# A multi-criteria approach for assessing the potential of renewable energy sources for electricity generation: Case Serbia

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Research paper

# A multi-criteria approach for assessing the potential of renewable energy sources for electricity generation: Case Serbia

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A B S T R A C T

When assessing the potential of renewable energy alternatives for electricity generation, it is necessary to implement a multi-perspective approach that includes economic, technical, environmental, and socio-political criteria. For the evaluation of criteria and alternatives, the Fuzzy Analytical Hierarchy Process (FAHP) method is applied. The obtained weights are formed according to the values of energy indicators and expert judgments. The use of a fuzzy numerical value scale for the assessment of expert judgments and energy indicators provides a more sensitive scoring system for differences between values than the typical rank of absolute energy indicator values. This approach is implemented for assessment of the potential of renewable energy sources that could be utilized in the Serbian electricity sector. The results of the FAHP reveal that hydropower and biomass have the highest potential among available renewable energy sources.



## 1. Introduction

Keeping the global temperature rise below 2 degrees Celsius requires a profound transition of the global energy system from a system based largely on fossil fuels to one that increases the efficiency and share of renewables (IRE, 2018). A transition towards long-term sustainability in global energy systems based on renewable energy sources (RESs) can simultaneously mitigate issues such as greenhouse gas emissions, pollution, and the exceeding of critical planetary boundaries (Bogdanov et al., 2019).

The on-going global energy transition from the fossil-based to the low-carbon energy sector has increasingly been incorporated in national energy strategies. At the core of these documents is the policy of increasing the proportion of energy from renewable sources.

The Serbian Energy Sector Development Strategy and the National Action Plan for Use of Renewable Energy Sources indicate a plan for increasing the share of RES in gross final energy consumption (RS2, 2016, 2013). Serbia was obliged to reach 27% of the gross energy final consumption provided from RESs by 2020 (RS2, 2016). Currently, in terms of target achievement, Serbia does not meet this target in all sectors (electricity, heating and cooling, and transport) (Ene, 2020).

Looking at the energy balance of the country, it can be concluded that the Serbian electricity sector could contribute to accomplishing renewable energy targets (SOR, 2020) since Serbia is largely dependent on coal. Around 2/3 of domestic electricity generation originates from lignite-fired thermal power plants.

The challenges of the initiated national energy transition may promise multiple benefits, such as economic growth, job creation, mitigation of climate changes, and the reduction of air pollution (ILO, 2018). However, the optimal renewable energy structure of future national electricity system and potential transition pathways are still open questions.

The objective of this paper is to identify RESs with the highest potential for electricity generation, which will consequently contribute to accomplishing the target of increasing the participation of RESs in gross final energy consumption. The multi-criteria decision analysis (MCDA) is known as an operational assessment and decision-making method appropriate for dealing with complex problems where uncertainty, conflicting criteria, and different interests need to be evaluated from qualitative and quantitative aspects (Campos-Guzmán et al., 2019). Various authors have focused on the implementation of different MCDA models and approaches to assess the potential of RES at the national and local levels.

Strantzali et al. (2017) used a multicriteria decision-making model to determine the optimal fuel mix for electricity generation in an isolated Greek island, with respect to the economic, technical, environmental, and social aspects.

Using the case of Lithuania's electricity sector and multiple criteria mathematical methods AHP (Analytic Hierarchy Process) and ARAS (Additive Ratio Assessment method) Štreimikiene et al. (2016) evaluated electricity generation technologies, considering their economic, technological, environmental, social, and political

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**Table 1**
Total installed capacity for electricity generation and amounts of produced electricity [MW] (Ene, 2020; SOR, 2020; MME, 2018, 2020).

| Energy source and production facility | Installed capacity (MW) | Produced electricity (GWh) | Share (%) |
|---|---|---|---|
| Coal | | 24,975.316 | 66.73 |
| Thermal power plants | 4,054 | | |
| Natural gas and fuel oil | | 829.08 | 2.22 |
| CHP | 332 | | |
| Autoproducers | 105.6 | | |
| Hydro | | 11,393.16 | 30.44 |
| Large hydropower plants (HPs) | 2,956 | | |
| Small and mini HPs <10 MW | 104 | | |
| Solar | | 13.04 | 0.03 |
| PV | 11 | | |
| Wind | | 150.42 | 0.40 |
| Wind power plants | 398 | | |
| Biomass | | 64.72 | 0.17 |
| Biogas power plants | 22 | | |

aspects and ranked them in order of priority. Ruiz et al. (2020) proposed a decision support tool that integrates the AHP algorithm into a Geographical Information System (GIS) package for site-suitability assessment of solar power plants.

Al Garni et al. (2016) implemented expert pairwise comparisons into the AHP to evaluate renewable energy alternatives for electricity generation in Saudi Arabia.

Rani et al. (2020) proposed a fuzzy TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method for evaluating and ranking renewable energy sources. A group of experts connected with renewable energy sources was selected to evaluate criteria and alternatives in the case of India. Based on the results, wind energy was found to be the optimal alternative.

Çolak and Kaya (2017) developed a new model to select and evaluate renewable energy alternatives in Turkey. The suggested fuzzy MCDA model combines AHP and fuzzy TOPSIS methods. Their findings showed that wind energy was the best source among available RESs. Shen et al. (2010) implemented a fuzzy AHP (FAHP) in order to select the available RES to accomplish the energy goal in the case of Taiwan's energy sector. The results showed that hydropower, solar energy, and wind energy will contribute to meeting the 3E policy goals (energy, environment, economy).

The new fuzzy integrated Delphi-FAHP-PROMETHEE methodology has been applied (Seddiki and Bennadji, 2019) with the objective to select the best renewable energy alternatives in a residential building in Algeria.

