OPTIMIZATION OF ENERGY MIX AND POSSIBILITIES OF ITS APPLICATION IN ENERGY TRANSITION USING MULTI-CRITERIA DECISION MAKING APPROACH

by

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Original scientific paper
https://doi.org/10.2298/TSCI221013224M

The process of optimizing energy production is becoming increasingly important with the development and use of RES and energy efficiency measures. Given that these are optimization processes that require taking into account several indicators according to which the set of optimal technologies for energy production will be ranked, and take their percentage share in the total percentage of energy supply. Indicators describing the process of energy production and utilization include technological, environmental, economic, energy, and limiting domains of their application. From that aspect, when the energy supply process is optimized from several possible alternatives according to the optimization factors defined in this way and the percentage of participation from each is calculated, a very realistic picture of the optimal energy mix of a state or local community is obtained. In this paper, a comparison of the energy mix for Copenhagen, Denmark and Banja Luka, Bosnia and Herzegovina is made. The process of comparing energy mixes was made possible by a previously developed mathematical model for optimizing and searching for an optimal energy mix based on the compromise ranking method, also known as the VIKOR, as well as entropy and analytic hierarchy process methods for defining weight values of criteria describing energy mix. Since we know that the introduction of new RES and the replacement of fossil fuels with them is a process of transition of existing energy sectors, the approach presented in this paper would greatly facilitate the transition process itself.

Key words: multi-criteria decision making methods, VIKOR, entropy and AHP methods, energy transition, optimal energy mix

Introduction

The energy mix represents the combination of available energy sources and technologies for energy generation in a country/region/local community. The energy mix is mainly considered as a function of technologies and basic economic parameters, with the aim to obtain a cost-effective combination of available energy technologies needed to meet energy demand in the certain area. Energy mix generally, can be consisted from different sources, renewable and non-renewable, different by the nature, stochastic and deterministic. Beside of that, there are

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a lot of different technologies for energy generation and distribution available on the market. The question needs to be answered is how to redistribute energy supply from different energy sources and combine different technologies for energy generation and distribution in a country/region/local community in order to achieve optimal energy mix. What is optimal energy mix, and how to get *the best* energy mix? In order to solve this problem, it is necessary to determine the current state of the energy mix in a given territory, and then define scenarios for its improvements in some future period, based on certain criteria defined in advance.

Multi-criteria decision analysis is a complex discipline that includes mathematics, management, informatics, psychology, social science, economics and some other disciplines depending on considered problem [1]. There are a lot of multi-criteria decision making (MCDM) methods developed, and they are all generally dealing with problems wherein, while making decisions, we are faced with multiple and usually conflicting criteria. There is a large number of researches and papers in which MCDM methods were used in the optimization of energy supply system of a country [1-7], or region [8-9], but there are very few that deal with the energy mix optimization of a local community [10]. The MCDM method is also used in sustainability assessment of the existing energy plants or as a tool for the evaluation of new energy system, in order to show decision makers how to find the best available options depending on the criteria which are selected as leading [11, 12]. Some authors have used ready-made computer simulation mathematical models (EneryPro, EnergyPlan, HOMER i dr.), in order to obtain an optimized energy system of a country/region/city, [13-16], [23]. In some of the papers, the combination of the AHP-VIKOR methods is most often used to determine the weights of criteria and to rank the alternatives [14, 17-20]. However, it is not used to determine the optimal energy mix. Beside of the mentioned multi-criteria methods, there are some other as ASPID used in the analysis and synthesis of parameters under information deficiency. This means that it is possible to evaluate considered options by using ASPID in situations when there are uncomplete, vague or interval (incorrect) information with different levels of reliability. The procedure is based on the fuzzy set synthesis technique, which is a mathematical system to support decision-making processes [2, 12]. Beside of AHP and EWM (entropy) method used in this work, for successful identification and analysis of the influencing factors on some specific energy resource, MCDM can be combined with SWOT. Good example is MCDM analysis of use of biomass as a support for national energy policy in Serbia by using combination SWOT-ANP (analytic network process) [1].

