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OPTIMAL ENERGY MIX IN RELATION TO MULTI-CRITERIA DECISION-MAKING (MCDM), REVIEW AND FURTHER RESEARCH DIRECTIONS

Maja Mrkić-Bosančić [1*], Srđan Vasković [2], Petar Gvero [3] and Gojko Krunić [4]

[1] Ministry of Energy and Mining of Republika Srpska, Bosnia and Herzegovina
[2] Faculty of Mechanical Engineering, University of East Sarajevo, Bosnia and Herzegovina
[3] Faculty of Mechanical Engineering, University of Banja Luka, Bosnia and Herzegovina
[4] Faculty of Production and Management, University of East Sarajevo, Bosnia and Herzegovina

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***Abstract**: The need for a transition to a society that will meet its energy needs from local resources and with minimal negative environmental impact 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 manner. Optimal redistribution of energy supply from different energy generation and distribution options to end users within the local community is called the energy mix. What sets itself the task is to find this way of sustainable use of all available energy and energy types from local communities, different regions to the entire country. This is not a simple task, because it includes many variables that must all be considered. Therefore, it is necessary to classify and define universal criteria (sustainability), which describe ways of supplying energy and energy in a particular locality. The criteria mainly describe energy needs, availability of energy resources, existing technologies, economic and environmental indicators, qualitative and quantitative values of different energy supply options. This paper aims to review the state of play in optimal energy mix research in relation to the local community. Also, this paper provides an overview and importance of the application of MCDM methods in this area. As a way out, in this paper we propose conclusions, directions and research opportunities in the field of seeking the optimal energy mix supply for local community, region or state, connected to the importance MCDM tools.*

***Key words:** Energy transition, energy mix, optimization, MCDM.*

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* Corresponding author.
E-mail addresses: mm.bosancic@mier.vladars.net (M. M. Bosančić), srdjan.vaskovic@ues.rs.ba (S. Vasković), petar.gvero@mf.unibl.org (P. Gvero), gojko.krunic@fpm.ues.rs.ba (G. Krunić).

1. Introduction

Over the past three decades, the European Union has been assigning to the local community (city, municipality) a primary role in energy consumption and coping with the consequences of the greenhouse effect. The local community directly suffers from the effects of pollution and climate change and can be relevant as a place of innovative policies with an emphasis on sustainability, adaptation, and mitigation of the above effects in a broader sense. Numerous studies and research in the international literature mainly focus on the assessment of energy consumption and carbon dioxide (CO_2) emissions, as well as on potential energy savings to be achieved by taking and performing the appropriate measures and activities. The city itself plays an important role in the implementation of sustainable solutions, especially if possibilities are identified for reducing energy consumption, making better use of energy generation capacity, i.e., if the city is regarded not only as a consumer, but also as an energy generator in real time. The need for a transition to a society that will meet its energy needs from local resources and with minimal negative environmental impact is no longer presented as an option but as a necessity. Local communities are characterized by a wide range of energy needs in different sectors, e.g., need for heating, cooling, public lighting, ventilation of buildings, transport, etc. At the local community level, there is the possibility of providing these types of energy through various, non-renewable, and renewable energy sources. The interaction between energy needs, available energy sources and available technologies for energy generation and distribution must be addressed at the local level.

1.1. Energy mix

Key questions: How to know the “right” energy mix and pattern of energy consumption in the future? What technologies, energy sources and criteria are needed to choose the optimal energy mix? What energy vision can guide us in future choices? To what extent and how are different fossil fuels and alternatives compared? Such questions are an integral part of quantitative models used for the purpose of making decisions about the optimal energy mix. Each geographical area has different energy sources, available natural resources, level of technology development, and energy systems for generation and distribution of energy to end users. Their sum results in determining the appropriate energy mix (Weijermars et al., 2012). At the local community level, there is the possibility of providing different types of energy through various, non-renewable and renewable energy sources. The interaction between energy needs, available energy sources and available technologies for energy generation and distribution must be addressed at the local level. The complexity of determining the energy mix is solved by answering the question ”What is the best” for the country, region or local community, because the answer changes drastically depending on the conditions in question. The best energy mix in terms of cost is not necessarily the best mix that is environmentally friendly and already in use. Despite all the difficulties in determining the energy mix, it is first necessary to assess different possibilities considering several, usually conflicting, criteria. The energy mix is often seen as a function of technologies and basic economic parameters if the goal is to have a cost-effective combination of available energy technologies needed to meet energy demand. However, it is much more complex than that, even on a small scale, at the local community level. Therefore, recognizing the energy mix as a significant local community problem can help to identify important variables and interrelationships. The choice of energy mix involves making decisions based on available knowledge (Balint et al., 2011). To date, renewable energy sources (RES), such as wind, solar, water and biofuels, have been considered as technical solutions primarily for local and regional needs, although energy generation from RES has the potential to expand into much larger markets. Regardless of the type of energy source, there are always different contextual, temporal, measurement, social, cultural, economic, environmental, and technological factors affecting the choice of source, as well as of energy generation, distribution, use and cost. Understanding energy mix alternatives in the light of interactions between technical, economic, and environmental systems is a key to creating a sustainable energy mix in local communities. There is no single energy mix that could meet all the operational needs of all environments, but it is possible to develop a mathematical model of an optimal energy mix that can be applied to different local communities.

1.2. Energy mix with techno-economic approach

An approach which is considered as techno-economic is presented by (Wang et al. 2009) for RES (wind and geothermal energy, small hydropower plants (SHPPs), solar and photovoltaic energy). The used technical indicators are as follows: construction period, technical lifetime, capacity factor and maximum availability, while the used economic indicators are investment costs, fixed and variable operating and maintenance costs, as well as the progress ratio. In the study Connolly and Mathiesen (2014) presented the way to transform Ireland’s fossil fuel-based energy systems (ES) into 100% RES-based energy systems. For each of the 7 phases, they calculated the ES technical and economic features. The results show that 100% RES-based ES can meet the same energy needs of end user as today’s ES and at the same cost. Although the paper does not mention the term ”energy mix”, in reality the study reflects the typical ES for the electricity and heat generation and distribution to the end user and suggests the replacement of energy sources.