Wang et al. (2020) integrated the FAHP and SWOT model for choosing and assessing the strategic renewable energy technologies in Pakistan by considering four indicators and 17 sub-indicators.

Various decision-making approaches, such as TOPSIS, VIKOR, and fuzzy analysis, were explored to subsequently rank various Indian states concerning their wind energy potential (Rathi et al., 2020).

Having in mind the prior analyses of modern approaches in assessing the national renewable energy potentials using MCDA, it can be concluded that many of the existing models in the literature are based on different fuzzy sets methods pioneered by Zadeh (Zadeh, 1978). One of the main reasons for that practice is that fuzzy sets are more proficient than crisp numbers for dealing with the ambiguity, information shortage, and uncertainty inherent in decisions made by human beings (Rani et al., 2020).

For decomposing the complex objective of the study into a hierarchical structure and for dealing with uncertainty in a decision-making process, FAHP appeared to be a useful tool. FAHP combines the fuzzy theory and the AHP method. The AHP method structures a problem hierarchically, descending from an objective to criteria, sub-criteria, and alternatives in successive levels (Saaty, 1990). To handle imprecision and uncertainty in the pairwise comparison process, the AHP scale is replaced with fuzzy numbers that represent the linguistic expressions in the FAHP (Liu et al., 2020). Therefore, the FAHP may be applied for dealing with complex problems of ranking and prioritizing, such as the multi-criteria assessments of different energy issues.

Despite the limitations of a one-country model, which should be kept in mind when considering the on-going increasing role of cross-border exchanges in the electricity sector, the multi-criteria approach can still provide a substantial contribution for prospective analysis of national and local potentials in increasing the share of RES (Gerse, 2015). In this paper, the FAHP method is used for assessing the four most potential RESs (biomass, hydro, solar, and wind) for electricity generation in Serbia.

Different resources were used to define the criteria and alternatives in the model, including a literature review, expert judgments, and national and international data which deals with the quantitative and qualitative analysis of the utilization of RES for electricity generation. In the parts of the presented assessment for which there are no reference data from governmental and expert bodies, data from expert assessments and studies of international expert organizations were used.

The novelty of this paper consists of the following:

- Expert assessment of the proposed economic, environmental, socio-political, and technical criteria, as well as the assessment of available RES technologies in Serbia regarding the socio-political criterion.
- The introduction of the well-known energy indicators (IPC, 2014; IRE, 2019; RS2, 2016) into the FAHP model to evaluate the strengths of selected RESs in Serbia regarding the selected criteria,
- A unique symbiosis of expert assessments with a set of energy indicators for the FAHP prioritization of RESs.
- New insight into the potential of RESs for electricity generation in Serbia based on a multi-criteria approach.