The application scope of the VIKOR method is a very diverse one [21-25], The method is used to solve problems wherein the decision maker (DM) defines several criteria, the criteria are most often conflicting and are often expressed in units of measure that are incomparable. Vasković [24] has developed a mathematical model for calculating the optimal biomass energy supply chain using both the VIKOR method and criteria of the equal weights. Based on the aforementioned research, based on MCDM methodology it can be seen that its use can cover a wide range of optimization parameters such as energy, economic, technical, environmental, different in nature, stochastic and deterministic.

The aim of this paper is to present a developed mathematical model, based on VIKOR-AHP-EWM, which according to the adopted input data, calculates the percentage of represented technologies, enables their ranking and comparison, and proposes a possible correction according to the desired projection.

Methodology

Methodology used for the solution the energy mix optimization problem in this paper, along with definition the basic criteria for optimization, is based on VIKOR-AHP-EWM methods.

In order to obtain criteria of different weights for MCDM model, two methods were used in this model: EWM and AHP. The AHP method is a subjective method in which every criterion is compared with each other and which determines the level of preference based on an ordinal ranking scale. With the increase of the number of criteria, AHP method becomes more inconsistent [26]. This shortcoming was eliminated by using the EWM method, considering that it is an objective method in which the subjectivity of DM was avoided. In this particular case, objectivity is needed because by using that kind of method, the accuracy of determination of the criteria weights, which is in direct relation the accuracy of distribution of the optimal energy mix. The EWM is the main method which is used for determination of the criteria weight, while the AHP is used for its control and correction. The EWM gives the model great flexibility when it comes to change input data when calculating the weights of criteria.

The VIKOR is MCDM method, and it was developed for multi-criteria optimization of complex systems, and as such is suitable for choosing the optimal energy mix of the country/region/local community. The advantage of the method is reflected in its programmability, *i.e.* controllability of the method in terms of giving min and max values to the criteria, determining the threshold of acceptability and advantage, and, finally, in the possibility of using the Q rank value to express the percentage of the considered technologies.

Mathematical model

The optimization of the energy mix is usually based on a complex concept of the energy system, leading to a significant number of optimization problems that usually cannot be solved without the use of a mathematical model. Based on previously presented methodology, a mathematical model for determination of the optimal energy mix of the state/region/local community was developed, and fig. 1 shows its general structure. The model itself is structured in three connected parts:
– The first part in which criteria, their calculations and the alternatives are defined.
– The second part in which the weights of criteria were calculated using the EWM and AHP methods and the values of Q_i assigned to the certain alternatives using the VIKOR method.
– The third part of the model includes the calculation of percentages of considered technologies for a given year and scenario by using Q_i values.

Table 1 provides a set of criteria and indicators for optimizing the combination of energy supply of the country/region/local community. By means of these criteria, commercially available technologies for energy generation were described. For this calculation a set of the criteria from 1-8 is adopted, and the following has been taken into account: technical-energy, economic, environmental, stochastic, quantitative, and qualitative characteristics of the energy technologies used in energy mix optimization. The calculation of the criteria itself was done in the Matlab program and represents the input to the optimization process.

Through the normalization process, all criteria values are standardized from the existing numerical structure of the initial matrix for the optimization the level of values in the interval from 0-1, and thus they are prepared for optimization using the VIKOR method. Due to the previously performed normalization process, in the further optimization process, the units in which the adopted criteria are expressed, have no influence on the final optimization results. In order to calculate the most accurate distribution of the percentage share in the energy mix, it is necessary to have objective calculations of the weights of the adopted criteria. The EWM method treats the uncertainty in the information structure of the decision matrix, known as Shannon's entropy [27].