1.3. Energy supply mix

The energy supply mix consisting of non-renewable energy sources can be optimized by using a set of economic criteria based on maximizing least costs or profits. The optimal supply mix with RES is more difficult to determine because it depends on the potential of each territory for generation technology. Territorial potential for RES inclusion becomes a major problem when the evolution of some generation technologies is favored over others. Understanding the territorial potential should facilitate society’s decision on which energy policy objectives (emission targets, delivery costs or share of imported energy) are desirable, achievable and optimal. The paper (Faundez, 2017) proposes a way to determine the mix of supply and demand for electricity generation in one territory, in the presence of RES (wind and solar) which must be provided in large areas. The model suggests how much “green” energy can be achieved at the location at the given set of prices.

1.4. Sustainable energy mix

A sustainable approach to defining and optimizing the energy mix considers energy policy, strategic and energy planning, and contextual factors affecting the choice of energy sources, technologies, restrictions, and opportunities. The development of a sustainable energy mix to meet environmental requirements implies a partnership between governments and key public and private actors in defining it. Transition to a sustainable energy mix means more than just the installation of technologies for energy generation from renewable energy sources (RES). A wide selection of sustainable development indicators and sustainability assessment methodologies is presented in the paper (Singh et al., 2009). An even broader list of indicators is presented in (Wang et al. 2009), while aspects of sustainability and energy planning are grouped into economic, technical, environmental and social criteria. The paper (Afgan & Carvalho, 2002) presents sustainability criteria: resources, economic, environmental and social criteria for technology selection. The considered indicators are: efficiency, cost of installation and electricity, CO_2 and surface areas. The authors (Doris et al., 2009) identified 14 indicators in the context of RES that can have a positive, negative, or neutral effect depending on the specific circumstances. These indicators include resource availability, technology availability, technology and energy costs, economic factors with project financing options, energy transmission issues, etc.

2. Materials and Methods

The concept of this review paper is based on a review of publications in a period ranging from 1957 to 2022. It included a review of publications in the following amounts: 96 papers in journals, 8 papers at conferences, 10 books, 1 chapter in a book, 2 doctoral dissertations, 3 master's theses, 2 reports and 3 other literary sources. One of the goals of this paper is a chronological presentation of the development of research in areas related to MCDM and the energy mix. Keywords for searching available databases and the Internet that were used: energy mix, local community, multicriteria optimization (MCDM), sustainable indicators, energy transition. The problem of finding the optimal energy mix has gained in intensity in the last 10 years, which shows the largest number of papers published in that period. The reasons for this are: greater use of renewable energy sources, reduction of CO_2 emissions, and the intensive development of renewable energy sources in the overall energy mix, recently. Conceptually, the overview in this paper was realized through the following structure of the forthcoming sections, which are given in three groups. The first group is "Energy Mix Optimization". Within this section, there are overviews of papers in the categories: Economic optimized energy mix, Techno operational-economic optimized energy mix. The second group of papers refers to "Technologies, conventional energy sources and RES", providing an overview of papers related to conventional and renewable technologies for energy production in terms of energy and exergy efficiency, stochastics and GHG emissions. The third group of papers and the section "Multi-Criteria Decision-Making" in this review paper refers to general methods for multicriteria optimization and their applications in finding optimal combinations of energy supply. Special attention is given to methods for determining the weight of the criteria for MCDM optimization process and especially Entropy and AHP method. According to the structure of the paper review based on the previously mentioned three sections below, the attributes of inclusion and exclusion criteria in the search are given according to the following Table 1.

Table 1. Inclusion and exclusion criteria for search papers in proposed areas

Inclusion criteria/descriptive attributes		
Energy Mix Optimization	Technologies, conventional energy sources and RES	Multi-Criteria Decision-Making
Energy mix, optimization, economic optimization of energy mix, techno operational-economic optimization, energy supply mix, sustainable energy mix	Technologies, conventional energy renewable energy, energy, and exergy efficiency, GHG emissions, exergy factor, stochastic of renewable energy, capacity factor, criteria for optimization	MCDM methods, optimization, MADM and MODM methods, Method ELECTRE, Method REGIME, WSM method, AHP method, VIKOR method, PROMETHEE method, TOPSIS method, Fuzzy MCDM, Stochastic MCDM, subjective, objective and hybrid weighting methods, ENTROPY method, criteria for optimization
Exclusion criteria/descriptive attributes		
There is no exclusion criterion in relation to the other two categories of papers in the search.	The optimization energy mix is the only search exclusion criteria in this area.	There is no exclusion criterion in relation to the other two categories of papers in the search.

What can be noticed from the previous table is that in most cases there are no exclusion criteria in the search for research and review papers. The only exception is the section "Technologies, conventional energy sources and RES", which by itself, due to its nature, excludes the notion of energy mix optimization in the search. However, in the other two areas, all attributes are included in the searches. Once the list of keywords and attributes is adopted, the search for papers can start.

The motivation for this paper occurs as the search for the answer: "How to combine all the mentioned items and use them in the search for the optimal energy mix"? By using Synthesis and Analysis methods and literature review as well as logical observation, we have proposed concrete conclusions in the process of optimization of the energy mix, choosing criteria for its optimization, as well as methods which be used to calculate the weight of optimization criteria in this process and further directions of this research. This will be presented in chapter: "Results and Discussion".

3. Energy mix optimization

The main goal of optimizing the energy mix is to choose the most efficient method of generation, transformation, and distribution of all forms of energy within a particular area, both national/regional and local. Energy mix optimization is mainly based on the complex concept of ES, which leads 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 for ES analysis have been developed that have had 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 ES planning. Optimization models can be applied: globally (Johnston et al. 2013), for parts of continents, such as models for the countries of northwestern Europe (Hirth, 2017), at the state level such as: Japan (Bhattacharya & Kojima, 2012), Algeria (Saiah & Stambouli, 2017), Portugal and Spain (Mendes & Soares, 2014), Korea (Geem & Kim, 2016), Lebanon (Kabakian & El Sayed, 2014), and Mexico (Vidal-Amaro et al., 2015), Texas-USA (Palmintier, 2013).

3.1 Economic optimized energy mix

In the 1970s, the main goal of research in energy planning was to focus on estimates of future energy needs. In the majority of cases, one criterion was used, while economic-energy relations were used to define the required energy. The option of the most efficient energy supply at the lowest possible cost was sought (Fontella, 1979; Hogan & Parikh, 1977). In that period. which involved the utilization of conventional fossil fuels, another methodology was used, which was more related to targeted programming.