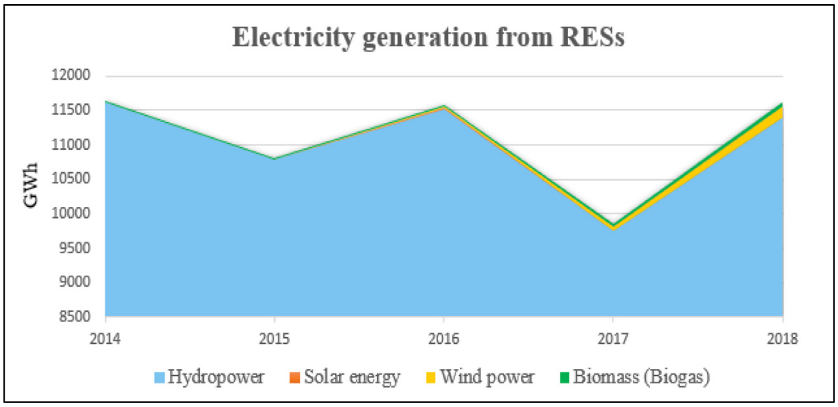


**Fig. 1.** The structure of electricity generation from RESs in Serbia (2014–2018) (SOR, 2016, 2017, 2018, 2019, 2020).

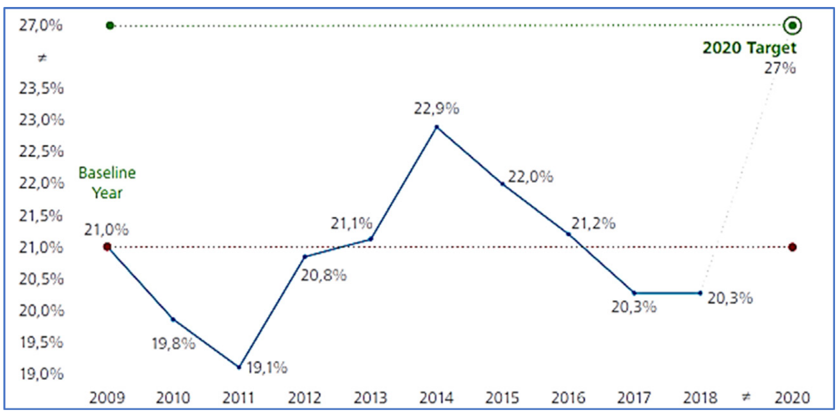


**Fig. 2.** Shares of energy from RES (Ene, 2020).

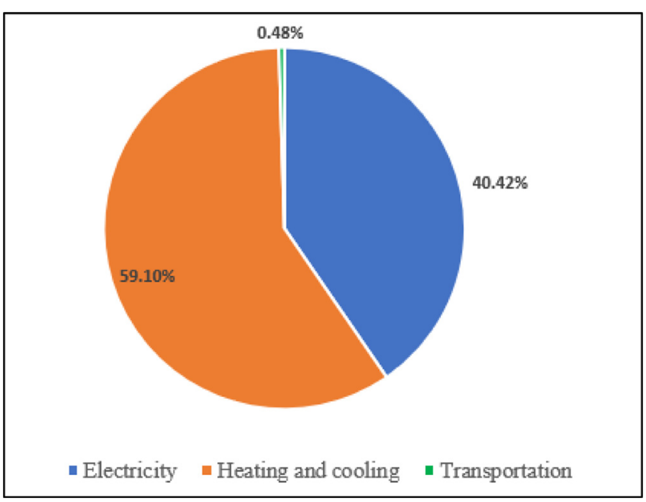


**Fig. 3.** The structure of renewable energy consumption by sectors (SOR, 2019).

## 2. Serbian electricity sector and RES potentials: state of the art

Since the paper presents a country-specific multi-criteria assessment methodology, the main national energy system characteristics related to electricity production and RES potential are briefly summarized in this section.

According to the Energy Balance, the total consumption of electricity in Serbia was 28,048 GWh (2.41 Mtoe) (SOR, 2020). Per capita, this is an average of 4005 kWh.

Serbia satisfies almost all its electricity demand from domestic production. Public Enterprise Electric Power Industry of Serbia (EPS) is the largest energy company in Serbia. The main activities of EPS are electricity generation, supply, distribution, and trading. Electricity generation in Serbia relies on lignite for around 70% of its electricity production. (EPS, 2018). EPS operates with 6 thermal power plants with 18 units, with a total capacity of 4054 MW (EPS, 2018). The resource for electricity generation in the EPS' thermal power plants is lignite, as a domestic energy source, from Kolubara and Kostolac mine basins. Thermal Power Plants Nikola Tesla (TENT) is the largest producer of electricity in southeast Europe (Gajić et al., 2019). It comprises of 14 units with a total installed capacity of 3141 MW. TENT generates more than 50% of electricity in Serbia (EPS, 2018).

The second biggest energy source for electricity production is hydropower (around 30% of electricity production is generated in hydropower plants). EPS comprises 15 hydro power plants with 49 units, 1 pumped-storage hydro power plant with 2 units, 1 pumping plant with 2 pumps and 16 small hydro power plants. Branch "Hydro Power Plant Djerdap" comprises 7 hydro power plants with 28 units, having installed capacity of 1592 MW and mean annual electricity generation of 7324 GWh for the period 2008–2017, which makes approximately 20% of EPS electricity generation (EPS, 2018).

The utilization of other RESs, such as solar, wind, and biomass is marginal. The structure of total capacities for electricity generation and amounts of produced electricity in 2019 are shown in Table 1, while the structure of electricity generation from RESs in the 2014–2018 period is shown in Fig. 1.

In Serbia, the National Renewable Energy Action Plan set a target of 27% of RES in its gross final energy consumption by

**Table 2**
Overview of the technical usable potential of RESs (RS2, 2016; SOR, 2020).

| Renewable energy source | Available technical potential in use in 2018 (Mtoe) | Unused available technical potential (Mtoe/per year) | Total available technical potential (Mtoe/year) |
|---|---|---|---|
| HYDRO ENERGY | 0.980 | 0.699 | 1.679 |
| SOLAR ENERGY | 0.001 | 0.045 | 0.046 |
| WIND ENERGY | 0.013 | 0.09 | 0.103 |
| BIOMASS[a] | 1.12 | 2.328 | 3.448 |

[a]Due to lack of data on biomass potential for electricity generation, it is presented the total energy potential of biomass.

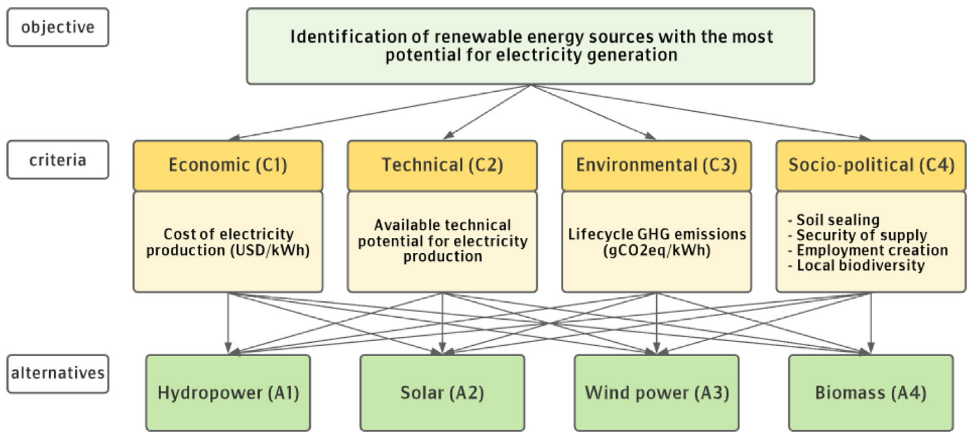


**Fig. 4.** FAHP hierarchical structure.

2020 (RS2, 2013) which is in accordance with the Decision of the Ministerial Council of the Ene (2012). According to available data, Serbia remains far from reaching its target of 27% (Fig. 2), being not only well below the 2020 renewables target, but also below the share of renewable energy in gross final energy consumption in the baseline year 2009 (Ene, 2020).

Although the country is increasing its renewable energy capacities, this trend is countered by rising energy consumption. In terms of target achievement, Serbia is lagging behind in all sectors: electricity, heating and cooling, and transport (Ene, 2020).

The structure of renewable energy consumption by sectors is shown in Fig. 3.

