessment Ratio Analysis (SWARA) to identify which aspects of tractor maintenance should be prioritized.

2.3 | Gaps in the Selection of Electric Tractors

Previous research on electric tractor selection has largely focused on technical specifications, while studies incorporating linguistic values are still underdeveloped. These technical approaches often overlook crucial economic and environmental factors that are equally important in tractor selection. Moreover, the application of certain newer methods has not been thoroughly explored, and their practical integration is lacking. Additionally, decision-making processes that account for uncertainty are underrepresented in agricultural research. This study addresses these gaps by:

I. Integrating and developing a hybrid methodology based on the FR approach combined with newer MCDM methods, providing a more simplified decision-making process.

II. Offering a holistic approach to evaluating electric tractors, incorporating technical, economic, and environmental factors to enable more reliable decision-making.

III. Focusing specifically on small farms and adapting the decision-making process to meet the needs of small-scale agricultural producers, with detailed procedures and steps for implementing MCDM methods, which have not been sufficiently explored in theory or practice.

By addressing these gaps, this research will contribute to a better understanding of how electric tractors can be effectively implemented in sustainable agricultural practices while improving the efficiency of agricultural production on small farms tailored to their unique business conditions.

3 | Methodology and Methods

A four-phase methodology was used to determine which small electric tractors would provide the best results for small farms in the Semberija region of BiH (*Fig. 1*).

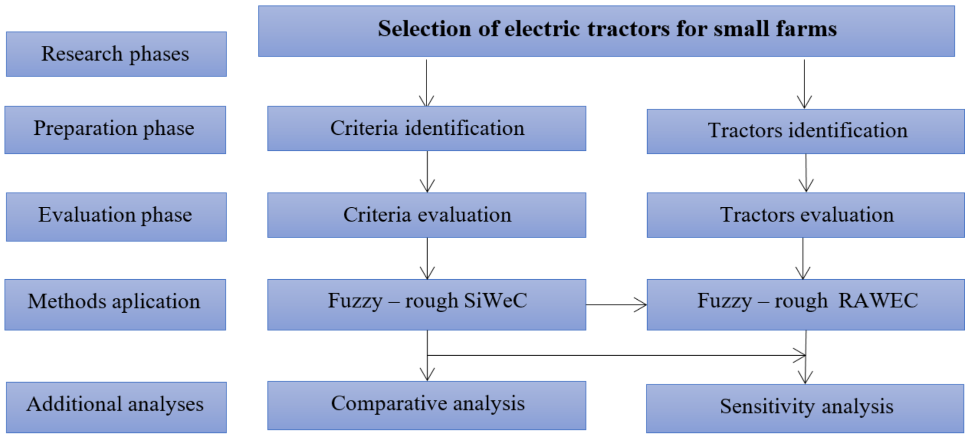


Fig. 1. Research methodology.

The preparation phase is set as the first phase of this research. The initial step in this phase is the selection of experts. Professors from agricultural faculties in Bijeljina were chosen as experts, as this city is the largest in the Semberija region and serves as its educational center in BiH. Five experts were selected, all of whom have extensive theoretical and practical experience with mechanization in agricultural production.

Table 1. Evaluation criteria.

Id	Criterion	Desc.	Ref.
C1	Autonomy	The working time of the tractor on a single charge	[18], [25]
C2	Charging time	Time needed to fully charge the battery.	[22], [25]
C3	Engine power	The tractor's ability to handle more demanding tasks	[17], [19], [23], [31]
C4	Towing capacity	The maximum load or weight the tractor can pull	[17], [19], [22], [23]
C5	Weight	Total mass of the tractor, affecting its operational stability	[18], [19], [31]
C6	Price	Purchase cost of the tractor	[18], [25], [27], [31]
C7	Maintenance	Time and costs associated with maintaining the tractor.	[16], [18], [27]
C8	Environmental impact	The tractor's effects on the environment	[24], [25]
C9	Technology and automation	Availability of advanced features in the tractor	[18], [25]
C10	Availability of spare parts	Access to service and spare parts	[16], [18], [27]

The second step in this phase was selecting the electric tractors for evaluation. The tractors chosen are those available on the market and accessible within the region. Six electric tractors were selected as alternatives for this study. The selected tractors are:

I. Solectrac e25 (T1) is an electric compact tractor with a horsepower 25. It comes with a 22-kWh battery that gives an operating range of 6 to 8 hours, which needs at least a 4-to-8-hour charge time. With a towing capacity of up to 454 kg, it is suitable for basic tasks. It runs entirely on electricity and does not have advanced features like autonomous driving.

II. Fendt e100 Vario (T2) is a powerful 100-horsepower tractor with a 100-kWh battery, providing 5 hours of operational autonomy and about 5 hours of charging time. It can tow up to 3,500 kg and features advanced technologies. Its cost and maintenance are among the highest of the tractors under review.

III. Rigitrac SKE 50 electric (T3), with a 50-hp engine and a 50-kWh battery, offers between 4 and 5 hours of autonomy. It is designed for all types of agricultural environments, with the ability to tow up to 2,000 kg. All-electric and environmentally friendly, it represents leading-edge technology, even though it is not at the fully autonomous level yet.