The idea of optimal capacity of the mix obtained from economic approaches corresponds to situations in which the economic" effects" of RES integration are minimized (Mendes & Soares, 2014) or where the supply or demand strategy claims that RES integration would be economically viable (Chao, 2011). Economic optimized energy mix with two technologies: wind turbines (WT) and combined cycle gas turbines (CCGT) is limited by business-economic needs. A two-stage model for the Iberian electricity market has been developed. The authors concluded that it is more profitable for Portuguese producers to allow electricity prices to rise when peak demand exceeds available capacity than to invest in new installed capacity (Mendes & Soares, 2014). According to Lund (Lund, 2014), business-economic studies favor obsolete technological schemes in situations of radical technological change, because they are based on cost-benefit methodology, and all costs related to the policy of reducing greenhouse gas emissions (GHG) or increasing the share of RES are considered as additional costs. To assess the economic potential of RES and obtain a cost-effective energy mix, Trutnevyte (2013) developed the EXPANSE tool based on the economic criterion of optimal cost. The tool was tested by using RES to supply heat to a Swiss region. He concluded that the economic potential of all RES cannot be used at the same time, because the full use of the economic potential of one RES reduces the economic potential of others, and the EXPANSE tool is used to analyze these interrelations. In the paper (Carraro et al., 2013), a set of scenarios for European energy markets is analyzed so as to assess economic incentives and climate goals. The scenarios' analysis was performed using the World Induced Technical Change Hybrid Model (WITCH), which is used in the global assessment of climate and energy policies. WITCH is divided into 13 macro-regions, including Western and Eastern Europe, with data from 2005. The peculiarities of the model are multiple interactions between areas that include: technological spillovers, common non-renewable resources (coal, natural gas and uranium), emissions trading/credit, trade in oil, gas and coal. It was concluded that the WITCH model is a suitable tool for analyzing the optimal energy mix in Europe, where "optimal" is the equivalent of "social maximization". Kabakian and El Sayed (2014) sought an optimal energy mix in terms of cost by analyzing the capacity potential of three RES technologies (hydro, wind and solar photovoltaic (PV)) assuming the demand of adequate amount of electricity by 2020 for Lebanon. A simulation optimization model with a cost criterion was used to determine the optimal supply mix from RES, according to two scenarios: a 12% target, and even more ambitious 20% share of RES in electricity generation and three levels of demand. The optimization was performed according to the criterion of minimizing the total costs of electricity generation and the optimal energy mix of RES was proposed. The target function, see Eq. (1), represents minimizing total costs:

$$\mathrm{min Cost}_{overall} = \sum i(LCOE_i \times Supply_i). \tag{1}$$

Where: i is the number of potential technologies, Supplyi is the optimal supply of each technology in kWh, $LCOE_i$ is the Levelized Cost of Electricity and condition, see Eq. (2),

$$\sum i\,(Supply_i) \geq Demand_{2020}. \tag{2}$$

Where $Demand_{2020}$ presents the projected cases of electricity demand by 2020.

In the study (Geem & Kim, 2016), Geem and Kim proposed an optimal energy mix of Korean electricity generation planning models for electricity generation from conventional energy sources (gas, coal, nuclear energy) and RES (hydro, wind, PV, and biomass) by imposing government regulations called renewable portfolio standard (RPS). This optimization model reduces costs of construction, operation and management, fuel, CO_2 emissions, while meeting minimum demand requirements and maximum annual installation potential. The target function of the energy mix problem is the minimizing of total costs of electricity generation, meaning the costs of construction, operation and management, fuel, and CO_2. The results showed that this optimization model could successfully generate an energy mix plan from 2012 to 2030.

Previous research has been mainly based on the analysis of RES integration into the power system of countries, regions, with one of the following target functions: minimizing the generation of surplus electricity, minimizing installed capacity, while minimizing total costs. The economic criteria used in the research Carraro et al. (2013), Lund (2014) and Haller et al. (2012) relate to the reduction of costs of: investment, operation and maintenance, fuel, electricity, net present value, repayment period, lifetime, equivalent annual cost, etc.

3.2 Techno operational - economic optimized energy mix

In the paper, Mondal et al. (2014) assessed future energy supply strategies for the United Arab Emirates (UAE) energy sector. The paper studies the selection of best technologies to meet future demands based on existing and innovated technologies. These analyses are done for UAE ES using the MAR-Ket ALocation (MARKAL) model, an ES planning optimization tool. The MARKAL model determines the optimal mix of energy supply and finds the solution with the lowest cost, which gives the minimum cost for the selection of technologies based on their techno-economic parameters (Weijermars et al., 2012). Four scenarios were analyzed, and these are: basic scenario, CO_2 reduction scenario, scenario of meeting the target of RES generation, international gas price scenario. The results of the model simulation show that the use of primary energy sources for the purpose of meeting demand is reduced, and the supply of primary energy sources is diverse. Taking into account the EU guidelines on the growing role of RES in the supply and CO_2 emissions reduction, paper (Surianu et al., 2012) represents the basis for selecting the optimal energy mix from RES to supply various consumers with heat and electricity in a tourist site located in the Carpathians. Data on technical and economic features of the main types of RES are given, and feasible technologies are analyzed to ensure energy supply for households by using different RES. The research used the software tool Hybrid Optimization Model for Electric Renewables (Homer), intended for the optimal selection of RES in the electricity generation and supply. The research provided a comparative technical and economic analysis of the possibilities of supplying the micro power system by using RES: wind, biogas, PEM fuel cells and photovoltaic panels (PV).

EnergyPro 4.4. EMD International A/S (EnergyPro) was used as a simulation software for a number of case studies of district heating systems (DHS) where the focus was on techno-economic optimization of ES at the regional and national level, such as Kiss (2016), Massoud (2015) and Brandweiner (2009). The goal of the optimization was to find a specific generation configuration that minimizes the present value of the life cycle costs, see Eq. (3), for the implemented energy generation units with the capacities of the generation units in the configuration as a decision-making variable.

$$\min \sum_{j=1}^{n} C_j x_j \,. \tag{3}$$

Where: C are life cycle costs, j is index for a certain generation unit (*j*=1,2,3 ... , *n*), *x* is the energy generation capacity of a certain generation unit. Data on technological performance and costs related to generation units are based on actual costs incurred in recent similar projects in the same region. Data on fuel, electricity and emissions costs are based on the forecasts of the Department of Energy and Climate Change in the United Kingdom and on the different energy price scenarios considered in the study. Data on demand is based on information obtained from local authorities, with supply losses. The results show that, from heating perspective, the cost-effectiveness of a renewable alternative is based on subsidies and emission taxes. Due to subsidies for renewable heat and the maximization of surface area, a solar thermal power plant is a cost-optimal solution in all scenarios.

