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MULTI–CRITERIA DECISION MODELING OF THE OPTIMAL COMBINATION FOR ENERGY SUPPLY SCENARIO: TEST MODEL FOR DANISH ENERGY SECTOR DATA

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Abstract: With the development of renewable energy sources, the energy sector is in a constant process of transition. This is mostly due to the increasing share of renewable energy sources in the total percentage of energy needs. The main issue in finding a solution to replace the use of fossil fuels is what methods and approaches are used to design present and future optimal energy scenarios for countries, regions and local communities in strategic terms. This problem certainly depends on several factors and to get an answer to this question it is necessary to define a list of criteria that will describe existing and future energy scenarios. In order to find the optimal variant of the scenario in which both renewable and non–renewable energy sources will be included, it is necessary to use MCDM methods. In this paper, the VIKOR method was used to search for the optimal value of the energy mix scenario, while the Entropy method and the AHP method were used to define the weights of the optimization criteria. As reference data for testing the developed mathematical model to search the optimal combination of energy mix, data related to the Danish energy sector for the reference year 2015 were used as a demonstration.

Keywords: energy sector, renewable energy sources, VIKOR method, energy mix scenario

1. INTRODUCTION

Today's energy market still relies heavily on fossil fuels. The primary energy source on the European Union (EU) market is oil and its derivatives. This is followed by natural gas from which the EU gets about 22% of electricity (Commission, 2021). However, increased demand and declining fossil fuel reserves are directing us towards the diversification of the energy mix, including Renewable energy source (RES). However, although there is a general view that diversification is needed, many arguments and counter–arguments about the sustainability of different alternative energy sources make the process of determining the optimal energy mix and process to meet the demand of any country, region or local community an increasingly complex task (OECD, 2012).

The energy transition is affecting many sectors, and poses an even greater challenge during the global energy crisis. The need to move to a society that will meet its energy needs from local resources, with minimal negative impacts on the environment is no longer presented as an option, but as a necessity. Energy resources are limited, and it is necessary to ensure that they are properly used and managed in a sustainable way. What is set as a task is to find a way to sustainable use all available energies and energy sources, at the level of the state of the region and the local community.

2. ENERGY MIX AND OPTIMISATION OF ENERGY MIX

— Energy mix

The optimal redistribution of energy supply from different energy sources and different energy production technologies within a country / region or local community is called the energy mix. The complexity of defining the energy mix is solved by answering the question "what is best" for the country, region or local community, because the answer changes drastically depends on the conditions in question. For example, the best energy mix in terms of cost is not necessarily the best mix that is environmentally acceptable, and is already in use. Despite the difficulties in defining the energy mix, it is first necessary to assess the different possibilities given several often conflicting criteria. In order to solve the problem of energy mix in local communities, it is important to design an energy mix that includes complex system behaviour and to assume that there is no high degree of certainty between action and outcome.

Energy mix is often seen as a function of technologies and basic economic parameters/indicators, if the goal is a cost–effective combination of available energy technologies needed to meet energy demand. However, it is much more complex than even on a small scale, at the local community level. In the paper (Bongers A,, 2021) Bongers studies how the energy mix of renewable and non–renewable energy sources is affected by technological shocks and their implications for energy transition, carbon emissions and the environment.

A large number of indicators are presented in (Wang J., Jing Y., Zhang C., Zhao J., 2009), while aspects of sustainability are grouped into technical, economic, environmental and social criteria. Technical criteria with indicators: construction period, technical service life, capacity factor and maximum availability. Economic criteria with indicators are: investment costs, fixed and variable operating and maintenance costs as well as the progress ratio. Environmental criteria with indicators: NOx emissions, CO2 emissions, CO emissions, SO2 emissions, particulate emissions, non–methane volatile organic compounds, land use, noise, etc. Social criteria with indicators: Social acceptability, job creation, social benefits and others. In (Afgan N.H., Carvalho M.G., 2002) sustainability criteria (resources, environment, economic and social) were used to select the technology. The considered indicators are: efficiency (%), installation cost (USD / kW), electricity costs (ct / kWh), CO_2 ($kgCO_2$ / kWh) and area (km2 / kW). Another approach considered techno–economic, for wind and geothermal energy, small hydropower, solar and photovoltaic energy, indicators were presented (Baysal M., Sarucan A., Kahraman C., Engin O, 2011). While technical indicators are: construction period, technical service life, capacity factor and maximum availability, economic indicators are investment costs, fixed and variable operating and maintenance costs as well as the progress ratio.