IV. Farmtrac FT25G (T4) is a 22-horsepower electric tractor with a 72V/300Ah battery that provides 6 to 7 hours of operation. It lacks modern technology features yet performs well in basic agricultural tasks. With a towing capacity of 400 kg, it is easy to operate and maintain.

V. Monarch Tractor MK-V (T5) is a 40-horsepower electric tractor with advanced autonomous controls. Its 75-kWh battery provides up to 10 hours of operation, and it has a towing capacity of 2,000 kg. Sensors, artificial intelligence, and self-driving capabilities are all built into the Monarch MK-V.

VI. John Deere SESAM (T6) is a 130-horsepower electric tractor with a 150-kWh battery that can operate for four and charge in three hours. It can tow up to 4,000 kg and incorporates advanced technology, enabling precise real-time management and control.

Following their selection, the criteria and tractors were evaluated as part of the second research phase. For this evaluation, linguistic values with nine levels were used, ranging from "Absolutely Bad (AB)" to "Absolutely Good (AG)". These linguistic values were chosen to make it easier for experts to judge the quality of the criteria and alternatives, as it is often more intuitive to determine whether something is "good" or "bad" than to assign a precise numerical rating. To simplify the evaluation process, the same value scale was applied to both the criteria and the alternatives (*Table 2*). Since five experts are participating in this research, their evaluations must be harmonized. This will be done using the Bonferroni mean operator.

Table 2. Linguistic ratings and fuzzy number membership functions.

Linguistic Value	Membership Function
Absolutely Bad (AB)	1, 1, 2
Very Bad (VB)	1, 2, 3
Bad (B)	2, 3, 4
Medium Bad (MB)	3, 4, 5
Medium (M)	4, 5, 6
Medium Good (MG)	5, 6, 7
Good (G)	6, 7, 8
Very Good (VB)	7, 8, 9
Absolutely Good (AG)	8, 9, 9

To apply these evaluations to determine the importance of the criteria and how well each tractor meets these criteria, the linguistic values must first be converted into fuzzy numbers [34]. This is achieved using membership functions, defining the fuzzy number corresponding to each linguistic value [35]. This step is essential, and it is part of the third phase.

After the criteria and alternatives are evaluated, the selected methods are applied. Since every approach has its own procedures and characteristics, it is up to the researcher(s) to choose which ones to use. In this case, we chose to promote two newer MCDM methods: 1) Simple Weight Calculation (SiWeC) to determine the importance of the criteria based on expert evaluations, and 2) Ranking of Alternatives with Weights of Criterion (RAWEC), which will rank the tractors according to how well they meet the criteria. Additionally, the FR approach is applied in this research, as it allows for decision-making under incomplete information and uncertainty. The following describes how these methods are used in a FR setting. The SiWeC and RAWEC methods are linked in this research in such a way that the weights obtained by the SiWeC method are used in the RAWEC method when calculating deviations. For this reason, the results of the SiWeC method should be calculated first, and only then should the tractors be ranked using the RAWEC method.

The FR SiWeC method subjectively determines the importance of criteria based on expert evaluations, as demonstrated by Puška et al. [36]. Its implementation relies on expert evaluation of the criteria, where experts judge the significance of each criterion. The FR SiWeC follows:

Step 1. Evaluation of the importance of criteria, where experts evaluate the importance of each criterion using linguistic values.

Step 2. Transformation of linguistic values into fuzzy numbers using a specific utility function to create fuzzy numbers, specifically, triangular fuzzy numbers

$$\tilde{x}_{ij} = \left(x_{ij}^{l}, x_{ij}^{m}, x_{ij}^{u}\right), \tag{1}$$

where x_{ij}^{l} is the first, x_{ij}^{m} second, andx_{ij}^{u} third fuzzy number.

Step 3. Determining the lower and upper bounds of FR numbers. The rough number's lower and upper limits are calculated for each fuzzy number. This allows for the inclusion of uncertainty in the decision-making process, as these bounds account for the range of expert evaluations. The FR numbers are expressed as intervals and are calculated using:

$$\underline{\mathrm{Lim}}(c_i^e) = \frac{1}{\underline{N}^e} \sum_{i=1}^{\underline{N}^e} \varphi \epsilon \underline{\mathrm{Apr}}(c_i^e). \tag{2}$$

$$\overline{\mathrm{Lim}}(c_i^e) = \frac{1}{\underline{N}^e} \sum_{i=1}^{\overline{N}^e} \varphi \epsilon \overline{\mathrm{Apr}}(c_i^e). \tag{3}$$

As a result, FR numbers are formed as follows:

$$\mathrm{FR}\left(\tilde{x}_{ij}\right) = \left(\left[x_{ij}^{lL}, x_{ij}^{lU}\right], \left[x_{ij}^{mL}, x_{ij}^{mU}\right], \left[x_{ij}^{uL}, x_{ij}^{uU}\right]\right). \tag{4}$$

Step 4. Normalization of the FR decision matrix, where all FR values are normalized by dividing them by the maximum value of those numbers $\max_i \alpha_i^{uU}$.