As can be found in (Østergaard, 2009) and (Lund, 2006), in the optimization of RES in systems, from techno-economic operational point of view, methodologies usually use the following variables as optimization criteria: reserve/return capacity, cost criteria, import and export dependence, primary energy consumption and fuel savings, share of RES, CO_2 emissions and surplus energy.

3.3 Technologies, conventional energy sources and RES

Many authors have researched, analyzed and compared different technologies that use conventional energy sources and RES for electricity and heat generation based on various criteria (technical, economic, environmental) and their indicators: energy and exergy efficiency, exergy efficiency, exergy factor, GHG emissions, energy efficiency of GHG costs, stochastic PDF, presented below.

3.3.1 Energy and exergy efficiency, exergy factor

Many research based on exergy analysis was conducted by numerous researchers around the world in various technologies, sources, and system applications (Siva et al. 2010). By means of exergy methods, better site selection and WT design can improve system efficiency, reduce economic costs, and increase wind power system capacity (Pope et al., 2010). Koroneos et al. (2003) discussed exergy analysis of solar, wind, and geothermal energy, and compared RES with conventional energy sources based on their efficiency. WT cannot benefit from total wind power. Energy losses are mainly caused by air escaping from the device, while the main exergy losses are related to internal consumption (Rosen & Bulucea, 2009).

Energy and exergy efficiency modeling techniques have been used for a long to estimate energy use to achieve energy and financial savings (Rosen & Dincer, 1997). Rosen (2001), Khaliq and Kaushik (2004) and Dincern et al. (2004) compared different types of technologies that use fossil fuels within countries, regions, and cities, based on energy and exergy analysis, and, as a result, presented potential energy losses and savings. Some authors, Xydis (2012) for Mount Helicon in southern Greece, Ozgener and Ozgener (2007) for the city of Izmir/Turkey, Hepbasli and Alsuhaibani (2011) for Greece, Baskut et al. (2010) for the village of Germiyan-Cesme/Turkey, Ozturk (2011) for 23 meteorological stations/Turkey, Zafar and Gadalla (2013) for the city of Dubai/UAE, Redha et al. (2011) for the city of Sharjah/UAE, studied the impact of meteorological parameters (such as air temperature, humidity and pressure) on the energy and exergy efficiency of WT and gave estimates of wind energy potential in these areas, as well as an estimate of time periods during which the energy consumption is increased. Sahin et al. (2007) and Kocer et al. (2014) presented a thermodynamic analysis consisting of the calculation of energy and exergy efficiency of WT and environmental impact factors for WT. They concluded that they could improve system efficiency, reduce economic costs and increase wind energy system capacity by means of energy and exergy efficiency calculations, better site selection and WT design.

The authors of papers (Sahin et al., 2007) and (Joshi et al., 2009) studied thermodynamic features of solar PV, PV/T systems, from the perspective of exergy and energy analysis, estimating exergy losses and efficiency. In the paper (Gong et al., 2012), 142 district systems in Sweden and the Marstal district heating system in Denmark were analyzed, using energy and exergy analysis and exergy factor as technical criteria indicators. The authors concluded that the higher the exergy factor, the greater the exergy losses in passive conversion to space heating. The great losses detected in the energy and exergy analysis are considered a challenge regarding the achievement of technical improvements in the system. One of the first applications of exergy parameters in MCDM in the optimization of energy chains based on biomass is elaborated in the paper (Vasković et al., 2016).

3.3.2. GHG emissions

The authors of papers (Cabrol & Rowley, 2012) and (Ibrahim et al., 2014) used models to study the performance of air source heat pump water heating system (ASHP-WH) and its potential to save energy and reduce GHG emissions in various locations in the UK and Lebanon. Kelly and Cockroft (2011) developed a numerical model to estimate the performance of an air to water heat pump (AWHP) during the reconstruction of a building in Scotland. An equivalent condensing boiler fueled by natural gas and an electric heating system were used as an alternative heating system for the building, and the annual energy consumption of these three systems was compared. The results showed that the GHG emissions from AWHP were lower compared to the emissions from the condensing boiler fueled by natural gas and the electric heating system. However, the operating costs of AWHP exceeded the costs of the natural gas condensing boiler, therefore the systems differ in incentives for renewable heat.

3.3.3. Stochastic PDF and Monte Carlo Simulations (MCS)

Stochastic modeling techniques allow for adequate consideration of uncertainties and provide support in making investment and operational decisions in such systems. The results show that the stochastic nature of RES has a price, sometimes a very high one. Estimating RES should be the first response to managing the changing nature of energy generation from these sources, prior to establishing energy storage strategies and systems in response to demand. This estimate has a positive impact on the reduction of integration costs; reduction of average annual operating costs; reduction of reserve shortages, etc. To generate data samples for random variables, random behavior should be somehow simulated, so that the model follows the data pattern with the highest homology compared to the actual data. To determine the pattern of a random variable, it is necessary to obtain the value of Probability Density Function (PDF).

The authors of papers, Parajuli (2016) the city of Jumle, Nepal and Ouahabi (2017), the city of Tetouanum, Morocco, Arikan et al. (2015), Elmadag region, Turkey, Amri et al. (2015), eastern region Mohammedia, Morocco, compare wind speed data obtained by using PDF with those obtained by measuring wind in these cities, in order to check their accuracy on the basis of the usual statistical indicators. PDF distribution models have been found to provide an adequate description of the frequencies of actual wind records in these regions/cities. They can be used to assess the features of wind resources in this region/city. The stochastic model presented in Pappala et al. (2009) uses a heuristic optimization method to reduce random wind power scenarios. The wind speed data are assumed to follow a normal PDF. A similar approach is presented in Siahkali and Vakilian (2010). In the paper (Cherif & Belhadj, 2014), an estimate of energy output in an independent hybrid wind turbine/PV system of the island of Djerba/Tunisia is given. Energy estimation using various PDFs is applied. The hybrid system design is based on all the features of the researched location. WT and PV capacity factors are presented. The obtained results show that the integration of all the losses and the use of PDF lead to a better energy estimate. In papers, Chang (2010) - six meteorological stations in Taiwan, Guwaeder and Ramakumar (2018) - four locations in Libya, Ayodele (2015), - Ibadan, southwestern Nigeria, the frequency distribution of global solar irradiation is studied and the distribution parameters are calculated. Various PDFs were used to obtain an adequate probability distribution that best matches the data for a certain period of the year. Energy demand in countries is increasing and RES may be a solution to meet some of these requirements. It was found that PV panels can provide an alternative energy source and an opportunity to generate financial gain, as well as to reduce oil and natural gas consumption.