— Optimisation of energy mix

Energy mix optimization is mainly based on the complex concept of Energy system, which leads to a significant number of optimization problems that usually cannot be solved without the use of a mathematical model.

The topic of energy mix optimization is covered by a combination of several different areas at different levels (national / regional / local): energy transition, energy policy, strategic energy planning and future development of energy systems, sustainability of energy systems, use of conventional energy sources and RES energy production technologies, RES stochastics. A sustainable approach for definition and optimization of the energy mix takes into the account energy policy, strategic and energy planning and contextual factors influencing the choice of energy sources, technologies, constraints and opportunities. The authors are in their article (Sobczyk, W.; Sobczyk, E.J ., 2021) analyzed eight energy, economic and social indicators for the EU–28 and Poland, and checked the progress in the modification of the energy mix in the period 2010–2018, and showed that the use of renewable energy sources, especially biomass, is compatible with policy I sustainable development goals.

The main goal of optimizing the energy mix is to choose the most efficient method of production, transformation, distribution and consumption of all forms of energy within a particular area, whether national / regional or local. Energy mix optimization is most often based on a complex energy system concept, leading to a significant number of optimization problems that usually cannot be solved without the use of a mathematical model. Since the early 1970s, many models have been developed to analyse energy systems that have multiple uses in terms of demand forecasting, better understanding of current and future interactions between supply and demand, energy and environment, energy and economy, and energy system planning.

3. CRITERIA AND METHODS FOR DETERMINING THE OPTIMAL ENERGY SUPPLY MIX

Figure 1 show the architecture of the mathematical model developed for determining the optimal energy supply mix. In order to optimize the energy mix, universal criteria have been defined through which all possible available technologies for energy production are described. For this reason, it was concluded that these criteria form a set of 1 to 9 criteria, shown in Figure 1, which took into account: economic, environmental, energy, stochastic, quantitative and qualitative energy assessments, mix / technology.

The adopted criteria are: energy and exergy efficiency of technology, exergy factor of technology, specific investment cost of 1 kW of installed power of technology, specific production cost of 1 kWh of energy, specific CO_2 emissions in kg / kWh, capacity factor and storage factor. When we use optimization with 8 criteria, the storage factor criterion is not used. By defining these criteria, it is possible to choose the method for defining the weights of the criteria and the Multiple Criteria Decision Making (MCDM) method. In the continuation of the paper, the methods for determination of the weight of the adopted criteria (Entropy and AHP method), the optimization method (VIKOR) and determining the Q factor are explained, as well as definition of the percentage of technologies, which are shown in figure 1.

4. METHODS FOR DETERMINATION OF THE WEIGHTS OF CRITERIA IN THE MCDM PROCESS AND MCDM METHODS FOR DETERMINATION OF THE ENERGY MIX AND ITS OPTIMIZATION

In the 1970s, the main goal of research in energy planning was to assess future energy needs. Mostly one criterion was used, and economic–energy relations were used to define the required energy needs. Namely, the option of the most efficient energy supply with the lowest possible costs was sought (IRENA, 2021). In that period of using conventional fossil fuels, another methodology was used, more targeted programming. In the 1980s, social and environmental aspects were included in the research, which resulted in greater use of multi–criteria methodologies. After the oil shock of 1973, there was a need to save energy and replace energy. Consideration has been given to the use of RES, which can replace conventional fuels and which pollute the environment less. Although initially the contribution of RES is low, technological development and competitiveness compared to conventional fuels, influence researchers to focus on identifying barriers to their penetration and suggesting ways to overcome them. All this has the effect of increasing the number of decision–makers, who have to choose between measurable, non–measurable and more criteria, and that a different concept of the energy planning process should be given for the widespread use of sustainable energy.