The available estimation of RESs potential in Serbia is from 2012 and it is an integral part of the Energy Sector Development Strategy (RS2, 2016). Potentials of RESs in Serbia are significant and estimated at 5.65 Mtoe (tons of equivalent oil) per year (RS2, 2016) (Table 2).

The largest part of the current usage of RESs refers to the traditional way of using biomass for heating and electricity generation by large hydropower plants (RS2, 2016).

Biomass potential is estimated at 3.448 Mtoe. In the total potential of renewable energy, biomass participates with 61% (RS2, 2016). The largest part of hydro potential (over 70%) is only concentrated on several rivers: Danube, Drina, Velika Morava, Lim, and Ibar. The remaining part of hydro potential and the possibility for its utilization needs to be determined following the non-energy criteria that are related to multipurpose water use. Wind energy in the Republic of Serbia can be used in the area with Kosava wind, south Banat, eastern Serbia, Pester, etc. Solar energy potential represents the energy potential that can be used to produce heating or electricity. On the greater part of the territory of Serbia, the number of hours of solar radiation is significantly higher than in most European countries. Annually, the average value of radiation energy is from 1200 kWh/m$^2$/per year in north-west Serbia to 1550 kWh/ m$^2$/per year in south-east Serbia, while in the central part it is about 1400 kWh/m$^2$/per year (RS2, 2016).

## 3. Materials and methods

### 3.1. Fuzzy AHP method

As the method of the MCDA, FAHP systematically solves the problem using the concepts of fuzzy set theory and hierarchical structure analysis, typical for the AHP method. The model for prioritizing RESs for energy generation first divides the objective of the research into a hierarchy. The top-level in the hierarchy is the objective of the research which is "Identification of renewable energy sources with the most potential for electricity generation". The second level represents criteria ($C_1$ - $C_4$). The RESs (alternatives $A_1$ - $A_4$) are on the third level, which is at the bottom of the hierarchy (Fig. 4).

Once the hierarchy is built, FAHP can be implemented. This FAHP approach is characterized by pair-wise comparisons of identified criteria in the first step, and pair-wise comparisons of RESs with respect to previously prioritized criteria in the second step.

For the assessment of identified criteria and for the prioritization of RESs regarding the socio-political criterion, five experts in the Serbian energy sector were polled in this research. Experts assigned a linguistic variable to each pair of criteria by making a pairwise comparison with respect to the priority of identified criteria, as well as a pairwise comparison of RESs with respect to socio-political criterion. Each of these linguistic variables is assigned one of the triangular fuzzy numbers (TFNs) (Table 3) (Dubois et al., 2007).

In the case of experts 'assessment of the criteria and experts' prioritization of RES alternatives regarding social criterion, the aggregation of experts' judgments (EJ) is done by using the geometrical mean (GM) method (Eq. (1)), with the assumption that the experts are of equal importance:

$$CEJ = \sqrt[5]{EJ_1 * EJ_2 * \ldots\ldots * EJ_5} \tag{1}$$

The GM is selected based on a literature review noting that, in the cases of aggregation of individual judgments, the GM is

**Table 3**
Fuzzy AHP scale (Ren and Sovacool, 2014).

| Linguistic variables | Intervals of differences | TFNs | Reciprocal TFNs |
|---|---|---|---|
| Equal importance | 0%–1% | 1, 1, 1 | 1, 1, 1 |
| Weak importance | 1.1–2.5% | 2/3, 1, 3/2 | 2/3, 1, 3/2 |
| Moderate importance | 2.6–6.5% | 1, 3/2, 2 | 1/2, 2/3, 1 |
| Strong importance | 6..6%–15% | 3/2, 2, 5/2 | 2/5, 1/2, 2/3 |
| Very strong importance | 15.1%–30% | 2, 5/2, 3 | 1/3, 2/5, 1/2 |
| Absolute importance | More than 30% | 5/2, 3, 7/2 | 2/7, 1/3, 2/5 |

commonly used to determine group preferences (Forman and Peniwati, 1998; Aczél and Saaty, 1983; Buckley, 1985). As pointed out, in the event of aggregation of judgments, GM preserves the reciprocal properties of the aggregated pairwise comparison matrices (Mikhailov, 2004).

For the prioritization of the RES alternatives regarding the economic ($C_1$), technical ($C_2$), and environmental criteria ($C_3$) (expressed by calculated indicators), for each pair of alternatives, pairwise comparison is determined based on the difference of share in the total sum of actual values of indicators. This means that belonging to the appropriate linguistic variable was determined according to the difference between indicators. For example, in the case of the technical criterion "Technical potential for electricity generation", expressed in GWh per year, the share of biomass is 50.83% and the share of wind energy 5.31%, which means that biomass has a higher share for 45.52%, i.e., biomass has "absolute importance" over wind energy.

Each of the linguistic variables is assigned one of the triangular fuzzy numbers (TFNs). The linguistic variables and corresponding intervals of the differences of indicator values' share, as well as the appropriate TFNs for the pairwise comparison of criteria and RESs, are presented in Table 3.

As can be seen from Table 3, numerical scales are represented by triangular fuzzy numbers (TFNs). The TFN is defined as fuzzy number M (l, m, u) on R (set of real numbers) if its membership function $\mu_M(x)$: R→ [0,1] is equal to (Chang, 1996):

$$\mu_M(x) = \begin{cases} \frac{x}{m-l} - \frac{l}{m-l}, & x\epsilon\,[l,m]\,, \\ \frac{x}{m-u} - \frac{u}{m-u}, & x\epsilon\,[m,u]\,, \\ 0, & otherwise, \end{cases} \tag{2}$$

In this paper, Chang's extent analysis method (Chang, 1996) is implemented to determine the relative importance of weights concerning the criteria and individual priority of each RES. According to Chang's approach, TFNs are used for a pairwise comparison scale of the FAHP. After the comparison matrix is set, the synthetic extent value $S_i$ of the pairwise comparison is calculated.