In their paper, Biswas et al. (2018) a Pareto method for finding optimal solutions for multi-criteria economic and environmental energy dispatch with stochastic wind-solar-SHPP. The stochastic nature of all the RES studied in this paper is analyzed using the corresponding PDFs and their available energy is thus calculated. The goal of optimization is to minimize the total costs and emissions of the plants involved.

In recent years, many prognostic algorithms have been developed providing point prediction, interval prediction, and/or prediction probability distribution function. Methodologies used for such a problem include Monte Carlo Simulations (MCS), compiling or running many prediction points (Bracale et al., 2013; Scolari et al., 2016).

3.3.4 Energy efficiency and the cost of reducing GHG

Paish (2002) studied the current status of SHPPs (Small Hydropower Plant). It is concluded that hydropower is only to a small extent one of the most efficient energy technologies. Research has been done on the current state of hydro potential, how economically viable it is and how much of it still needs to be used. Although the initial capital cost of building a hydropower plant can be high, its long-term reliability and minor environmental effects cannot be ignored. Vitaljić (2006) presented the methodology used to determine the cost of specific reduction of GHG emissions for each RES (solar, wind, SHPP and biomass) in the Split-Dalmatia County/Croatia. He concluded that this county, with its RES potential, in which solar energy prevails, can ensure its own economic development with a significant reduction in CO_2 emissions.

4. Multi-Criteria Decision-Making

Multi-criteria decision-making (MCDM) is considered a complex decision- making tool, which includes quantitative and qualitative factors. The MCDM was introduced by Saaty (1980, 1988, 1996) and was originally developed to assess priorities. The application of MCDM methods provides support in solving problems of different rank that arise in the energy sector. This method of providing support in making decisions can be a major component in supporting energy development scenarios and, particularly, to facilitate the process of different generation technologies and energy sources selection.

4.1 MCDM methods

The multi-criteria methodology is presented through various studies to obtain a comprehensive approach to this issue. It is possible to incorporate various elements from social and managerial units, such as economic, technical, energy, environmental (Saaty, 1996), as well as a few restrictions. Although different criteria give different results, this methodology still requires the decision maker to analyze the settings and determine the weights of all criteria. According to the available literature, MCDM is divided into two basic groups of methods: Multi Attribute Decision Making (MADM) and Multi Objective Decision Making (MODM) (Pohekar & Ramachandran, 2004; Tummala & Čupić, 1991; Polatidis et al., 2006; Chai et al., 2013). Mardani et al. (2015) divided MADM into three classes, Jahan et al. (2009) proposed for MODM to be classified into three classes as well. Figure 1 presents a mix of both.

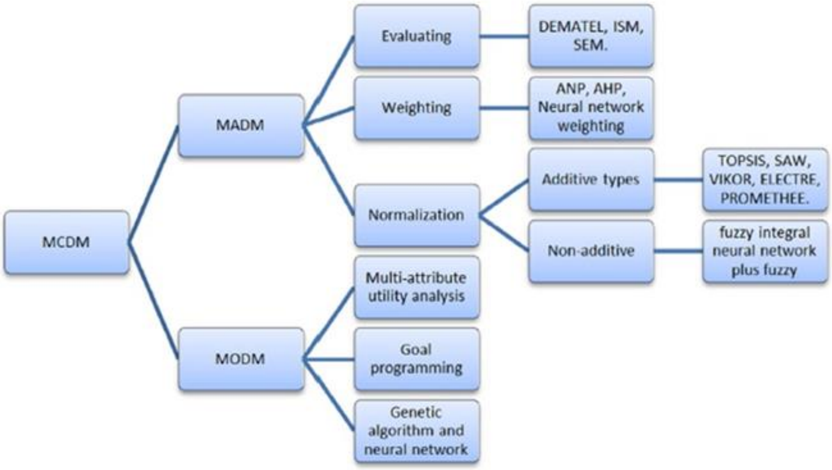

Figure 1. MCDM classification divided into MADM (Mardani et al., 2015) and MODM (Jahan et al., 2009)

Pohekar and Ramachandran (2004) offered two classifications:

- By method: deterministic, stochastic and fuzzy methods (not elaborated),
- By type of data used: quantitative, qualitative or mixed.

Many authors (Zavadskas et al., 2014; Chai et al., 2013; Figueira et al., 2005; Hwang & Yoon, 1981; Pohekar & Ramachandran, 2004; Wang et al., 2009; Mardani et al., 2015; Kolios et al., 2016) tried to systematize and give an overview of MCDM methods.

Deterministic methods (DMCDM) are used to describe one of the many possible outcomes of a reference problem. These methods are mainly used to describe simple, natural phenomena based on physical laws and are not useful for large and complex applications. Therefore, real-world behavior is better reflected by applying methods relevant to stochastics. DMCDMs generally assume that all criteria and their complexity are expressed in crispy values and therefore, ranking of alternatives can be carried out without any problems.

Stochastic methods (SMCDM) may be more informative than determined because it explains the uncertainty due to the different behavioral features of the target system. The problem of selecting alternatives with multiple criteria in stochastic variables is called stochastic multi-criteria decision-making SMCDM. Stochastic methods can increase the confidence of the decision-maker in final results and analyses and may be more appropriate in cases where heterogeneity of important factors is critical, as it increases the uncertainty of the system under consideration.

While SMCDM calculates all sorts of ways to achieve a goal, Fuzzy MCDM method (FMCDM) tries to find one best way to perform a task (Buckley, 1990). Fuzzy MCDMs were developed due to inaccuracies in assessing the relative importance of attributes and evaluating the feasibility of alternatives in relation to criteria. Inaccuracy is present due to a variety of reasons: incomplete information, inaccessible information, and partial ignorance.