$$\bar{\bar{n}}_{ij} = \left(\left[\frac{\alpha^{lL}}{\max_i \alpha_i^{uU}} \cdot \frac{\alpha^{lU}}{\max_i \alpha_i^{uU}}\right] \cdot \left[\frac{\alpha^{mL}}{\max_i \alpha_i^{uU}} \cdot \frac{\alpha^{mU}}{\max_i \alpha_i^{uU}}\right] \cdot \left[\frac{\alpha^{uL}}{\max_i \alpha_i^{uU}} \cdot \frac{\alpha^{uU}}{\max_i \alpha_i^{uU}}\right]\right). \tag{5}$$

Step 5. Calculation of standard deviation ($\mathrm{st.dev}_j$) for experts, where FR numbers corresponding to each expert's ratings are used to compute the standard deviation.

Step 6. Weighting of normalized values with standard deviation, where the weighted normalized values are calculated by multiplying the normalized values by the standard deviation:

$$\bar{\bar{v}}_{ij} = \bar{\bar{n}}_{ij} \times \mathrm{st.dev}_j. \tag{6}$$

Step 7. Calculation of average values of criteria using the Bonferroni mean operator. This is a modification of the classic SiWeC method, where the sum of the ratings is replaced with the values of the Bonferroni operator.

$$\bar{\bar{s}}_j = \left(\frac{1}{k(k-1)} \sum_{\substack{i.j=1 \\ i \neq j}}^{k} \bar{\bar{n}}_i^{(UL)p} \bar{\bar{n}}_i^{(UL)q}\right)^{\frac{1}{p+q}}. \tag{7}$$

Step 8. Calculation of FR criteria weights. Lastly, each criterion's weights are determined using:

$$\bar{\bar{w}}_{ij} = \left(\left[\frac{s_j^{lL}}{\sum_{j=1}^{n} s_j^{uU}} \cdot \frac{s_j^{lU}}{\sum_{j=1}^{n} s_j^{uL}}\right] \cdot \left[\frac{s_j^{mL}}{\sum_{j=1}^{n} s_j^{mU}} \cdot \frac{s_j^{mU}}{\sum_{j=1}^{n} s_j^{mL}}\right] \cdot \left[\frac{s_j^{uL}}{\sum_{j=1}^{n} s_j^{lU}} \cdot \frac{s_j^{uU}}{\sum_{j=1}^{n} s_j^{lL}}\right]\right). \tag{8}$$

These weights will be applied to the FR RAWEC method. First, the criteria weights will be determined, followed by an evaluation of how well each tractor satisfies the criteria.

The RAWEC method ranks alternatives based on deviation from the criteria weights [37]. What sets this method apart is its use of two normalizations, which convert the criteria into maximum and minimum values. The method initially applied by Puška et al. [38] has been adapted for the FR approach in this research. The steps of the FR RAWEC method follow:

Step 1. Evaluation of alternatives using linguistic values. Experts evaluate the electric tractors using linguistic terms that describe how well each tractor meets the criteria.

Step 2. Transformation of linguistic values into fuzzy numbers. Similar to the FR SiWeC method, the linguistic evaluations are transformed into fuzzy numbers to allow for uncertainty in decision-making.

Step 3. Determining the lower and upper bounds of FR numbers. The lower and upper bounds of the FR numbers are determined to reflect the interval of possible values, just as in the previous method.

Step 4. Harmonizing experts' ratings into a summary decision-making matrix. Once the expert ratings are transformed into FR numbers, these evaluations are harmonized, and a summary decision-making matrix is formed. The Bonferroni mean operator is used for this step:

$$\bar{\bar{x}}_j = \left(\frac{1}{k(k-1)} \sum_{\substack{i,j=1 \\ i \neq j}}^{k} \bar{\bar{x}}_i^{(UL)p} \bar{\bar{x}}_i^{(UL)q} \right)^{\frac{1}{p+q}}. \tag{9}$$

Step 5. Normalization of FR numbers.

$$\bar{\bar{n}}_{ij} = \left(\left[\frac{\alpha^{lL}}{\max_j \alpha_i^{uU}}, \frac{\alpha^{lU}}{\max_j \alpha_i^{uU}} \right], \left[\frac{\alpha^{mL}}{\max_j \alpha_i^{uU}}, \frac{\alpha^{mU}}{\max_j \alpha_i^{uU}} \right], \left[\frac{\alpha^{uL}}{\max_j \alpha_i^{uU}}, \frac{\alpha^{uU}}{\max_j \alpha_i^{uU}} \right] \right). \tag{10}$$

The distinctive feature of this normalization is that no value exceeds 1, which is crucial for the further calculation of deviations from the criteria weights.