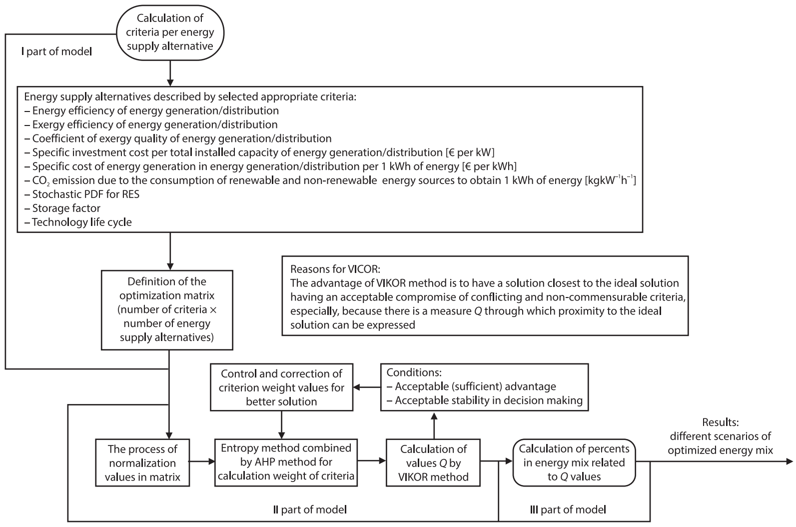


Figure 1. General structure of the developed mathematical model

Table 1. Criteria and indicators for optimizing the combination of energy supply of the country/region/local community

Category	Criterion	Indicator	Mark	Units
Technical/energy	Efficiency	Energy efficiency, criterion function	f_{1j}	%
	Efficiency	Exergy efficiency, criterion function	f_{2j}	%
	Quality	Coefficient of exergy quality for different products	f_{3j}	%
	Maturity	Technical life cycle of the plant	f_{8j}	Years
Economic	Economic feasibility	Specific investment costs per total installed capacity of all plants	f_{4j}	€/kw
	Economic feasibility	Specific costs of energy generation per 1 kWh of energy generated	f_{5j}	€/kwh
Environment/ stochastics	Emission	CO_2 emissions in the chain due to the consumption of fossil fuels to obtain 1 kWh of energy	f_{6j}	kg/kwh
	Capacity factor/stochastics	CF/PDF probability density function	f_{7j}	%

The value of entropy ranges from 0-1. The higher the E_i value, the greater the degree of differentiation of the index i, and the greater weight is given to it. The amount of the information contained in the normalized decision matrix and emitted by each criterion f_i can be measured as the value of entropy E_i. The weight of indicator i is given [27]:

$$w_i = \frac{1-E_i}{\sum_{i+1}^{m}\left(1-E_i\right)} \tag{1}$$

The AHP method [28] is based on a pairwise comparison alternatives by determining the weight for every unique criterion. The aim of the method is to define an optimal alternative and categorize the other, taking into account the criteria describing them. The best alternative is the one having the highest value:

$$AHP_i = \sum_{j=1}^{n} \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}} w_j \tag{2}$$

where AHP_i is the result of i alternative, m – the number of alternatives, n – the number of criteria, a_{ij} – the real value of i alternative in terms of j criterion, and w_j – the weight of j criterion.

The VIKOR MCDM method after that determines the compromise ranking list and the compromise solution that is closest to the ideal solution [29]. Outcome from the VIKOR method calculations is the value, Q_i, for multi-criteria ranking of the alternatives. The VIKOR has verification options: acceptable advantage and acceptable stability. In this way, we have been provided with feedback in terms of achieving the compromise solution by correcting the weights obtained from the selected criteria in order to meet the conditions of stability and acceptable advantages of the solution for multi-criteria ranking of the energy mix technologies alternatives.