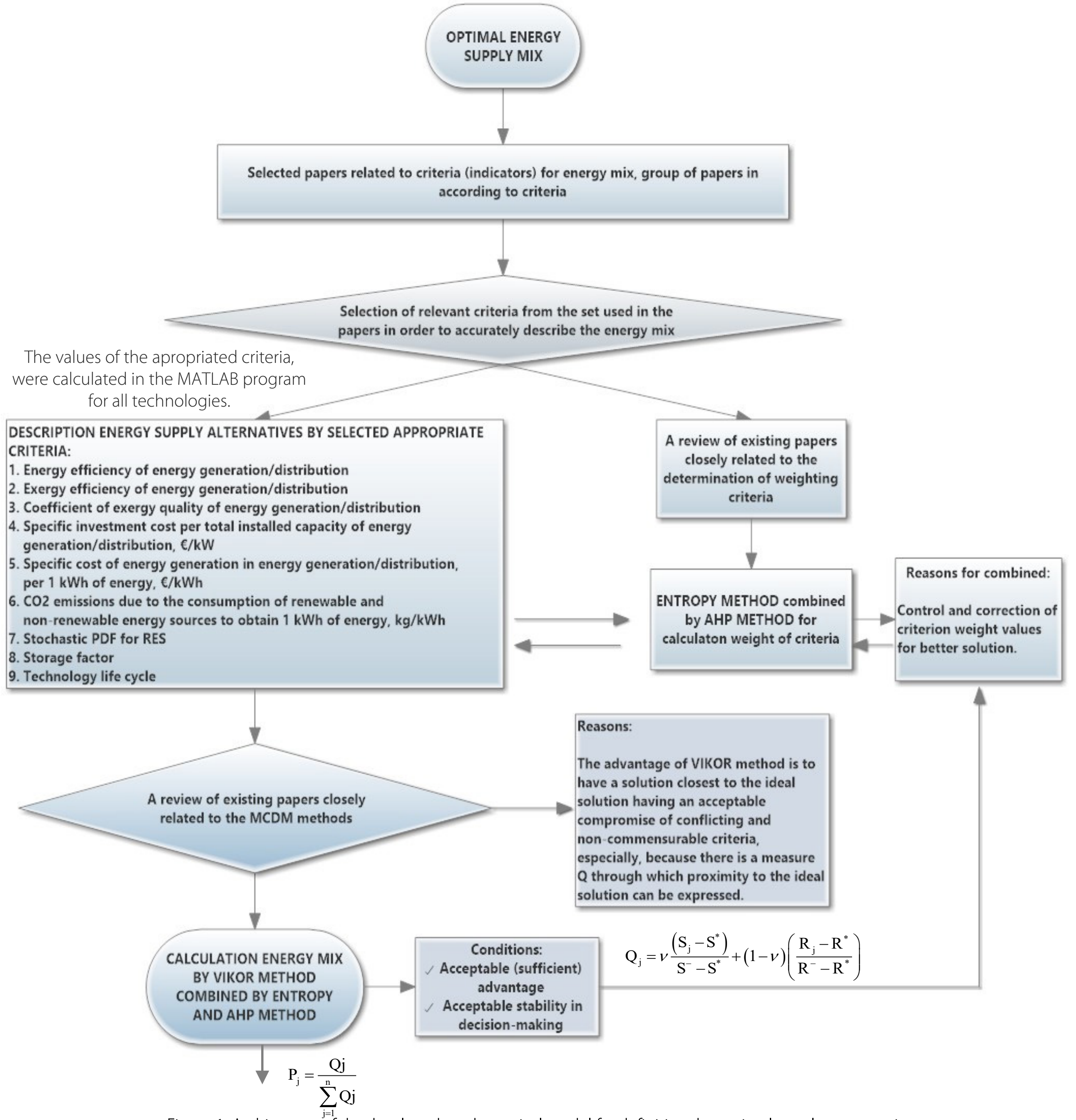

Figure 1. Architecture of the developed mathematical model for definition the optimal supply energy mix

— Methods for determination of the weights of criteria in the MCDM process

Evaluating the relative importance of criteria weights in the optimization process is usually a key challenge for the MCDM method (Freerk A. Lootsma, 1999).