4.2 Showcase of application of MCDM methods for determining the energy mix and its optimization

The MCDM methodology was applied as the main approach, as it is often used to analyze and plan the future of energy (Afgan & Carvalho, 2002; Løken, 2007). MCDA was applied at the regional level to generate an optimal energy mix and estimate the current energy mix. The most significant papers and MCDM methods are presented below. Such studies were performed for the city of Belgrade (Grujić et al., 2014) ELECTRE, several countries, including Greece (Mourmouris & Potolias, 2013) REGIME, Japan (Hong et al., 2013) multi-criteria decision-making analysis (MCDMA), Tunisia (Brand & Missaoui, 2014) TOPSIS, Taiwan (Gwo-Hshiung et al., 1992) AHP and PROMETHEE, Cyprus (Theodorou et al., 2010) AHP, PROMETHEE, ELECTRE, Lithuania (Sliogeriene et al., 2013) AHP, ARAS, SAD (Klein & Whalley, 2015) MCDA, Jordan (Malkawi et al., 2017) AHP.

(Method ELECTRE) In the paper (Grujić et al., 2014), Grujić and associates analyzed the development of the energy sector and the future energy consumption of Belgrade up to 2030, with an emphasis on the district heating system (DHS). They used three scenarios: realistic, optimistic, and pessimistic. These scenarios consider different levels of economic development, investments in the energy sector, replacement of fossil fuels, introduction of RES and implementation of energy efficiency measures. The proposed model for selecting the optimal DHS compared different possibilities for meeting the expected new heat demand through eight criteria (economic, environmental and security of energy supply) for each scenario using the ELECTRE method. The proposed options are a combination of different energy sources (natural gas, coal, liquid fuels, biomass, solar, geothermal energy) and technologies for their use. The author’s conclusion is that the optimal choice in the optimal scenario is a combination of CHP and centralized use of geothermal energy. In the other two scenarios, the optimal option is a combination of gas boilers and geothermal energy.

(Method REGIME) Mourmouris and Potolias (2013) used MCDM to study the case of the Thassos Island/Greece. The research was aimed at finding the optimal amount of each RES that can be generated in the region and that can contribute to the optimal energy mix. The MCDM REGIME method was used for the analysis, and the selected criteria were economic, social, technical-technological, and environmental. The results proved that the exploitation of RES at the regional level can meet the growing demands for supply through environmentally friendly energy systems (a combination of wind energy, biomass, and PV systems).

(WSM method) The paper (Klein & Whalley, 2015) compares 13 currently operational renewable and non-renewable options for electricity generation in the USA. The MCDM-WSM analysis was used, with quantitative input values (minimum, nominal and maximum) for 8 sustainability criteria (equalized energy costs, GHG life-cycle and air pollutant emission criteria, soil and water level, accident-related incidents, jobs and annual capacity factor) and 10 representative scenarios. The results in several preferential scenarios indicate that bioenergy and geothermal energy have the greatest success in the USA. Other RES technologies offer significant improvements in sustainability over fossil fuels or nuclear technologies, and the use of nuclear technology is in most scenarios more favorable than the use of fossil fuels.

(AHP method) In their work Abid and Bahloul (2011) developed the AHP method to facilitate the activities of stakeholders (environmentalists, industry, local community and local authorities) in the field of energy resource (potential) planning for the Aydin Province district/Turkey. The hypothetical results showed that the highest priority is given to investments in the field of solar energy that can be made

by the local population and authorities. Industry and Government can make investments in geothermal power plants and decentralize coal-fired power plants using clean technologies.

(AHP&VIKOR method) In his paper Cristobal (2011) used the VIKOR method to select RES projects that correspond to the RES plan launched by the Spanish government. The method was used along with the AHP method to determine the importance of the weights of different criteria, which allow decision-makers (DM) to assign these values based on their preferences. The results show that the option of using biomass, that is, combustion in conventional power plants is the best choice, followed by wind energy and solar thermal alternative energy.

(Fuzzy AHP and fuzzy TOPSIS method) Buyukozkan and Guleryuz (2016), evaluate sustainable energy sources and select optimal energy alternatives for Turkey. The evaluation of sustainable energy technology alternatives implies subjective and qualitative evaluation and requires different complex factors, and the sustainability criteria used for the selection of energy technologies in Turkey are economic, social, technical and environmental. They used MCDM-fuzzy AHP and fuzzy TOPSIS models for energy resource evaluation. Fuzzy AHP was used to determine criteria weights and fuzzy TOPSIS to evaluate alternatives.

(VIKOR method) The VIKOR method introduces a multi-criteria ranking index based on an individual measure of proximity to an “ideal” solution, some of the analyzed alternatives (Opricović, 1994; 1998; Pašić et al. 2009). In his doctoral dissertation, Vasković (2016) used the VIKOR method with the definition of energy, economic and environmental criteria to assess the quality of the biomass supply chain and to access an optimal variant of energy and biofuel production. The paper (Arnette & Zobel, 2012) is a contemporary review of categorization, analysis, and interpretation of current research in VIKOR applications. Also, VIKOR method has been used to choose the best appropriate RES alternative for installation at Banaras Hindu University (BHU) campus, India (Kumar & Samuel, 2017).

4.3 Methods for determining 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 (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 et al. 2009), which is of course not an adequate and accurate approach for final evaluation in all more serious approaches related to MCDM (Ginevičius, 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 have not taken the objective conditions into account (Zardari et al., 2015). 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 et al., 2015). The weights were determined according to the relationship between the original data in the 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 & Parkan, 2005). To overcome the shortcomings of the subjective and objective weighting methods, in recent years, occurred the methods which combine the subjective and objective weighting (Meng & Chi, 2015). Figure 2 shows the classification of methods for determining weights, with the emphasis on the development of combined methods in recent times. Novel methods proposed in the last decade are as follows: BWM (Rezaei, 2015), BWM-I (Pamučar et al., 2020), CILOS (Zavadskas & Podvezko, 2016), IDOCRIW (Zavadskas & Podvezko, 2016), FUCOM (Pamučar et al., 2018), LBWA (Žižović & Pamučar, 2019), SAPEVO-M (Gomes et al., 2020), and MEREC (Keshavarz-Ghorabaee et al., 2021). The new methods represent an improvement of the old methods (subjective and objective) for determining the weights of the criteria, colored with red color in Figure 2.