Measure for multi-criteria ranking Q_i, according to the VIKOR method, for $i = 1, 2,...m$ alternatives and $j = 1, 2,...n$ number of criteria, was given:

$$Q_i = v\frac{\left(S_i - S^*\right)}{S^- - S^*} + \left(1 - v\right)\left(\frac{R_i - R^*}{R^- - R^*}\right) \tag{3}$$

$$S_i = \sum_{j=1}^{n} w_j \frac{f_j^* - f_{ij}}{f_j^* - f_j^-} \tag{4}$$

$$R_i = \max_j \left[w_j \frac{f_j^* - f_{ij}}{f_j^* - f_j^-} \right] \tag{5}$$

$$S_i = \min_i S_i,\ S^- = \max_i S_i,\ R^* = \min_i R_i,\ R^- = \min_i R_i \tag{6}$$

where f_i^* is the best and f_i^- the worst values of all function criteria, $j = 1, 2,\ldots n$

$$f_j^* = \max_i f_{ij},\ f_j^- = \min_i f_{ij} \tag{7}$$

if i function denotes the max attribute

$$f_j^* = \min_i f_{ij},\ f_j^- = \max_i f_{ij} \tag{8}$$

where i is the function denotes the min attribute, w_i – the weight of criterion, v – the *strategic coefficient* always belonging to the interval from 0-1, S_i – the measure of deviation expressing the requirement for maximum group benefit, R_i – the measure of deviation expressing the requirement to minimize the maximum distance of some alternative from the *ideal* solution, and Q_i – the value represents the determination of the compromise ranking list that combines S_i and R_i values.

The calculation of percentage of the participation of the considered technologies, p_i, was done on the basis of the rank value Q_i:

$$p_i = \frac{1-Q_i}{16-\sum_{i=1}^{16} Q_i} \tag{9}$$

where i = 1...16, is the number of alternatives (energy supply chains, that is, participants in the energy mix). In general, Q_i is the rank value of the each of the alternatives determined by the VIKOR method. In a fundamental meaning this is the value which represents distance from the ideal value. For the each alternative assigned value of Q_i exists, and the smaller this value is, the closer it is to the value 0, it is a variant solution that is better and close to optimal, that is: 1-Q_i interprets the percentage content of an individual variant solution against the sum of all values 1-Q_i, respectively for i = 3 variants we have: for percent of alternative 1, $p_1 = (1 - Q_1)/(1 - Q_1 + 1 - Q_2 + 1 - Q_3)$, *i.e.* $p_1 = (1 - Q_1)/(3 - Q_1 - Q_2 - Q_3)$, which in the end leads to general eq. (9), for i = 16 alternatives (technologies for energy production).

Analysis of the results

Input data

The percentage of considered technologies is the optimal percentage predicted by the model for the considered year and scenario. Developed mathematical model was tested on the base of data from two countries Denmark and Bosnia and Herzegovina (B&H) and two cities Copenhagen and Banja Luka. Three years were analyzed, 2015, as the referent year, 2035 and 2050 year, and two scenarios, called *wind scenario* and *coal scenario*. Mathematical model was tested and calibrated, first on the example of Denmark and the city of Copenhagen, due to available and quality data, and the existence of the projections of the technologies participation, with high share of different RES, for the previously specified years, which were available. After that mathematical model was used for testing and the analysis of the scenarios for B&H and the city of Banja Luka. The reason why this approach was selected is to demonstrate the universality of the model from the aspect of comparison of different technologies that are present or are planned for the production of heat and/or electricity. In this way, it is possible to choose the optimal combination of energy supply for the country/region or local community. Data of the Danish Energy Agency were used to create and test the model, namely: Energy Statistics 2015 [30], catalog with data on technologies of energy plants, [31], scenarios (DEA Fossil 2035, DEA Fossil 2050, DEA Wind 2035, and DEA Wind 2050) developed within [32]. Data used for B&H were from: Framework Energy Strategy of B&H up to 2035 [33], Framework Energy Strategy of FB&H up to 2035 [34] and Energy Development Strategy of the Republic of Srpska up to 2035 [35], Energy Balance of the Republic of Srpska – Plan for 2015, Annual Report for 2016 of the Transmission Company of B&H [36].