The weight of the criteria shows their importance in the MCDM process and if their values are well determined the result of such an analysis will be good. The simplest method used in many studies is to use equal values of criteria (Wang J., Jing Y., Zhang C., Zhao J., 2009), which is of course not an adequate and accurate approach for final evaluation in all more serious approaches related to MCDM (Ginevičius R., 2011). There are several methods for determining the weights of the criteria and they are classified into three groups: subjective, objective and hybrid (integrated) methods. In subjective methods, the determination of criteria weights is dependent on the preferences of decision–makers which are not take in an account objective conditions (Zardari N.H., Ahmed K., Shirazi S.M., Yusop Z.B. , n.d.). The main disadvantage of these methods is that they are not efficient enough when the number of criteria increases. In objective weighting methods, the preferences of decision–makers have no role in determining criteria weights (Zardari N.H., Ahmed K., Shirazi S.M., Yusop Z.B., 2015). The weights were determined according to the relationship between the original data in objective weighting method. Compared to subjective weighting methods, objective weighting methods have a better mathematical approach to objectively determining weights, but worse interpretability. Therefore, their conclusions are sometimes inconsistent with the actual importance of the criteria (Wang Y., Parkan C., 2005. To overcome the shortcomings of the subjective and objective weighting methods, in recent years, methods which combine the subjective and objective weighting (Meng B., Chi G., 2015). Table 1 shows the classification of methods for determining weights, with the emphasis on the development of combined methods in recent times. In the following text, there are a brief description of two methods for determining the weights of the criteria, AHP (subjective) and entropy method (objective). The reasons why they were selected to define the weights of the criteria will be described in the results and discussion.

Table 1. Classification of weighting methods

Classification of weighting methods		
Subjective weighting methods	Objective weighting methods	Hybrid (integrated) weighting methods
✓ Point Allocation, ✓ Ranking method, ✓ Pairwise comparition (AHP) ✓ Ratio method, ✓ Swing method, ✓ Delphi method, ✓ Nominal group technique, ✓ Simple multi–attribute Ranking ✓ Technique (SMART)	✓ Entropy method, ✓ Standard Deviation method, ✓ CRITIC (Criteria Through Inter–criteria Correlation), ✓ SECA (Simultaneous Evaluation of Criteria and Alternatives) ✓ In development…	✓ Combined Entropy–AHP, ✓ Maximum entropy weighting, ✓ Geometric Operator Weighting, ✓ Maximizing and comparison the difference in evaluation results subjective and objectives methods, ✓ Highly in development…

≡ ENTROPY method

The entropy method is an objective method for determining the weight of criteria. The weights of the criteria are determined mathematically based on the information collected about the criterion, without the influence of the decision maker (DM) (Aldian A., Taylor M.A.P., 2005). Entropy methods treats uncertainty in the information structure of the decision matrix, known as Shannon entropy. Criteria weights are generated directly based on the rating of alternatives and they eliminate the problem of subjectivity, incompetence, or absence of a decision maker.

The entropy method is an excellent method for evaluating, from an unregulated set of different alternatives of the energy mix, the weights of different types of criteria with which these alternatives are described (technical, energy, economic, environmental, stochastic, investment, etc.).

The advantage of the Entropic method is the simple determination of the relative weights of the criteria (w_1, w_2, ..., w_m). The disadvantage is the proper definition of the decision matrix, ie that there are a sufficient number of alternatives (Srdjevic, B., Medeiros Y. D. P., Faria A. S., 2004). The method focuses on the difference between attribute weight data. An attribute that distinguishes data more efficiently has more weight.

≡ Analytical Hierarchy process (AHP)

AHP is a subjective method of determining the weight of criteria. The analyst presents a set of questions to DM, on the basis of which they give their subjective opinion. This takes a lot of time, especially when there is no agreement between the decisions of the creator of the problem under consideration. In AHP method, decision–maker compares each criterion with others and determines the level of preferences for each pair of such criteria. The use of ordinal scale (1–9) is adopted to help in determining the preference value of one criterion against the other. The advantage of the AHP method is that it is easy to use; scalable, and the hierarchical structure can be easily adapted to problems of different sizes. The disadvantages of the AHP method are: artificial limitation of the use of the 9–point scale, and the decision problem is decomposed into numerous subsystems, the number of even comparisons within and between which it is necessary to make a significant number of even comparisons.