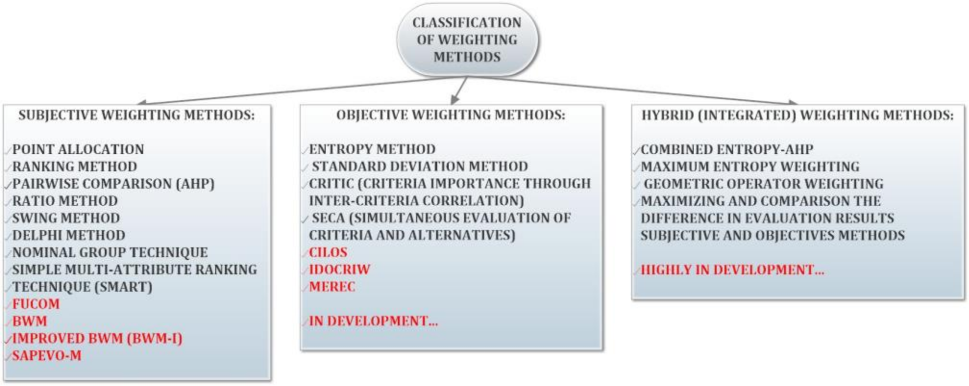

Figure 2. Classification of weighting methods

In the following text, there are a brief description of three methods for determining the weights of the criteria, AHP, Entropy method and MEREC method. The reasons why they have been selected to define the weights of the criteria will be described in the results and discussion.

When it comes to AHP method, criteria weights are evaluated subjectively, with the help of a decision-maker (DM), which, in some way, can lessen the importance of individual criteria with certain acceptable discrepancies. Analytical Hierarchy process (AHP) method, where the 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 (Şahin, 2021).

However, the subjective evaluation of criteria is neither sufficiently efficient nor accurate when it comes to quantitative and budgetary criteria. For data expressing technical, inhomogeneous, deterministic, and highly probable performance measures of the alternatives that we are optimizing, the weights of such criteria must be objectively determined. This area of optimization also includes the optimization and selection of the optimal energy mix.

The ENTROPY method 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 paper investigating the problem of obtaining and comparing subjective and objective values of criteria weights, combining the AHP method and the Shannon entropy model, is described in (Al-Aomar, 2010). 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 application of combined methods for determining the objective values of criteria weights, together with one of the existing MCDM methods, has only recently gained importance in engineering. In (Dev et al., 2020), the MCDM Entropy-VIKOR technique was used to select a composite material among the tested materials. The Entropy method was applied to calculate criteria weights, and the VIKOR method was applied to rank the produced composite materials. All these paths and ways of applying both, the MCDM methods and the methods for determining the weights of the criteria, served to form final conclusions and discussions on the application of MCDM for determination of an optimal energy mix.

The MEREC method is an objective method that considers the impact of removing a criterion on the performance values of decision alternatives based on the remaining criteria, in contrast to other objective methods that assign weights to criteria by controlling the variance in the performance of the alternative (Shanmugasundar et al., 2022).

5. Results and Discussion

The purpose of this paper is to provide an overview of the current situation in the field of energy mix optimization as a very current issue that is gaining more and more importance. It should be noted that by considering this situation through the previous review, conclusions can be drawn about necessary directions of further research development of both methodological, mathematical, and descriptive characteristics of the energy mix and ways of its optimization. First, the previous review of the literature revealed one big shortcoming in this area, which is the absence of an integral universal approach among: the way of describing the characteristics of the energy mix (criteria), mathematical methods for calculating the optimal energy mix, MCDM techniques for optimization and techniques for calculating weighting factors for the adopted optimization process criteria. Bearing in mind that the development of MCDM techniques is inextricably linked to sustainable development, it is perfectly clear why it is of great significance to integrate this approach into the process of energy mix optimization. In the very beginning, the energy sector relied only on the economic optimization of the energy mix. With the development of energy needs, the process of energy mix optimization became of techno-operational economic type, and nowadays has grown into the domain of multi-criteria optimization. Besides considering the energy and exergy characteristics of the mix and the environmental impact, it is necessary to present certain energy sources in the energy mix with their stochastic behavior and capacity factor.

The following Table 2 shows the evaluation of reviewed, several the most significant papers according to the adopted evaluation criteria related to: the application of the MCDM method in the optimization in the papers, the number of optimization criteria in papers, the time dimension in the developed and reviewed models and the closeness of the paper to the interpretation of the energy mix.

Table 2. Criteria for judging the quality of papers and the adequacy of the methodological procedures

Publication	Application of the	Number of	Time	Only ranking	Contribution to value of

	MCDM	criteria			energy mix
(Malkawi et al., 2017)	AHP ✓	7		✓	✓
(Cristobal, 2011)	VIKOR AHP ✓	7	✓, partly	✓	✓
(Sliogeriene et al., 2013)	AHP ARAS ✓	20		✓	
(Buyukozkan & Guleryuz, 2016)	Fuzzy AHP, Fuzzy TOPSIS ✓	4		✓	
(Brand & Missaoui, 2014)	TOPSIS ✓	13	✓, partly	✓	
Publication	Optimal energy mix	Number of criteria	Time	Only ranking	Contribution to value of energy mix
(Kabakian & El Sayed, 2014)		Up to 3 criteria	✓		✓
(Mondal et al., 2014)		Up to 3 criteria	✓		✓
(Geem & Kim, 2016)		Up to 3 criteria	✓		✓
(Heide et al., 2010)		Up to 3 criteria	✓		✓, partly
(Makkonen, 2017)		Up to 3 criteria	✓		
Publication	Technology	Number of criteria	Time	Only ranking	Contribution to value of energy mix
(Dincern et al., 2004)		Up to 3 criteria			
(Becker et al., 2014)		Up to 3 criteria	✓		✓, partly
(Komiyama & Fujii, 2014)		17	✓		✓, partly
(Thangavelu et al., 2015)	strive to MCDM methods	8	✓		✓
(Faundez, 2017)		Up to 3 criteria	✓		✓, partly

A sample of five papers per three observed areas (Multi-Criteria Decision-Making, Optimal energy mix, and Technologies related to conventional energy sources and RES), were taken into consideration. The marked cells in Table 2 represent the best evaluated reviewed papers according to the previously adopted criteria for the evaluation of quality papers and the adequacy of the methodological procedures inside them, regarding to optimization of the energy mix.

The key question and goal of this review paper is to establish the degree of application of MCDM methods in the optimization of the energy mix and to try to open the questions and possibilities of applying the analyzed methods in the optimization of the energy mix. In accordance with the paper ratings in Table 2, we should strive to papers, methodologies and research that interpret the application of MCDM methods in the calculation of the energy mix: Cristobal (2011), Malkawi et al. (2017), Brand and Missaoui (2014) and Thangavelu et al. (2015).

The general conclusion can be made as follows: The models which combine all three mentioned areas "(Multi-Criteria Decision-Making, Optimal energy mix, and Technologies related to conventional energy sources and RES)" in one integral whole are very poorly represented in the research papers reviewed in the framework of this review.