The extent analysis method for FAHP is represented by the following steps (Chang, 1996):

Let $M_{gi}^j (j = 1,2,\ldots, m)$ be TFNs that represent the value of criteria and RES alternatives in the comparison matrices. Then the value of fuzzy synthetic extent ($S_i$) is defined as (Chang, 1996):

$$S_i = \sum_{j=1}^{m} M_{gi}^j \left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} \tag{3}$$

Two more steps are required before starting the calculation of the fuzzy synthetic extent ($S_i$). First, it is necessary to obtain a sum of TFNs values for each criterion and RES:

$$\sum_{j=1}^{m} M_{gi}^j = \left( \sum_{j=1}^{m} l_{gi}^j, \sum_{j=1}^{m} m_{gi}^j, \sum_{j=1}^{m} u_{gi}^j \right), i = 1, 2, \ldots, n \tag{4}$$

Second, it is necessary to find $(-1)$ power of summation $\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j$:

$$\left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} = \left( \frac{1}{\Sigma_{j=1}^{n} u_i}, \frac{1}{\Sigma_{j=1}^{n} m_i}, \frac{1}{\Sigma_{j=1}^{n} l_i} \right) \tag{5}$$

**Table 4**
Global electricity costs in 2018 (IRE, 2019).

| RES | USD/kWh |
|---|---|
| Hydro | 0.047 |
| Solar | 0.085 |
| Wind | 0.056 |
| Biomass | 0.062 |

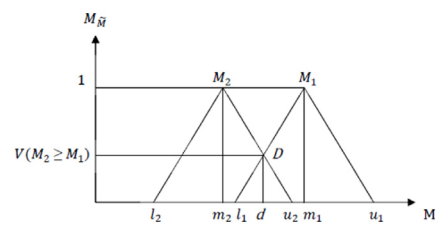


**Fig. 5.** Intersection point D (Chang, 1996).

The degree of possibility of $M_1 \geq M_2$ is defined as:

$$V(M_1 \geq M_2) = \sup_{x \geq y} [\min(\mu_{M1}(x), \mu_{M2}(y))] \tag{6}$$

Since $M_1$ and $M_2$ are convex fuzzy numbers then the following rules are applied:

$$V(M_1 \geq M_2) = 1 \text{ iff } m_1 \geq m_2 \tag{7}$$
$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M1}(d)$$

where d is the ordinate of the highest intersection point D between $\mu_{M1}$ and $\mu_{M2}$(Fig. 5).

When $M_1$= ($l_1$, $m_1$, $u_1$) and $M_2$= ($l_2$, $m_2$, $u_2$), the ordinate d is given by next equation:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) \tag{8}$$

$$\mu_{M2}(d) = \begin{cases} 1, & if\ m_2 \geq m_1 \\ 0, & if\ l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2-u_2)-(m_1-l_1)} & otherwise \end{cases}$$

To compare $M_1$ and $M_2$, it is needed to calculate both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.

The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers $M_i$ ($i$ = 1,2, …, $k$) can be defined:

$$V(M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M_1) \text{ and } (M \geq M_2) \text{ and } \ldots \text{ and } (M \geq M_k)] = \min V(M \geq M_i), i = 1, 2, 3, \ldots, k \tag{9}$$

Assume that:

$$d'(A_i) = minV(S_i \geq S_k) \tag{10}$$

for $k$ = 1,2, …$n$; $k \neq i$. Then the weight vector is given by:

$$W'(d'(A_1), d'(A_2), \ldots, d'(A_m))^T \tag{11}$$

where ($A_i$ = 1,2, …, $n$) are $n$ elements.

Via normalization, the normalized weight vectors are (Chang, 1996):

$$W(d(A_1), d(A_2), \ldots, d(A_n))^T \tag{12}$$

**Table 5**
Overview of the unused technical potential of RESs for electricity generation in Serbia (RS2, 2016; SOR, 2020).

| RES | GWh/year |
|---|---|
| Hydropower | 8,129.37 |
| Solar | 523.35 |
| Wind energy | 1,046.7 |
| Biomass | 10,025.06 |
| Total | 19,724.48 |

**Table 6**
Lifecycle GHG emissions from RESs (IPC, 2014).

| Lifecycle emissions (median) | |
|---|---|
| RES | $gCO_2eq/kWh$ |
| Hydro | 24 |
| Solar | 44.5 |
| Wind | 11 |
| Biomass | 230 |

**Table 7**
Aggregated comparison matrix for criteria ($C_1$–$C_4$).

| | $C_1$ | | | $C_2$ | | | $C_3$ | | | $C_4$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $C_1$ | 1.00 | 1.00 | 1.00 | 0.67 | 1.30 | 1.50 | 1.00 | 1.54 | 1.94 | 1.50 | 1.50 | 2.50 |
| $C_2$ | 0.55 | 0.77 | 1.11 | 1.00 | 1.00 | 1.00 | 0.87 | 1.39 | 1.78 | 1.14 | 1.84 | 2.11 |
| $C_3$ | 0.47 | 0.62 | 0.87 | 0.49 | 0.67 | 0.94 | 1.00 | 1.00 | 1.00 | 0.68 | 0.92 | 1.28 |
| $C_4$ | 0.46 | 0.59 | 0.85 | 0.41 | 0.53 | 0.70 | 0.78 | 1.08 | 1.47 | 1.00 | 1.00 | 1.00 |

where W is a nonfuzzy number that represents the relative weights of the analyzed criteria and RES alternatives.