— MCDM methods for determination of the energy mix and its optimization

MCDM methods deal with the multi–objective decision–making process. Goals are usually opposed and therefore the solution depends on the preferences of the decision maker and must be a compromise. In most cases, different groups of decision makers are involved in the process. Each group brings different criteria and views that must be resolved within the framework of understanding and mutual compromise. The reason why this method was chosen is being reviewed here. It is possible to incorporate various elements from social and managerial units, such as economic, technical, energy, environmental (Saaty T.L., 1996), as well as a number of restrictions. Although different criteria give different results, this methodology still requires from the decision maker to analyse the settings and determine the weights of all criteria.

Some of the important MCDM methods are: ELECTRE, REGIME, AHP, ANP, WSM, TOPSIS, PROMETHEE, VIKOR, et al. In the article authors (Saraswat S.K., Digalwar A.K., 2021), evaluates fossil and RES for sustainable development based on economic, technical, social, environmental, political and flexible criteria. The entropy method was used to determine the weight of the criteria, and the fuzzy AHP was used to prioritize sustainable energy alternatives. The decision model considers thermal, gas, nuclear, solar, wind, biomass and hydropower.

The result of the proposed model was compared with six different fuzzy MCDM techniques (fuzzy TOPSIS, fuzzy VIKOR, fuzzy PROMETHEE II, fuzzy WSM, fuzzy WPM, fuzzy WASPAS) to establish the correlation index. The optimal scenario of the energy mix is based on the development of solar, wind and hydro energy with cross–border import–export capacity for the time frame until 2030.

≡ Multicriteria Optimization and Compromise Ranking (VIKOR)

In 1979, Opricović presented in his doctoral dissertation, the basic ideas of VIKOR, and in 1990 (Opricović S., 1990) the term VIKOR appeared as an abbreviation for Multicriteria Optimization and Compromise Ranking. From the review of the MCDM method, the VIKOR method has emerged as an adequate way to calculate the optimal energy mix. The reasons for its application are considered in two aspects: "The solution closest to the ideal solution that has an acceptable compromise of conflicting and incommensurable criteria" and "Measure Q through which proximity to the ideal solution can be expressed." On the other hand, the VIKOR method has already been widely practiced and programmed. Measure Q can be used to define and distribute the optimal percentage values of the individual alternatives analyzed, which may represent some of the supply options in the overall energy mix. In order to calculate the most accurate distribution of the percentage of the energy mix, we must have objective calculations of the weights of the adopted criteria. This is also the reason why the Entropic Method has been proposed and used for this purpose. However, there are cases when the entropy method does not give satisfactory results, especially in the case when many criteria are equal to zero. For these reasons, a combined approach to control with one of the subjective methods, such as AHP, can be used. In such cases, the weight values can either be compared and corrected with each other or even combined in terms of achieving average weight values. Finally, the VIKOR method has verification options: acceptable advantage and acceptable stability. In this way, we can achieve feedback in terms of achieving a compromise solution by correcting the weight obtained from the selected criteria in order to meet the conditions of stability and acceptable benefits of the solution.

The compromise ranking of VIKOR shown in Figure 2 (Mateo J.R.S.C., 2012) has five steps and n and m represent a number of criteria and alternatives.

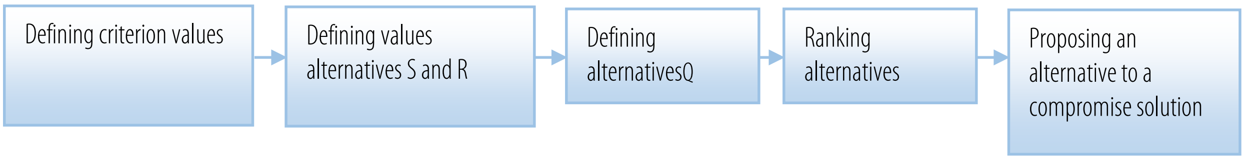

Figure 2. VIKOR metodology

The first step is to determine the best f_i^* and the worst f_i^- values of all function criteria, i = 1,2,. . ,n

$$f_i^* = \max_j f_{ij} \qquad f_i^- = \min_j f_{ij} \tag{1}$$

if the i–th function represents a revenue attribute

$$f_i^* = \min_j f_{ij} \quad , \quad f_i^- = \max_j f_{ij} \tag{2}$$

if the i–th function represents a cost attribute

In the second step, the value is calculate

S_j, R_j, za j=1,2,…,n

where w_i are the weights of the criteria, expressing the preference of the decision maker as the relative importance of the criteria

$$S_j = \sum_{i=1}^{n} w_i \frac{(f_i^+ - f_{ij})}{(f_i^+ - f_i^-)} \tag{3}$$

$$R_j = \max_i \left[w_i \frac{(f_i^+ - f_{ij})}{(f_i^+ - f_i^-)} \right] \tag{4}$$