Step 6. Calculating the deviation from the criterion weight. At this step, the criterion weights ($\bar{\bar{w}}_j$) are multiplied by the difference between 1 and the normalized FR numbers.

$$\bar{\bar{v}}_j = \sum_{i=1}^{n} \bar{\bar{w}}_j \cdot \left(1 - \bar{\bar{n}}_{ij}\right). \tag{11}$$

$$\bar{\bar{v}}'_j = \sum_{i=1}^{n} \bar{\bar{w}}_j \cdot \left(1 - \bar{\bar{n}}'_{ij}\right). \tag{12}$$

Step 7. Transformation of FR numbers into crisp numbers.

$$v_i = \left(\frac{v_i^{lL} + v_i^{lU} + v_i^{mL} + v_i^{mU} + v_i^{uL} + v_i^{uU}}{6} \right). \tag{13}$$

$$v'_i = \left(\frac{v'^{lL}_i + v'^{lU}_i + v'^{mL}_i + v'^{mU}_i + v'^{uL}_i + v'^{uU}_i}{6} \right). \tag{14}$$

Step 8. Calculating the final value of the RAWEC method.

$$Q_i = \frac{v'_j - v_j}{v'_j + v_j}. \tag{15}$$

The electric tractor with the highest value for Q_i is considered the best alternative according to the FR RAWEC method.

Once the electric tractors are ranked, the fourth phase of the research involves conducting additional analyses. The aim of these analyses is twofold: first, to confirm the research results and compare them with the findings obtained using other methods, and second, to determine if the ranking is sensitive to the weights of individual criteria. In comparative analysis, the criteria weights produced by the FR SiWeC method and the summary matrix are used as the foundation for decision-making. The ranking of the tractors is then compared using other FR methods [39]. This comparison aims to verify the results of the RAWEC method and, if differences arise, investigate the cause of the divergence in the ranking. Following the comparative analysis, a sensitivity analysis is carried out. In this analysis, the criteria weights obtained from the FR SiWeC method are adjusted by 30%, 60%, and 90% for individual criteria, while the weights of the remaining criteria are left unchanged. This approach tests if changes in a single criterion's weight affect the electric tractors' overall ranking. By altering the weight of individual criteria, the stability of the ranking and the influence of each criterion on the final decision can be assessed. More scenarios were not used in the sensitivity analysis because it is not important to determine how much the weight of a certain criterion should be reduced, but rather to establish whether that criterion affects the ranking of tractors. For this reason, the number of scenarios was reduced, and only three weight changes for individual criteria were considered.

4 | Results

Gathering expert assessments is the first step toward establishing the criteria's weights. Each expert evaluates the importance of the individual criteria using linguistic values (*Table 3*). The membership functions are then used to convert these linguistic values into fuzzy numbers (*Table 2*). After transforming the linguistic values, the lower and upper bounds of the fuzzy numbers are calculated.

Table 3. Linguistic evaluations of criteria.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Expert 1 (E1)	VG	G	MG	G	MB	AG	VG	VG	G	G
Expert 2 (E2)	G	G	M	G	MG	AG	G	G	G	G
Expert 3 (E3)	MG	AG	M	G	M	AG	G	VG	AG	AG
Expert 4 (E4)	AG	G	VG	G	MG	VG	G	AG	AG	VG
Expert 5 (E5)	VG	VG	G	G	VG	AG	AG	AG	G	AG

The value very good is transformed into the fuzzy number (7, 8, 9), good becomes (6, 7, 8), medium good is assigned (5, 6, 7), and AG is represented by (8, 9, 9). To explain the transformation process, we will use the example for expert E1, and the transformation of their evaluations into fuzzy numbers is calculated as follows:

$$C_{11}^{lL} = \frac{7+6+5+7}{4} = 6.25; C_{11}^{lU} = \frac{7+8+7}{3} = 7.33; C_{11}^{mL} = \frac{8+7+6+8}{4} = 7.25. \tag{16}$$

$$C_{11}^{mU} = \frac{8+9+8}{3} = 8.33; C_{11}^{uL} = \frac{9+8+7+9+9}{5} = 8.40; C_{11}^{uU} = \frac{9+9+9}{4} = 9.00. \tag{17}$$

Once these limits are determined, the FR decision-making matrix is constructed. The next step is the normalization of this matrix (*Table 4*). Since the highest value of all FR numbers is 9, all values are normalized by dividing by this number. After normalization, the standard deviation for each normalized FR number is calculated for each expert. These normalized values are then multiplied by the standard deviation to adjust for the variability in expert evaluations. The Bonferroni mean operator is applied to harmonize these different assessments, and the final criteria weights are determined.

Table 4. Normalized decision matrix by FR SiWeC method.