### 3.2. The scope and inventory data

The proposed FAHP method for the prioritization of RESs alternatives in Serbia is implemented in well-known technologies for electricity generation that are recognized in (IPC, 2014; IRE, 2019), and also in the Decree on Criteria and Procedure for Qualification for Privileged Electricity Producer Status in Serbia (new, 2013):

- Hydropower plants — This includes both run-of-the-river and reservoir hydropower plants, over a wide range of capacities. The most common type of hydroelectric power plant uses a dam on a river to store water in a reservoir. Some hydroelectric power plants just use a small canal to direct the river water through a turbine.
- PV power plants — This includes roof-mounted solar radiation power plants using solar energy which are constructed on top of a building, and ground-mounted solar radiation power plants.
- Wind power plants — This includes on-shore wind power plants. Wind generators can be installed on unused or infertile soil if the basic condition in that area is met.
- Biomass and biogas power plants — This includes power plants using biodegradable waste materials from agricultural production processes, forestry, and households, manure from farms, products of forest management activities, biodegradable residues from food processing and from the wood industry. Biogas power plants are power plants with one or more aggregators using gas from its facilities (reactors) formed from biomass by an anaerobic process.

#### 3.2.1. Economic criterion ($C_1$)

The economic criterion of RESs refers to the cost of producing electricity from a particular RES. As an energy indicator that reflects economic criterion, here "The global weighted-average costs of electricity" (USD/kWh) is introduced. This indicator is available in IRENA's report on renewable power generation costs in 2018 (IRE, 2019), and it is calculated for all commercially available renewable power generation technologies. As it pointed out, the analysis of costs in IRENA's report was focused on estimating the costs of renewables from the perspective of investors, whether they are a state-owned electricity generation utility, an independent power producer, or a community looking to invest in renewables. The analysis excludes the impact of government incentives or subsidies, system balancing costs associated with variable renewables, and any system-wide cost-savings (IRE, 2019).

The limitation of this approach is the fact that all RESs are site-specific and that is not taken into consideration. The costs of electricity production from RESs depend on solar insolation, wind speed, characteristics of water flows, or the biomass supply chain. In addition, except for biomass, all RESs are intermittent in character and demand some kind of energy storage. Therefore, the proposed approach can be considered as a rough estimation, but acceptable due to the lack of more detailed data.

The values of the chosen indicator for assessing usage of RESs for electricity generation in Serbia are presented in Table 4. The favorable circumstance related to the Serbian energy sector and issue of intermittence is the existence of pump storage, and at least a few hundred MW of intermittent capacities can be connected without further investments (RS2, 2016).

#### 3.2.2. Technical criterion ($C_2$)

For the comparison of RESs regarding the technical criterion, the "Unused available technical potential for electricity generation" is used as an indicator (Table 5). In this context, the technical potential is defined as achievable energy generation from RES for the given system performance, topographic, environmental, and land-use constraints (NRE, 2020). Additional characteristics of RES facility operation such as efficiency, flexibility, mode of operation, etc., were taken into consideration to some extent when RES potential was determined in the current Energy Sector Development Strategy of the Republic of Serbia (RS2, 2016). In the case of the technical potential of biomass for electricity generation, the value is given based on the assumption of 37% biomass power plant efficiency (AEB, 2015).

#### 3.2.3. Environmental criterion ($C_3$)

Although electricity generation from RESs can bring more significant reductions in greenhouse gasses (GHG) emissions, there is still a negative impact on the environment. When assessing this negative impact on the environment, it is important to evaluate RESs from a lifecycle perspective and to consider emissions in the fuel chain and the manufacturing of the energy conversion technology. Indicator "Lifecycle GHG emissions per unit of final energy delivered" (IPC, 2014), measured in kg of carbon dioxide ($CO_2$) - equivalents ($CO_2eq/MWh$), is introduced as a measure of RESs' negative impact on the environment.

As a literature source for values of lifecycle emissions indicator, data from the Fifth Assessment Report of the Intergovernmental Panel on Climate Change are used (IPC, 2014) (Table 6).

#### 3.2.4. Socio-political criterion ($C_4$)

Although the usage of RESs often receives relatively wide public support, socio-political concerns do exist and are related to different aspects of each RES. For the socio-political criterion of using RESs in Serbia, experts' judgments are implemented here, due to a lack of appropriate indicators to reflect the influence of each RES on the social and political dimension in Serbia.

Therefore, to prioritize RESs regarding socio-political criterion, experts expressed their opinions and judgments concerning 4 sub-criteria (SC):

**Table 8**
The values of the S and $W_C$ for criteria ($C_1$–$C_4$).

| S | | | | $W_C$ | |
|---|---|---|---|---|---|
| $S_1$ | 0.1980 | 0.3189 | 0.5324 | **$C_1$** | **0.3488** |
| $S_2$ | 0.1695 | 0.2985 | 0.4603 | **$C_2$** | **0.3236** |
| $S_3$ | 0.1257 | 0.1914 | 0.3139 | **$C_3$** | **0.1661** |
| $S_4$ | 0.1261 | 0.1912 | 0.3081 | **$C_4$** | **0.1615** |

1. **Soil sealing** ($SC_1$) - Negative influence of electricity generation from RESs on soil sealing (Artmann, 2014). In this manner, soil sealing is defined as the permanent covering of soil by artificial materials that consequently reduces the provision of services such as food production since fertile agricultural areas get lost.
2. **Security of supply** ($SC_2$) - Security of supply refers to the capability of each RES to ensure reliable electricity supply (such as generation and transmission capacity) and to maintain normal customer supply (Groissböck and Gusmão, 2020).
3. **Employment Creation** ($SC_3$) - direct employment generated by activity related to renewable energy technologies, throughout their lifecycle, from when the energy source is first extracted to the closure stage (Panagiotis and Paroussos, 2018).
4. **Local biodiversity** ($SC_4$) - negative impacts on biodiversity from renewable energy projects, as well as energy transport and distribution system (Moreira, 2019).