In the next step, Qj is defined for j=1.2,... N, as follows:

$$Q_j = \nu \frac{(S_j - S^*)}{S^- - S^*} + (1-\nu)\left(\frac{R_j - R^*}{R^- - R^*} \right) \tag{5}$$

where are:

$$S^* = \min_j S_j \; , \quad S^- = \max_j S_j \; , \quad R^* = \min_j R_j \; , \quad R^- = \max_j R_j \tag{6}$$

The coefficient ν is called the “strategic coefficient”, and always belongs to the interval [0,1], where a value greater than 0.5 focuses more on meeting most criteria, while values less than 0.5 set a higher priority of minimizing individual differences from the ideal solution (alternative). The next step is to sort the alternatives, sorting by the values of S, R and Q in descending order.

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The last step is to propose an alternative compromise solution $F^{(1)}$ which is best ranked by measure Q (minimum) if the following two conditions are met:

1. „ An acceptable advantage ":

$$Q(F^{(2)}) - Q(F^{(1)}) \geq DQ, \tag{7}$$

where is $F^{(2)}$ alternative with second position in the rankings according to Q and where is

$$DQ = 1/(m-1)), \tag{8}$$

and m is the number of alternatives.

2. „ Acceptable stability in decision making":

Alternative $F^{(1)}$ it must also be ranked best with S or / and R. This trade–off solution is stable in the decision–making process, which could be a strategy of maximizing group utility (when needed). $\nu > 0{,}5$), or "by consensus" $\nu \approx 0{,}5$, or "with a veto" ($\nu<0{,}5$). ν is the weight of the strategy of deciding on maximum utility in the group.

If one of the conditions is not met, a series of compromise solutions is proposed, consisting of:

- ≡ Alternative $F^{(1)}$ i $F^{(2)}$ if only the condition is not met 2.
- ≡ Alternative $F^{(1)}, F^{(2), \dots} F^{(M)}$ if only the condition is not met 1.

$F^{(M)}$ is determined by the relationship

$$Q(F^{(M)}) - Q(F^{(1)}) < DQ \tag{9}$$

for the maximum M (the positions of these alternatives are "in close proximity").

After the values of the criterion weights were determined by the Entropy and AHP methods, the VIKOR method was used to form optimization matrices from which alternatives of energy supply based on the Qi factor were ranked.

The percentage of technologies is calculated on the basis of the factor Q_i is expressed by the following equation:

$$P = \frac{Q_i}{\sum_{i=1}^{n} Qj} \tag{10}$$

Using these methods, a mathematical model was created that is used to optimize the energy mix. The mathematical model, which has been developed, is of a universal character and can be applied to different countries / regions / local communities and with it the choice of the optimal combination of energy supply can be made. The paper presents the testing of the model for Denmark for 2015.

5. WHY DANISH ENERGY DATA WAS USED?

Denmark started the energy transition before all other countries, when the concept of energy transition did not even exist. The Danish government decided on this approach to "green" energy on its own initiative in order to achieve energy independence, through planning a strategic energy framework, defining laws for the transition to renewable energy, with fiscal and financial instruments and educating Danish citizens about the need to switch to an energy system, completely based on RES.

Denmark is a rich and economically stable country with a strong economy which is aimed at maximizing the use of RES and increasing energy efficiency. Denmark is also a leader in the use of RES in the production of electricity and heat in Europe. Although Denmark is small country compared to some other countries, it is a leader in developing and testing new technologies.