In the mathematical model developed in the MATHLAB program, the total of 16 technologies represented on the market for the heat and/or electricity generation were analyzed. As a result, optimization criteria were obtained that were used to select the optimal combination of energy supply for Denmark/B&H and Copenhagen/Banja Luka, as local communities. The number of technologies changed depending on the country/city, selected year and scenario. The technologies analyzed within the model are: thermal power plant-TPP (fuel oil), CHP (biomass-wood chips, gas, coal, fuel oil, waste), photovoltaic panels-FNP, wind power plants-WPP, hydro power plant-HPP, hot water boilers-TB (fuel oil, gas, biomass, coal), heat pumps-HP, geothermal power plants-GTPP and solar thermal power plants-STPP. Their combination depended on the considered territory, year and scenario. Based on the mathematical model calculation Based on the mathematical model, a calculation was made for Denmark and Copenhagen, B&H and Banja Luka with 8 adopted and explained criteria in tab. 1, for 3 years (2015, 2035, and 2050) and two scenarios (wind and fossil).

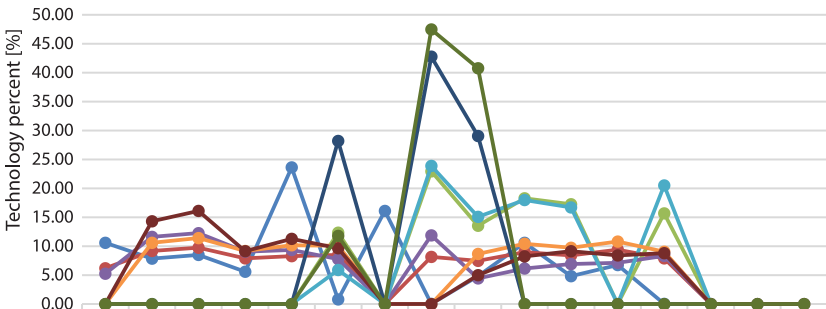
Results

For better understanding, the results of the calculation of the optimal energy mix are presented graphically. The zigzag diagrams in figs. 2-4, show the data from the Danish strategy and the parallel results of the developed mathematical model for Denmark, B&H, Copenhagen and Banja Luka for 2015 and 2035, and 2 Scenarios. In this way, a comparison of the developed mathematical model with the Danish ways of solving this problem was made possible. The analysis was also made for the data referring to Denmark and Copenhagen for the year of 2050, however, since there are no projections or concrete data for B&H and Banja Luka for the year of 2050, diagrams are not presented in this paper. There is a certain difference between what the Danish strategy actually proposes and the developed mathematical model for calculating the optimal percentage for data referring to Denmark, B&H, Copenhagen and Banja Luka. The explanation of every colors and abbreviations used in all figures in this chapter is given.

The *D 2015* is the state of estimated technologies in Denmark in 2015 was obtained on the basis data of electricity and heat consumption on the basis of which the percentages of technologies were calculated.

The *ENTR D 2015/2035* and *AHP D 2015/2035* represent optimal values according to the development of real technologies in Denmark in 2015/2035, which were used in the model, by EWM and AHP methods, wind and fossil scenario.

The *ENTR B&H 2015/2035* and *AHP D 2015/2035* represent optimal values according to the development of real technologies in B&H in 2015/2035, which were used in the model, by EWM and AHP methods, wind and fossil scenario.