Using the predetermined linguistic variables experts performed a pairwisecomparison of RESs with respect to the chosen sub-criteria. It is important to note that all four sub-criteria have equal importance. Based on the experts' judgment regarding the socio-political criterion (Table 12), biomass, as an energy source for electricity generation, is clarified as the first alternative (W=0.4871), solar energy is the second (W=0.1909), hydropower is the third (W=0.1658), and wind power is the fourth alternative (0.1581).

## 4. Results

After identifying appropriate indicators and collecting experts' judgments for the prioritization of RESs, the next step is to implement the FAHP methodology.

In the application of the FAHP for assessment of RES potentials for electricity generation, a comparison matrix is formed based on experts' judgment of proposed criteria ($C_1$–$C_4$). A linguistic variable of each expert's judgment is converted into TFNs. Table 7 introduces the aggregated comparison matrix based on experts' judgments for the criteria ($C_1$–$C_4$).

Using Eqs. (3)–(5), the values of the fuzzy synthetic extent (S) for the analyzed criteria are obtained. Weight vectors (W) of criteria ($C_1$ – $C_4$) are obtained by using Eqs. (6)–(12). Table 8 shows the values of the S and the $W_C$, which represents the priority of each criterion.

In the next hierarchy level, the comparison matrix of proposed RESs is formed with respect to the criteria by applying the same methodology. The comparison matrices of RES alternatives ($A_1$–$A_4$) regarding $C_1$, $C_2$, and $C_3$ are presented in Tables 9–11. The following tables also show the priority of each RES regarding the specific criteria (W).

In the case of assessment of the RESs regarding the socio-political criterion ($C_4$), the collected experts' judgments are also aggregated by using the geometrical mean (GM) method (Eq. (1)), with the assumption that the experts' judgments are of equal importance. After the results of prioritization for the 4 sub-criteria are obtained, the social criterion $C_4$ is calculated, based on the assumption that all 4 sub-criteria are of equal importance.

**Table 9**
Aggregated comparison matrix and priority of RESs regarding the economic criterion $C_1$.

| $C_1$ | $A_1$ | | | $A_2$ | | | $A_3$ | | | $A_4$ | | | W |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $A_1$ | 1.00 | 1.00 | 1.00 | 2 | 2.5 | 3 | 1 | 1.5 | 2 | 1 | 1.5 | 2 | **0.4306** |
| $A_2$ | 0.33 | 0.40 | 0.50 | 1.00 | 1.00 | 1.00 | 0.40 | 0.50 | 0.67 | 0.40 | 0.50 | 0.67 | **0** |
| $A_3$ | 0.50 | 0.67 | 1.00 | 1.50 | 2.00 | 2.50 | 1.00 | 1.00 | 1.00 | 0.67 | 1 | 1.5 | **0.2847** |
| $A_4$ | 0.50 | 0.67 | 1.00 | 1.50 | 2.00 | 2.50 | 0.67 | 1 | 1.5 | 1.00 | 1.00 | 16.00 | **0.2847** |

**Table 10**
Comparison matrix and priority of RESs regarding the technical criterion $C_2$.

| $C_2$ | $A_1$ | | | $A_2$ | | | $A_3$ | | | $A_4$ | | | W |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $A_1$ | 1.00 | 1.00 | 1.00 | 2.5 | 3 | 3.5 | 2.5 | 3 | 3.5 | 0.40 | 0.50 | 0.67 | **0.4189** |
| $A_2$ | 0.29 | 0.33 | 0.40 | 1.00 | 1.00 | 1.00 | 0.50 | 0.67 | 1.00 | 0.29 | 0.33 | 0.40 | **0** |
| $A_3$ | 0.29 | 0.33 | 0.40 | 1.00 | 1.50 | 2.00 | 1.00 | 1.00 | 1.00 | 0.29 | 0.33 | 0.40 | **0** |
| $A_4$ | 1.50 | 2.00 | 2.50 | 2.50 | 3.00 | 3.50 | 2.50 | 3.00 | 3.50 | 1.00 | 1.00 | 1.00 | **0.5811** |

**Table 11**
Comparison matrix and priority of RESs regarding the environmental criterion $C_3$.

| $C_3$ | $A_1$ | | | $A_2$ | | | $A_3$ | | | $A_4$ | | | W |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $A_1$ | 1.00 | 1.00 | 1.00 | 1 | 1.50 | 2 | 0.50 | 0.67 | 1.00 | 2.50 | 3 | 3.50 | **0.3330** |
| $A_2$ | 0.50 | 0.67 | 1.00 | 1.00 | 1.00 | 1.00 | 0.40 | 0.50 | 0.67 | 2.50 | 3 | 3.50 | **0.2373** |
| $A_3$ | 1.00 | 1.50 | 2.00 | 1.50 | 2.00 | 2.50 | 1.00 | 1.00 | 1.00 | 2.50 | 3 | 3.50 | **0.4297** |
| $A_4$ | 0.29 | 0.33 | 0.40 | 0.29 | 0.33 | 0.40 | 0.29 | 0.33 | 0.40 | 1.00 | 1.00 | 1.00 | **0** |

Table 12 shows the priority for all 4 socio-political sub-criteria (W-SC) and the final priority (W) of RESs regarding the socio-political criterion ($C_4$).

When the results of the prioritization are obtained, it is possible to integrate the priorities of alternatives related to the criteria and to get the final rank of each alternative (RESs). Table 13 shows the final rank, which is obtained by summing the priority of each alternative previously multiplied by the corresponding weight vectors ($W_C$) of the criteria.