Denmark was taught from previous experiences. Until 1973, the Yom Kippur War and the Great Oil Crisis, Denmark was largely dependent (on about 92%) of cheap oil imports. Denmark has responded to the crisis by switching oil to cheaper coal, introducing a tax on petrol and CO_2, and banning driving on Sundays. The first energy plan was adopted by Denmark in 1976 in order to increase energy security and reduce energy dependence on energy imports. The new oil crisis of 1979 directed them to further changes in the energy sector. In the period 1985–2000, Denmark adopted energy plans:

- ≡ the first in 1981 reaffirms the commitment to reduce dependence on energy imports,
- ≡ the second in1990 focuses on RES, primarily biomass

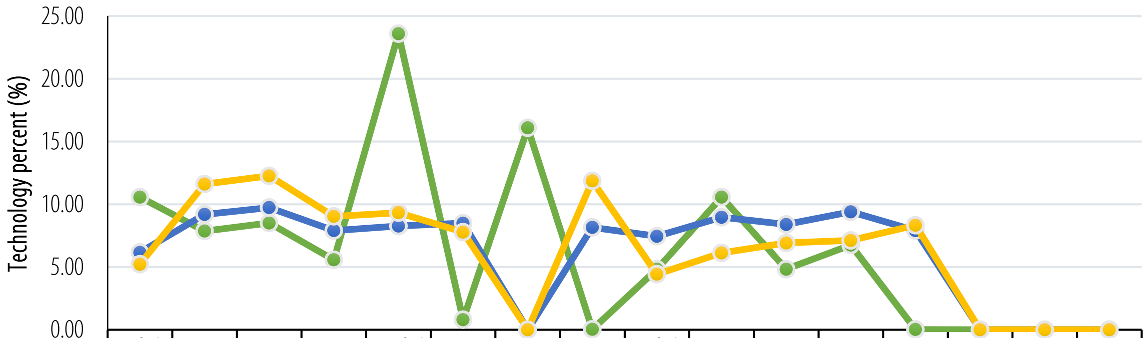
≡ the third in1996 focuses on developing a sustainable energy system and reducing Denmark's greenhouse gas emissions.

After that period, Denmark's goal is to completely eliminate fossil fuels by 2050.

Denmark is suitable for testing the developed model and its calibration, both due to the presence in the mix of different RES, and due to the availability of their data. Denmark is a very good example because it has long had a vision for the future, in order to achieve its goals in the framework of energy transition and decarbonisation of the energy sector. Denmark was chosen because it pointed out the need to link national energy and local strategic documents. In order to achieve Denmark's long–term energy goal, Danish experts have recognized that different parts of the country (local communities) must play different roles in achieving it, and that there must be good cooperation between the local community, energy companies, public institutions and government. For the development and testing of the model, data from the Danish Energy Agency were used, namely: Energy Statistics 2015 (Danish Energy Agency, 2015), catalogue with data on energy plant technologies, (Energystyrelsen, 2020), scenarios (DEA Fossil 2035 , DEA Fossil 2050 and DEA Wind 2035 and DEA Wind 2050) developed under (Agency, 2014). The model was calibrated based on data from Denmark for 3 years in 2015, 2035 and 2050 and 2 scenarios (wind and fossil scenario), given that for Denmark there are projections of the behavior of the considered technologies in those periods. Denmark is suitable for testing the developed model and its calibration, both due to the presence in the mix of different RES, and due to the availability of their data.

6. RESULTS

The reasons for using Danish data are a very systematic approach to introducing the use of RES and available data for all technologies. The test results of the developed model are presented with the diagram in Figure 3.



	TE fuel oil	CHP biomasa	CHP gas	CHP coal	CHP fuel oil	FNP	VE	HE	TK fuel oil	TK gas	TK biomasa	CHP waste	TK 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 D 2015	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
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

Figure 3. Ranking of technologies by percent for Denmark, Entropy and AHP method, 2015, 8 criteria

D 2015 is the state of estimated technologies in Denmark in 2015 was obtained on the basis data of electricity and heat consumption (Danish Energy Agency, 2015), (Mathiesen, B. V., Lund, H., Hansen, K., Ridjan, I., Djørup, S. R., Nielsen, S., Sorknæs, P., Thellufsen, J. Z.,Grundahl, L., Lund, R. S., Drysdale, D., Connolly, D., & Østergaard, P. A. , 2015) on the basis of which the percentages of technologies were calculated.

ENTR D 2015 and AHP D 2015 represent optimal values according to the developed of real technologies in Denmark in 2015, which were used in the model, by Entropy and AHP methods.

The chart in Figure 3 analyzes the projected percentage of technologies according to the Danish scenario and the optimal values according to the developed model for 2015 for Denmark.