The normalized decision matrix				
	C1	**C2**		**C10**
E1	0.69 0.81 0.81 0.93 0.93 1.00	0.67 0.73 0.78 0.84 0.89 0.93	…	0.67 0.78 0.78 0.89 0.89 0.96
E2	0.61 0.78 0.72 0.89 0.83 0.97	0.67 0.73 0.78 0.84 0.89 0.93	…	0.67 0.78 0.78 0.89 0.89 0.96
E3	0.56 0.73 0.67 0.84 0.78 0.93	0.73 0.89 0.84 1.00 0.93 1.00	…	0.78 0.89 0.89 1.00 0.96 1.00
E4	0.73 0.89 0.84 1.00 0.93 1.00	0.67 0.73 0.78 0.84 0.89 0.93	…	0.70 0.85 0.81 0.96 0.96 1.00
E5	0.69 0.81 0.81 0.93 0.93 1.00	0.69 0.83 0.81 0.94 0.93 1.00	…	0.78 0.89 0.89 1.00 0.96 1.00
The normalized matrix weighted by the standard deviation				
	C1	**C2**		**C10**
E1	0.10 0.12 0.12 0.14 0.14 0.15	0.10 0.11 0.12 0.13 0.13 0.14	…	0.10 0.12 0.12 0.13 0.13 0.14
E2	0.08 0.10 0.10 0.12 0.11 0.13	0.09 0.10 0.10 0.11 0.12 0.12	…	0.09 0.10 0.10 0.12 0.12 0.13
E3	0.09 0.11 0.10 0.13 0.12 0.14	0.11 0.14 0.13 0.16 0.14 0.16	…	0.12 0.14 0.14 0.16 0.15 0.16
E4	0.09 0.11 0.11 0.13 0.12 0.13	0.09 0.09 0.10 0.11 0.11 0.12	…	0.09 0.11 0.10 0.12 0.12 0.13
E5	0.09 0.10 0.10 0.12 0.12 0.12	0.09 0.10 0.10 0.12 0.12 0.12	…	0.10 0.11 0.11 0.12 0.12 0.12
The average criteria values calculated using the Bonferroni mean operator				
	C1	**C2**		**C10**
$\bar{\bar{s}}_j$	0.09 0.11 0.11 0.13 0.12 0.14	0.09 0.11 0.11 0.12 0.13 0.13	…	0.10 0.12 0.11 0.13 0.13 0.14
The final criteria weights				
	C1	**C2**		**C10**
$\bar{\bar{w}}_{ij}$	0.07 0.09 0.09 0.12 0.11 0.15	0.07 0.09 0.09 0.12 0.12 0.14	…	0.08 0.10 0.09 0.12 0.12 0.15

Based on the FR SiWeC method results and the experts' evaluations, the most important criterion is C7-maintenance. However, other criteria do not deviate significantly in importance, and they all equally influence the ranking of electric tractors.

With the criteria weights established, the next phase involves evaluating the electric tractors based on these criteria, using the experts' evaluations. The evaluation process follows the same steps as before, creating FR decision matrices for each expert. These five individual matrices are then consolidated into one summary matrix using the Bonferroni mean operator (*Table 5*).

Table 5. Evaluation of alternatives using linguistic values.

E1	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
T1	G	MG	G	MG	MG	G	MG	G	VG	G
T2	MG	MG	MG	M	MG	M	M	MB	M	G
T3	M	MB	M	G	MG	G	M	MG	MG	M
T4	M	MB	M	MG	G	G	MG	G	MG	M
T5	G	VG	VG	MG	G	G	VG	G	MG	M
T6	MG	G	M	MB	M	MB	M	MG	MG	MG
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
E5	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
T1	VG	MG	AG	G	MG	AG	MG	G	VG	G
T2	MG	MG	MG	M	MG	G	M	MB	M	AG
T3	M	MB	M	G	MG	G	MG	MG	MG	M
T4	M	MB	AG	MG	G	G	MG	G	G	MG
T5	G	AG	VG	MG	MG	AG	G	G	MG	AG
T6	MG	G	G	MG	M	MB	M	MG	MG	G

Next, the normalization of these values is performed. A key feature of the FR RAWEC method is using two normalizations. In the first normalization, all criteria are considered benefits, while in the second normalization, they are treated as costs, resulting in different formulas for each case. Using Criterion C1 and Tractor T1 as an example, the normalizations are done as follows:

$$n_{11} = \left[\frac{4.0}{7.3} = 0.55; \frac{4.0}{7.3} = 0.55\right]\left[\frac{5.0}{7.3} = 0.69; \frac{5.0}{7.3} = 0.69\right]\left[\frac{6.0}{7.3} = 0.82\,; \frac{6.0}{7.3} = 0.82\right]. \qquad \textbf{(17)}$$

$$n'_{11} = \left[\frac{3.4}{6.0} = 0.56; \frac{3.4}{6.0} = 0.56\right]\left[\frac{3.4}{5.0} = 0.67; \frac{3.4}{5.0} = 0.67\right]\left[\frac{3.4}{4.0} = 0.84\,; \frac{3.4}{4.0} = 0.84\right]. \quad \textbf{(18)}$$

The other normalization values are calculated similarly, forming two normalized decision matrices. Once the normalization process is complete, the deviation from the criterion weights is calculated. Using Criterion C1 and Tractor T1 as an example, this calculation proceeds as follows:

$$S_{11} = [0.07 \cdot (1 - 0.82) = 0.01; 0.09 \cdot (1 - 0.82) = 0.02]. \quad \textbf{(19)}$$
$$[0.09 \cdot (1 - 0.69) = 0.03; 0.12 \cdot (1 - 0.69) = 0.04]. \quad \textbf{(20)}$$
$$[0.11 \cdot (1 - 0.55) = 0.05\,; 0.15 \cdot (1 - 0.55) = 0.07]. \quad \textbf{(21)}$$
$$S'_{11} = [0.07 \cdot (1 - 0.84) = 0.01; 0.09 \cdot (1 - 0.84) = 0.01]. \quad \textbf{(22)}$$
$$[0.09 \cdot (1 - 0.67) = 0.03; 0.12 \cdot (1 - 0.67) = 0.04]. \quad \textbf{(23)}$$
$$[0.11 \cdot (1 - 0.56) = 0.05\,; 0.15 \cdot (1 - 0.56) = 0.07]. \quad \textbf{(24)}$$