	TPP fuel oil	CHP biomass	CHP gas	CHP coal	CHP fuel oil	FNP	WPP	HPP	TB fuel oil	TB gas	TB biomass	CHP waste	TB coal	GTPP	STPP	HP
D 2015	10.57	7.86	8.50	5.57	23.60	0.79	16.09	0.03	4.82	10.57	4.82	6.75	0.01	0	0	0
ENTR D2015	6.16	9.19	9.74	7.90	8.26	8.49	0	8.16	7.45	8.96	8.39	9.40	7.90	0	0	0
ENTR BiH 2015	0	0	0	0	0	12.34	0	22.95	13.52	18.27	17.23	0	15.68	0	0	0
AHP D 2015	5.22	11.61	12.26	9.04	9.33	7.78	0	11.86	4.42	6.12	6.91	7.12	8.33	0	0	0
AHP BiH 2015	0	0	0	0	0	5.89	0	23.87	15.09	17.97	16.70	0	20.48	0	0	0
ENTR K 2015	0	10.58	11.40	9.18	10.15	10.05	0	0	8.65	10.41	9.72	10.78	9.06	0	0	0
ENTR BL 2015	0	0	0	0	0	28.21	0	42.76	29.03	0	0	0	0	0	0	0
AHP K 2015	0	14.30	16.09	9.14	11.27	9.64	0	0.00	4.98	8.22	9.14	8.41	8.81	0	0	0
AHP BL 2015	0	0	0	0	0	11.76	0	47.48	40.76	0	0	0	0	0	0	0

Figure 2. Ranking of technologies by percentage for Denmark, Copenhagen, B&H and Banja Luka, EWM and AHP methods, 2015, wind/fossil scenario, 8 criteria

The *ENTR K 2015/2035* and *AHP K 2015/2035* represent optimal values according to the development of real technologies in Copenhagen in 2015/2035, which were used in the model, by EWM and AHP methods, wind and fossil scenario.

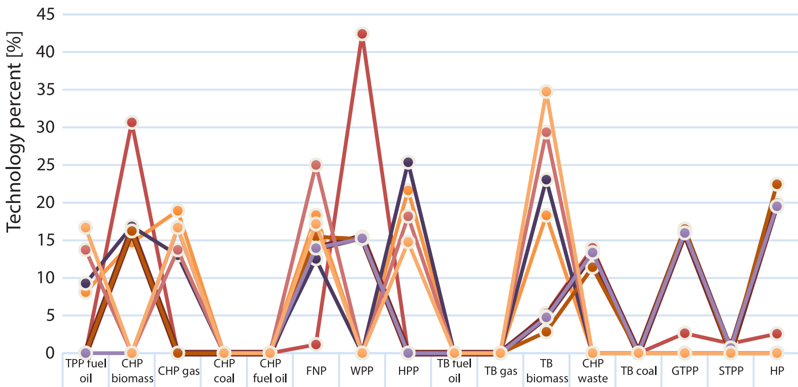
The *ENTR BL 2015/2035* and *AHP BL 2015/2035* represent optimal values according to the development of real technologies in Banja Luka in 2015/2035, which were used in the model, by EWM and AHP methods, wind and fossil scenario.

The chart in fig. 2 analyzes the projected percentage of technologies according to the Danish scenario and optimal values according to the developed model for the year of 2015 for Denmark, B&H, Copenhagen and Banja Luka. The weights of criteria were determined by using two methods, EWM and AHP. In the Danish strategy, the first-ranked technology is CHP (fuel oil) and, according to the developed mathematical model, CHP (gas).

In some parts of the zigzag diagrams, figs. 2-4, the percentages also match (they follow the light blue (D 2015/2035 fossil scenario and red D 2035 wind scenario) line on the diagram), while in some parts they deviate. These deviations of the Danish strategy and estimates for 2015 and 2035 from the optimal values given by the developed mathematical model for the same year may be primarily a consequence of forcing a certain technology in the sense that there is an excess or lack of potential for its use.

By both methods, B&H and Banja Luka have HPP as the first-ranked technology. The AHP method, as a control method, quite well follows the weight values of criteria determined by EWM.