The weights of the criteria were determined on two methods, Entropy and AHP.

The reasons for using both methods to determine the weights of the criteria are the comparative verification of the Entropy method with AHP method and vice versa, and possible corrections in cases of overestimated weight values.

The diagram shows the year 2015 for Danish data. There is a certain difference between what the Danish strategy really proposes and the developed mathematical model for calculating the optimal percentage for Danish data.

In certain parts of the zigzag diagram the percentage also coincide (follow the light blue, orange and purple lines on the diagram), while in some they deviate. These deviations of the Danish strategy and estimates for

2015 from the optimal values provided by the developed mathematical model for the same year, may be primarily due to forcing some of the technologies in the sense that there is a surplus or lack of potential for use. In the case of an excess of the percentage of some of the technologies used in relation to the proposed optimal percentage provided by the model, this would mean their correction in terms of reducing the percentage of participation towards the optimal value. In the opposite case, the lack of the proposed percentage according to the given scenario in relation to the optimal value obtained by the model, one should strive to increase according to the proposed one. Of course, increases can go to those limits that have certain potentials for use, while reductions are not necessarily limited, but the existing percentage of use are not close to optimal.

7. CONCLUSIONS

Presented model and zigzag diagram can contribute a lot in terms of adopting strategic steps that the energy sector should follow for the observed and adopted set of criteria in order to achieve optimal values in its field. Distinguishing optimal values from matematical model can only be justified by the existence of the potential of a particular technology.

The developed mathematical model defines the appropriate energy, economic, technical, environmental, but also stochastic parameters of energy production (ie universal criteria) applicable at the state / region / local community level, which are adapted for multicriteria optimization. These parameters are universal and can be applied to the mathematical description of the energy mix of any country / region and local community. The weights of the criteria were determined using two methods, Entropic and AHP methods. The reasons for using both methods to determine the weight of the criteria are the comparative verification of the Entropy Method (which is an objective method) with the AHP method (subjective method) and vice versa, as well as possible correction in cases of overestimated weight values.

Multicriteria optimization is a logical way to fully create a realistic picture of the currently optimal energy mix, taking into account the necessary and sufficient number of criteria by which this problem is described. Such an approach gives universality to the application of a given concept for the calculation of these parameters. The real reason why the VIKOR method was used in solving the problem of choosing the optimal mix of the local community is the possibility of checking the advantages and stability of the obtained solutions. The VIKOR method is quite popular among decision makers due to its computational simplicity and ability to give almost accurate results. After modeling the actual current situation at the level of the observed state, a real insight into the current state of the site is gained, which according to the VIKOR methodology includes a precisely defined redistribution of the share of individual components of energy supply.

By verifying the developed mathematical model, a large number of numerical data were obtained that can be used to evaluate technologies and the observed and adopted criteria in order to achieve optimal values of energy combination. According to the adopted input data, the model calculates the percentage of represented technologies and enables their ranking and comparison, and suggests a possible correction according to the desired projection. The developed model combines several approaches in its structure:

Access to composing the logical structure of the energy mix and adopting criteria for assessing the quality of technologies,

≡ Access to multi–criteria optimization to select the optimal combination of energy supply
≡ Approach to mathematical modeling of energy mix elements,
≡ Introduction of the concept of stochastics for energy production.

The model was tested on the data of two countries Denmark and Bosnia and Herzegovina and 2 municipality Copenhagen and Banja Luka, for 3 years (2015, 2035 and 2050) and 2 wind and fossil scenarios, with 8 and 9 criteria, although not shown in this paper, but will be presented in one of the following papers.

The developed mathematical model and the proposed concept have a practical application in terms of adopting strategic steps to be taken by the energy sector for the observed and adopted set of criteria in order to achieve optimal values in its field. Distinguishing optimal values from a mathematical model can only be justified by the existence of the potential of a particular technology.

Note: This paper was presented at International Conference on Applied Sciences – ICAS2022, organized by University Politehnica Timisoara, Faculty of Engineering Hunedoara (ROMANIA) and University of Banja Luka, Faculty of Mechanical Engineering Banja Luka (BOSNIA & HERZEGOVINA), in May 25–28, 2022, in Banja Luka (BOSNIA & HERZEGOVINA).

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