The deviations are calculated for all tractors and criteria in this manner, and these values are summed up for each tractor (*Table 6*). Finally, the FR numbers are converted into crisp numbers, and the RAWEC method is applied to calculate the value of each alternative. For the first alternative, the calculation is as follows:

$$Q_1 = \frac{0.56 - 0.14}{0.56 + 0.14} = 0.596. \quad \textbf{(25)}$$

The results indicate that the highest-rated tractor is T1-Solectrac e25, followed by T5-Monarch Tractor MK-V, while the tractor receiving the lowest expert ratings is T6-John Deere SESAM.

Table 6. Final ranking by RAWEC method.

Tractors	$\bar{\bar{v}}_j$	v_j	$\bar{\bar{v}}'_j$	v'_j	Q_i	Rank
T1	[0.02,0.03][0.09,0.13][0.25,0.33]	0.14	[0.34,0.42][0.48,0.63][0.67,0.84]	0.56	0.596	1
T2	[0.11,0.19][0.23,0.38][0.43,0.64]	0.33	[0.16,0.42][0.34,0.53][0.67,0.77]	0.48	0.186	4
T3	[0.14,0.23][0.26,0.41][0.46,0.67]	0.36	[0.13,0.27][0.33,0.50][0.54,0.74]	0.42	0.074	5
T4	[0.11,0.15][0.24,0.33][0.44,0.57]	0.31	[0.24,0.31][0.39,0.52][0.60,0.76]	0.47	0.206	3
T5	[0.10,0.17][0.21,0.34][0.40,0.58]	0.30	[0.18,0.33][0.36,0.54][0.57,0.78]	0.46	0.209	2
T6	[0.17,0.24][0.31,0.44][0.54,0.71]	0.40	[0.15,0.22][0.32,0.44][0.53,0.69]	0.39	-0.011	6

To confirm the results of the FR RAWEC, a comparative analysis was performed [40]. Comparative analysis is crucial in validating the obtained results [41]. Here, seven additional FR methods were used: FR (Combined Compromise Solution (CoCoSo) FR SAW, FR Additive Ratio Assessment (ARAS) FR CRADIS, FR Multi-Attributive Border Approximation area Comparison (MABAC), FR Weighted Product Method (WPM) and FR Weighted Aggregated Sum Product Assessment (WASPAS). The selection of these methods was based on the following reasons:

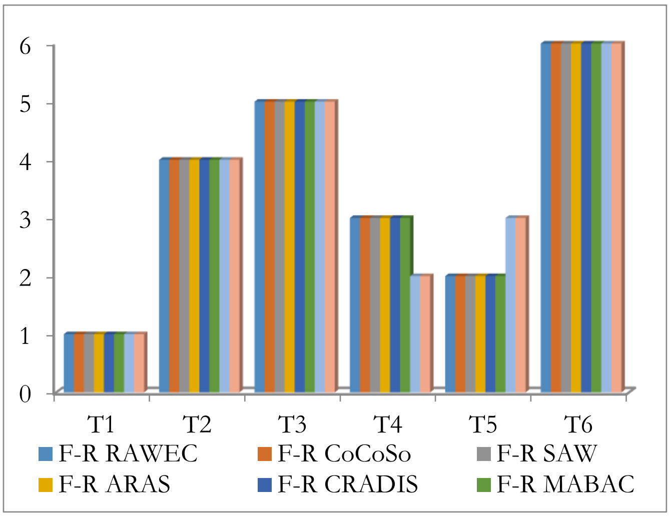
I. CoCoSo, ARAS, and MABAC methods use different normalizations. Additionally, the MABAC method includes a unique way of weighting the normalized values, making it suitable for this comparative analysis.

II. SAW and WPM methods use the same normalization and involve only three simple steps, making them some of the most straightforward MCDM methods.

III. CRADIS and WASPAS methods apply a compromise-based ranking. CRADIS compromises between deviations from ideal and anti-ideal solutions, while WASPAS represents a hybrid approach that combines SAW and WPM's elements.

The results of these methods revealed slight differences in the rankings, particularly for tractors T4 and T5 when using the FR WPM and WASPAS methods (*Fig. 2*). The reason for this discrepancy lies in the minimal differences observed in the results of the FR RAWEC method for these two tractors. Additionally, the WPM method scales the normalized values with the weight values after normalization, and since WASPAS incorporates the WPM method, this accounts for the variation in rankings.

Despite these differences, the comparative analysis confirmed the overall accuracy of the FR RAWEC method results. Based on all the methods used in the analysis, the best-performing tractor was the T1-Solectrac e25,



which consistently ranked as the top choice for small farms in the Semberija region. This alignment across methods reinforces the robustness of the initial rankings obtained through the RAWEC method.

Fig. 2. Comparative analysis results.