The chart in fig. 3 analyzes the projected percentage of technologies according to the Danish scenario and optimal values according to the developed model for the year of 2035 for Denmark, B&H, Copenhagen and Banja Luka, for wind scenario. When the weights of criteria are calculated with EWM and AHP, for Denmark and Copenhagen deviations of the Danish strategy and estimates for 2035 from the optimal values given by the developed mathematical model for the same year may be primarily a consequence of forcing of a certain technology in

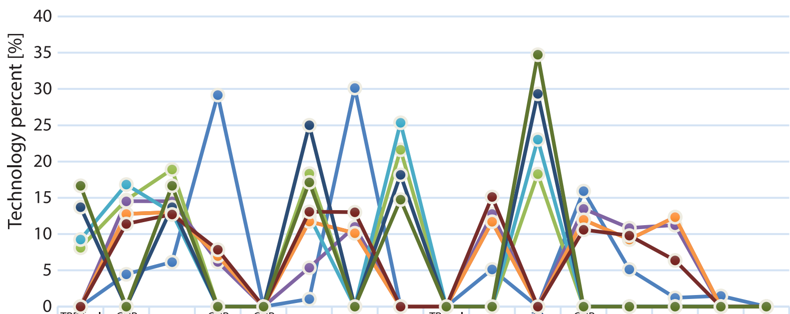


	TPP fuel oil	CHP biomass	CHP gas	CHP coal	CHP fuel oil	FNP	WPP	HPP	TB fuel oil	TB gas	TB biomass	CHP waste	TB coal	GTPP	STPP	HP
D 2035	0	30.66	0	0	0	1.16	42.41	0	0	0	5.28	13.99	0	2.64	1.28	2.59
ENTR D 2035	0	16.21	0	0	0	15.48	15.17	0	0	0	2.83	11.41	0	16.47	0	22.43
ENTR BiH 2035	8.11	14.70	18.93	0	0	18.34	0	21.63	0	0	18.30	0	0	0	0	0
AHP D 2035	0	16.36	0	0	0	13.94	15.45	0	0	0	4.86	13.22	0	16.01	0.26	19.90
AHP BiH 2035	9.28	16.84	12.99	0	0	12.51	0	25.34	0	0	23.04	0	0	0	0	0
ENTR K 2035	0	16.21	0	0	0	15.48	15.17	0	0	0	2.83	11.41	0	16.47	0	22.43
ENTR BL 2035	13.73	0	13.73	0	0	25.01	0	18.17	0	0	29.35	0	0	0	0	0
AHP K 2035	0	0	16.55	0	0	13.94	15.24	0	0	0	4.77	13.36	0	15.95	0.69	19.52
AHP BL 2035	16.67	0	16.67	0	0	17.16	0.00	14.78	0	0	34.73	0	0	0	0	0

Figure 3. Ranking of technologies by percentage for Denmark, Copenhagen, B&H and Banja Luka, EWM and AHP method, 2035, wind scenario, 8 criteria

the sense that there is an excess or lack of potential for its use. In this scenario, in the Danish strategy the first ranked technology is WPP and according to the developed mathematical model are heat pumps (HP). By both methods, B&H has HPP as the first-ranked technology, while Banja Luka has T (biomass) as the first-ranked technology in the year of 2035 for wind scenario.

The chart in fig. 4 analyzes the projected percentage of technologies according to the Danish scenario and optimal values according to the developed model for the year of 2035 for Denmark, B&H, Copenhagen and Banja Luka, for fossil scenario. When the weights of criteria are calculated with EWM and AHP, for Denmark and Copenhagen deviations of the Danish strategy and estimates for 2035 from the optimal values given by the developed mathematical model for the same year may be primarily a consequence of forcing of a certain technology in the sense that there is an excess or lack of potential for its use. In the Danish strategy, the first-ranked technology is WPP, and according to the developed mathematical model, when applying the EWM method it is CHP (gas), and with the AHP method CHP (biomass). By both methods, B&H has HPP as the first-ranked technology, while Banja Luka has TB (biomass) as the first-ranked technology in the year of 2035 for fossil scenario. In a case of excess percentage of some of the technologies used in relation the proposed optimal percentage predicted by the model would mean their correction in terms of reducing the percentage of share according to the optimal value. In the opposite case, if there is a lack of the percentage proposed by a given scenario in relation the optimal value obtained by the model, the percentage should be increased towards the proposed one. Certainly, increases can go up to those limits that have certain potential for use, while reductions are not necessarily limited, but the existing percentage of use is nowhere near optimal.