According to the multi-criteria assessment, hydropower ($A_1$) has the highest priority (0.3678). With nearly the same priority is biomass (0.3660). Wind power is in third place (0.1962). In comparison with biomass, hydropower, and wind power, solar energy (0.0702) is not recognized as a priority source for increasing the share of electricity generation in Serbia.

## 5. Discussion

Biomass and hydropower superiority over the other analyzed RESs should be viewed in the light of several facts. Mainly, this is due to the significant share of the unused technical potential of hydropower and biomass. Another fact, common for biomass and hydropower, is that electricity generation from biomass and hydropower provides more continuity in energy supply. The argument for the highest priority of biomass is also in the fact that biomass fuels are typically used for the combined generation of heat and power (CHP).

The minor share of solar and wind in the technical potential for electricity generation is the main weak point of these two RESs. In this paper, available, official data for technical potential was used. Therefore, the propulsive development of technologies and its impact on the calculation of the technical potential of

**Table 12**
The priority of RESs regarding the socio-political criterion $C_4$.

| $C_4$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ |
|---|---|---|---|---|
| W-$SC_1$ | 0.0793 | 0.3155 | 0.3324 | 0.2728 |
| W-$SC_2$ | 0.2922 | 0.11 | 0.0799 | 0.5178 |
| W-$SC_3$ | 0.151 | 0.06 | 0.05 | 0.7468 |
| W-$SC_4$ | 0.1406 | 0.2781 | 0.1702 | 0.4111 |
| W | **0.1658** | **0.1909** | **0.1581** | **0.4871** |

**Table 13**
The final rank of RESs according to multi-dimensional criteria.

| Criteria | | Alternatives | | | |
|---|---|---|---|---|---|
| | $W_C$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ |
| $C_1$ | 0.3488 | 0.4306 | 0 | 0.2847 | 0.2847 |
| $C_2$ | 0.3236 | 0.4189 | 0 | 0 | 0.5811 |
| $C_3$ | 0.1661 | 0.3330 | 0.2373 | 0.4297 | 0 |
| $C_4$ | 0.1615 | 0.1658 | 0.1909 | 0.1581 | 0.4871 |
| Final rank | | **0.3678** | **0.0702** | **0.1962** | **0.3660** |

solar and wind in these two sectors could not be taken into consideration. In addition, intermittency in electricity generation is still one of the major challenges to increase the integration of solar and wind power potential for electricity generation (Lund, 2007).

In the case of hydropower potential in Serbia, the weakest point is related to the socio-political criterion, more precisely, to the raising of concerns about the potential negative environmental impact of small hydropower plants. Bearing in mind the local multipurpose of small and sensitive watercourses, better communication should be ensured with local communities and their involvement in the decision-making process.

The environmental criterion expressed by the "Lifecycle emissions" indicator (gCO2eq/kWh) was the weakest point of biomass in the analysis. This requires careful consideration of electricity generation from biomass in terms of GHG reduction policy and preservation of natural resources.

## 6. Conclusion

After years of depending on regulatory support instruments, renewable energy sources have become a powerful and cost-effective source for electricity generation. The costs of the implementation of RESs in energy systems are substantially reduced so in some regions of the U.S and Europe, electricity from RESs could become cheaper than electricity produced from traditional high-carbon energy resources. As costs continue to fall, the renewable energy sector will only keep growing and solidify as a strong investment opportunity.

In the Serbian energy mix, the current share of renewable energy source utilization is still not enough to meet the goal of increasing the share of RES in the gross final energy consumption. The promising sector for wider utilization of renewable energy sources is the electricity sector, due to the possibility of producing electricity from any renewable energy source and reduced investment costs in appropriate technologies.

In this paper, the assessment of renewable energy alternatives for Serbia is handled as a multi-criteria decision-making problem with the final objective being to determine the best renewable energy alternatives for electricity generation. The presented approach of the integrated assessment concerning conflicting criteria might serve decision-makers in long-term energy planning.

The proposed FAHP model which involves pairwise comparisons based on experts' judgments and energy indicators is applied to assess the selected RESs regarding the economic, technical, environmental, and socio-political criteria. The results show that the two alternatives, hydropower and biomass, are identified as almost equally promising for a sustainable increase in the share of renewables in electricity generation. Such results need to be interpretated together with data served as an input for the evaluation.

The main difficulty identified in conducting this research was the limited availability of updated information. At the moment, Serbia's strategic documents and energy studies do not offer updated information regarding RESs' potential, prices, environmental impact, etc. for electricity generation. For more precise prioritization and planning, more detailed information about characteristics of specific location is necessary (solar irritation, wind speed, characteristics of river flow, biomass supply chain, etc.), as well as specific information about the technical characteristics of proposed facilities (efficiency, flexibility, mode of operation, etc.). This requires further work in collecting and analyzing data from the relevant locations.

The presented approach shows that the problem of research is multidimensional coupled with the lack of information, so it is not feasible to conduct analysis using a method limited exclusively to the evaluation of energy indicators without multi-criteria decision-making methodology. This approach could be useful as a starting point in the process of developing a more comprehensive and universally accepted approach for sensitive assessment of the wider set of energy indicators relevant to the utilization of RESs.

Future research could be focused on investigating a different integrated fuzzy multi-criteria decision-making methodology for solving this problem.

### CRediT authorship contribution statement

**Boban Pavlović:** Conceptualization, Methodology, Investigation, Project administration, Writing - original draft. **Dejan Ivezić:** Conceptualization, Formal analysis, Supervision Writing - Reviewing & Editing. **Marija Živković:** Supervision, Visualization, Writing - Reviewing & Editing.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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