Following the comparative analysis, a sensitivity analysis was conducted to validate the findings further and assess potential errors' impact in defining the criteria' weighting coefficients [42]. For the sensitivity analysis, each of the 10 criteria was reduced in weight across three stages (30%, 60%, and 90%), resulting in 30 scenarios. In each scenario, the weight of one criterion was decreased while the weights of the remaining criteria remained constant [43]. This approach enabled the evaluation of how altering the importance of individual criteria affected the overall rankings of the tractors. The sensitivity analysis revealed results that supported the initial findings. In all 30 scenarios, T1-Solectrac e25 maintained its top ranking, further confirming its suitability as the best tractor for the given context (*Fig. 3*). However, the rankings of tractors that occupied the second, third, and fourth positions fluctuated based on the scenarios applied. For instance, T5-Monarch Tractor MK-V secured the second-place ranking in most of the scenarios, although it performed the worst in Scenario 9, where the weight of Criterion C3-Engine Power was reduced by 90%. This drop in ranking suggests that T5's strong engine was a key factor in its overall performance. When the significance of engine power was diminished, tractors T2 and T4 outperformed it, indicating that T5's advantage lay heavily in its engine power. Other variations in rankings for T2, T4, and T5 can similarly be traced back to changes in specific criteria weights. The rankings of tractors T3 and T6 remained consistent across all scenarios. These tractors were consistently ranked in the penultimate and last positions, based on the experts' evaluations, regardless of the changes in criterion weights. This suggests that these tractors underperformed across multiple criteria, making their rankings less sensitive to fluctuations in individual criterion weights.

The sensitivity analysis revealed both strengths and weaknesses in the performance of the observed tractors. If reducing the weight of a specific criterion improved the ranking of a tractor, this indicates that the tractor did not perform well on that criterion. For example, T5-Monarch Tractor MK-V benefitted from scenarios where the significance of engine power was high, but as that weight was reduced, other tractors with better performance in non-engine-related criteria, such as T2 and T4, rose in the rankings. This means that to improve its overall ranking, T5 would need to enhance its performance in criteria other than engine power. This analysis showed both good and bad aspects of the observed tractors. If reducing one of the criteria improves a tractor's ranking, it indicates that it does not have the best results for that criterion. In order for that tractor to improve in the overall ranking, it must improve that criterion. In this way, the sensitivity analysis measures how an individual tractor meets certain criteria compared to other criteria.

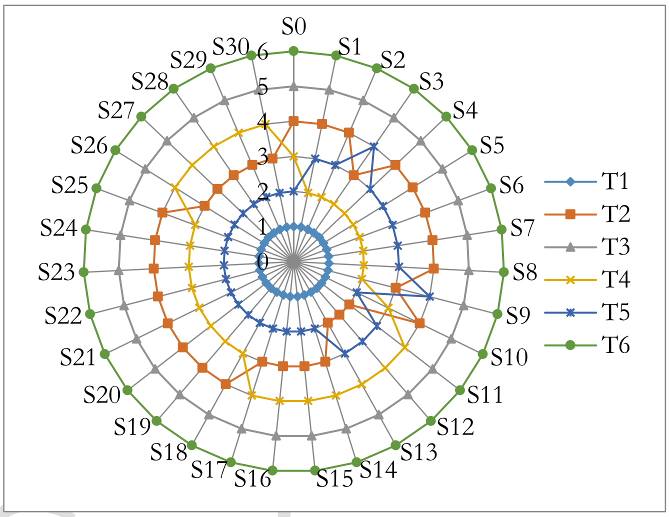


Fig. 3. Sensitivity analysis results.

5 | Discussion

The transformation of agricultural production has become essential [44], particularly concerning environmental protection. Increasing efforts are being directed towards reducing CO2 emissions and production costs. Additionally, the development of electric vehicles in the past decade has extended to agricultural machinery. The availability of electric agricultural equipment, especially tractors, is steadily increasing. Tractors are the most important machinery in agriculture [45], as they can perform various tasks with the help of attachments, effectively replacing other types of agricultural machinery. The unique feature of electric tractors is that their engines are powered by batteries, eliminating the need for fossil fuels during operation. This makes them environmentally friendly and helps reduce CO2 emissions in agricultural production.

Given the variety of electric tractors available on the market, selecting those that can best meet the unique needs of small farms in Semberija is important. This research was conducted with that objective in mind. A FR approach, which combines the fuzzy and rough set theories, was used for expert decision-making. This approach was selected because it facilitates decision-making using linguistic values, particularly when information is incomplete and uncertain. Using this approach, the advantages of the fuzzy and rough approaches are utilized [46], [47]. The fuzzy approach enables the possibility of making decisions based on imprecise information, while the rough approach allows for the inclusion of uncertainty in decision-making. Since five experts participated in this research, their evaluations needed to be harmonized, which was accomplished using the Bonferroni mean operator. The purpose of this operator is to calculate average ratings for individual FR numbers.