	TPP fuel oil	CHP biomass	CHP gas	CHP coal	CHP fuel oil	FNP	WPP	HPP	TB fuel oil	TB gas	TB biomass	CHP waste	TB coal	GTPP	STPP	HP
D 2035	0	4.49	6.15	29.19	0	1.04	30.16	0	0	5.14	0	15.95	5.14	1.23	1.51	0
ENTR D 2035	0	12.80	13.02	6.98	0	11.75	10.13	0	0	11.70	0	11.99	9.26	12.36	0	0
ENTR BiH 2035	8.11	14.70	18.93	0	0	18.34	0	21.63	0	0	18.30	0	0	0	0	0
AHP D 2035	0	14.54	14.53	6.19	0	5.37	11.02	0	0	12.78	0	13.50	10.85	11.23	0	0
AHP BiH 2035	9.28	16.84	12.99	0	0	12.51	0	25.34	0	0	23.04	0	0	0	0	0
ENTR K 2035	0	12.80	13.02	6.98	0	11.75	10.13	0	0	11.70	0	11.99	9.26	12.36	0	0
ENTR BL 2035	13.73	0	13.73	0	0	25.01	0	18.17	0	0	29.35	0	0	0	0	0
AHP K 2035	0	11.43	12.72	7.87	0	13.08	13.02	0	0	15.13	0	10.60	9.79	6.37	0	0
AHP BL 2035	16.67	0	16.67	0	0	17.16	0.00	14.78	0	0	34.73	0	0	0	0	0

Figure 4. Ranking of technologies by percentage Denmark, Copenhagen, B&H and Banja Luka, EWM and AHP methods, 2035, fossil scenario, 8 criteria

Conclusions

During the energy transition period, it is necessary to have a clear picture of the current energy mix as well as a vision of the future energy mix of the country/region/local community. In this work, the optimal energy mix was determined, a certain number of criteria influenced the choice of which.

The model, which is primarily intended to deal primarily with the energy supply of the local community, *i.e.* determining the optimal energy mix, has been developed to such a level, that depending on the available data, it can treat different territories from the local community level to the state level. The model was successfully tested on the example of Denmark and B&H and local communities Copenhagen and Banja Luka, and the obtained results provided a quality basis for the strategic energy planning of the selected territories.

The obtained results showed that the model is universal because it can be applied to different technologies, conditions and available data and as such has a wide possibility of practical application in the planning and design of energy installations or strategic decision-making in the sector for a specific territory. The results obtained by modelling the combination of energy supply process and optimization concept showed some deviation in the certain cases. These cases were related to the situations when some energy potential excesses existed in the projected strategies of the analyzed countries and the local communities.

The application of MCDM methods in the optimization of the energy mix opens up a special direction in the energy sector and the integration of renewable energy sources into distribution grids that supply energy to consumers. If demands of consumers towards the distribution and generation sectors are also taken into account, then a very complex system is obtained, the work of which needs to be harmonized and the optimal values that take into account the demands of both sides obtained. This paper reveals exactly this topic and sets up possibilities for further research in the field.

Nomenclature

a_{ij} – real value of *i* alternative in terms of *j* criteria, [–]
E_i – entropy of information value, [–]
f_j – normalized values of criteria, [–]
p_i – percentage of the participation of the considered technologies (alternatives) in energy mix, [–]
Q_i – measure for multi-criteria ranking by VIKOR method, [–]
R_i – measure of deviation expressing the requirement to minimize the maximum distance of somealternativ from the *ideal* solution. [–]
S_i – measure of deviation expressing the requirement for maximum group benefit by VIKOR method, [–]
v – weight of the strategy of the majority of criteria (or the maximum group utility), [–]
w_i – weight of indicator (criteria), [–]

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Paper submitted: October 13, 2022
Paper revised: December 6, 2022
Paper accepted: December 19, 2022