Ten criteria were used to evaluate the electric tractors, mostly focusing on technical criteria, with some consideration for economic and environmental factors. The decision-making process could not rely on just one type of criterion; instead, a wide range of criteria was included to improve the tractor evaluation process. The experts used linguistic values to evaluate the importance of these criteria. The FR SiWeC method was employed to obtain the results regarding the importance of the criteria. This method does not require the experts to compare or rank the criteria against each other, simplifying their task. Each criterion was assigned roughly equal weight, with no significant deviation, ensuring that all criteria equally influenced the final decision.

Six electric tractors, all available in the Semberija region, were evaluated using these criteria. The same linguistic value scale was applied throughout, simplifying the evaluation process for the experts. Using a scale ranging from "AB" to "AG", all criteria could be assessed uniformly without considering whether a criterion was cost- or benefit-related. This consistency made the experts' task even simpler. Once the tractors were evaluated based on the criteria, the FR RAWEC method was used. Like SiWeC, RAWEC is a newer MCDM method chosen to promote its application in research. The RAWEC method had not previously been used in its FR form. This research established steps to do so and enhanced the method with the Bonferroni mean operator, which helped harmonize the criteria evaluations. When applying the RAWEC method, the normalized values did not exceed 1, as the defined deviation formula required. Therefore, all values were divided by the maximum FR number for each criterion, and the remaining values were divided by the minimum FR number for the corresponding criterion. This approach could be used in future research to avoid negative deviations. The results indicated that the Solectrac e25 (T1) tractor showed the best outcomes. One reason is that this tractor is one of the most affordable on the market, with the lowest maintenance costs. Although it is not designed for heavy-duty tasks, it meets the needs of smaller farms in the Semberija region.

Additional analyses were conducted in the form of comparative analysis and sensitivity analysis. Comparative analysis compared the results of the FR RAWEC method with other MCDM methods. The results were nearly identical across methods, with only slight variations observed in the FR WPM and FR WASPAS methods, where the rank order of the two tractors differed. This variation is attributed to the WASPAS method incorporating the WPM method, which applies specific weighting and scales the normalized values based on the criteria's weights. In contrast, other methods employ multiplication, leading to differences in the ranking. While some tractors showed minor deviations in rank, it was logical for different methods to demonstrate different orders in some cases. The sensitivity analysis revealed that tractors ranked second, third, and fourth changed positions with varying weights assigned to certain criteria. This occurs because tractors with strong performance in one criterion may have weaker performance in another, making it essential to identify areas where tractors need improvement in future models.

This research aims to assist small agricultural producers in Semberija by reducing their environmental impact and operational costs. However, the choice of tractor may vary according to individual preferences. Some farmers prioritize engine power, while others focus on towing capacity or price. One challenge with electric tractors is the battery charging time, as they cannot be used while charging. Solar-powered chargers should be considered to reduce agricultural production's environmental impact further. The transition from traditional to electric tractors can be accelerated with government incentives for purchasing electric tractors, emphasizing the need for greater state involvement. Electric tractors are necessary to apply sustainable and smart agriculture [48]. In addition, it is necessary to use other modern agricultural tools [49], [50] to improve agriculture in Semberija.

6 | Conclusion

This research demonstrated the use of the FR approach in selecting electric tractors for small farms in the Semberija region. Expert opinions and the FR SiWeC and FR RAWEC methods were used to determine which electric tractor is best suited for this purpose. These methods were chosen due to their novelty and ease of use, requiring no complex mathematical operations. The results indicated that criterion C7-Maintenance was slightly more important than the other criteria, but all criteria had a nearly equal impact on the final decision. Comparative analysis confirmed the results, identifying the Solectrac e25 as the best electric tractor based on the evaluated criteria.

Like all research, this one has limitations as well. These limitations include the selection of the ten criteria and six tractors, which could be expanded upon in future research. Adding more criteria can complicate the evaluation process, so maintaining a balanced number of criteria is important. Future research could focus specifically on the importance of individual criteria, helping to refine decision-making. The selection of tractors also presents a limitation; new tractors may be introduced in future studies, but it is essential to consider the availability of these tractors in the region being studied.

Another limitation is the complexity of the FR approach itself. This method is more complicated than using the fuzzy or rough set methods independently, as it combines both approaches. Researchers must first calculate fuzzy values and then determine each fuzzy number's lower and upper bounds. Although this approach introduces additional complexity, it enhances the robustness of decision-making, making it "safer "for decision-makers. For this reason, the FR approach should be developed further in future research, as it provides added flexibility. In this study, the Bonferroni mean operator was used to harmonize expert evaluations, but future research could explore alternative operators or functions to achieve this goal.

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Author Contributions

For research articles with multiple authors, provide a short paragraph that identifies each contribution. The following statements should be used: "Conceptualization, A.P. and M.N; Methodology, D: B; Software, A.P; Validation, D.B., M.N. and A.Š.; formal analysis, A.P.; investigation, M.N.; resources, D.B.; data maintenance, A.Š.; writing-creating the initial design, A.P.; writing-reviewing and editing, D.B.; visualization, A.Š.; monitoring, M.N.; project management, A.Š.; funding procurement, M.N. All authors have read and agreed to the published version of the manuscript.

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Data Availability

None.

Conflicts of Interest

The authors declare no conflict of interest.

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