Instead of some extensive discussion, a complete overview of the papers from section 3 and section 4 as well as logical conclusions are given in Figure 3. As an example in Figure 3, two basic MCDM methods were taken into consideration: the Entropy method for determining the weights of criteria and the VIKOR method for ranking variants of the optimal energy mix.

In general, for the selection of the optimal energy mix, all objective methods for determining the weights of the criteria are proposed, while the new improved methods are certainly very useful in solving this problem. The scheme in Figure 3, refers to the possibilities of optimizing the energy mix that can consist of all types of energy obtained with different production technologies (renewable and non-renewable energy sources). To optimize the energy mix, it is necessary to define universal criteria to describe all possible available technologies for energy production. For this reason, a review of the literature in section 3 concluded that these criteria form a set of 1 to 9 criteria, shown in Figure 3, which considered: economic, environmental, energy, stochastic, quantitative, and qualitative assessments of the energy mix/technology. Defining of these criteria opens the possibility of choosing the method for defining the weights of the criteria and the MCDM method. Section 4 of the literature review has made a more significant contribution to this analysis. Also, from the review of the MCDM method, the VIKOR method is imposed as an adequate way to calculate the optimal energy mix. We meet the reasons for its application in two aspects: "Solution closest to the ideal solution having an acceptable compromise of conflicting and non-commensurable criteria" and "Measure Q through which proximity to the ideal solution can be expressed". On the other hand, the VIKOR method is already widely practiced and programmed. That measure Q can be used in defining and distributing the optimal values of the percentage of individual analyzed alternatives, which can represent some of the supply options in the overall energy mix. 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.

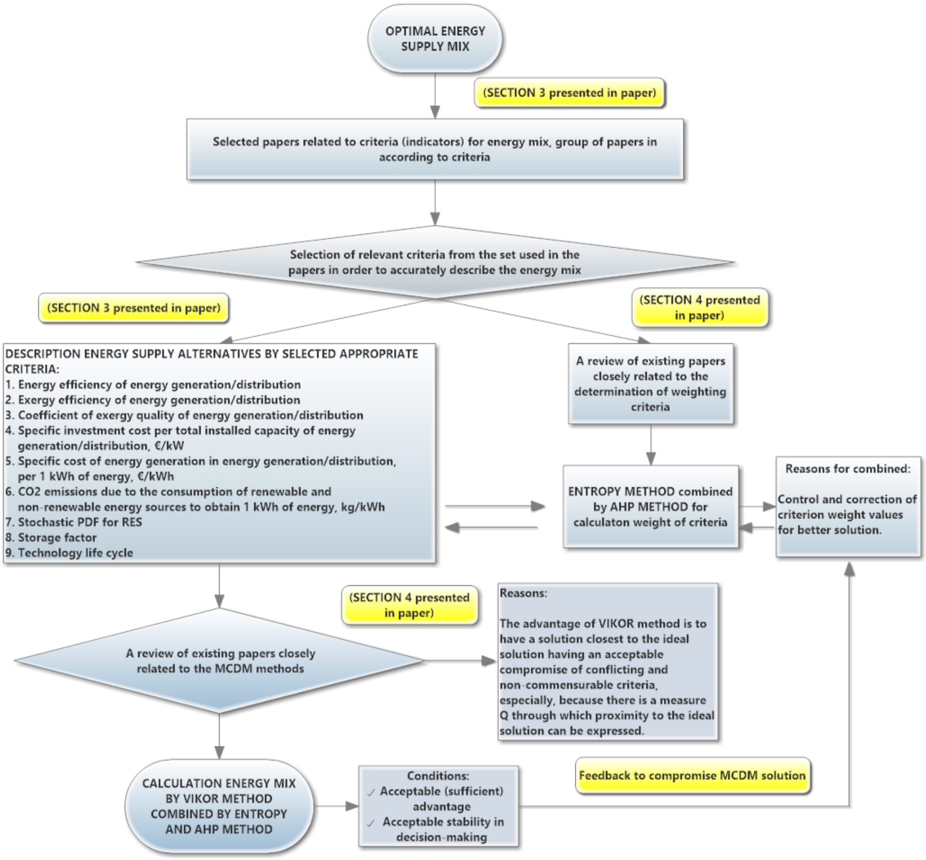

Figure 3. General architecture and conclusions in the field of application MCDM and weighting methods to finding optimal energy mix

We should also mention the MEREC method, which also has great potential for this issue, and certainly all hybrid approach methods. 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, the use of a combined control approach 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 accomplish feedback in terms of achieving a compromise solution by correcting the weights obtained from the selected criteria to meet the conditions of stability and acceptable benefits of the solution.

The issue of optimizing the energy mix in accordance with Figure 3 has been published in a paper (Bosančić et al., 2022). Data from the Danish energy sector were used to calibrate the proposed model.

One of the main challenges in the optimization of the energy mix is the interpretation of the potential of an energy resource and its availability in time as an alternative in the optimization process. On the other hand, limitations are very important. Limitations primarily refer to the amount of available energy potential from the observed variants in the energy mix. New energy mix optimization models should take this into account. Further research in this area should aim to the development of MCDM expert systems that would simultaneously optimize the energy mix according to previously defined criteria, but also optimize the state of the energy mix in real time in accordance with limitations per each individual component in defined optimization matrix.

6. Conclusions

According to the available literature, previous energy systems and energy mix optimizations were mainly based on economic and techno-operational economic approach, with the objective function of minimizing total/operating costs of generation, that is, of capacity. There are a few papers in which MCDM methods were used in the optimization of energy supply systems, but there are very few of them when it comes to optimizing the local community energy mix. This certainly opens a new approach and direction to this problem that needs to be explored in mathematical and practical applications.

The topic of energy mix optimization is covered by a combination of several different fields 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 generation technologies, RES stochastics. The overall analysis of all presented papers puts forward the question of how the local community can be more comprehensively presented, that is, how the knowledge about energy, economic, technical, environmental, as well as stochastic parameters of energy generation and distribution in the local community can be improved. Hence, the need for detailed analysis and description of the previously roughly stated elements of the system (having in mind the stochastic nature of some RES), with as many necessary and sufficient factors, criteria and dependences as possible, in order to get more accurate, clearer and systematized description of the current state and the unique optimal energy mix of the local community. The energy transition will contribute to the development of a new model of the energy market, where the energy consumer is an active user but also an energy producer. All this affects: the change in the share of energy used for energy production, energy and energy imports, the structure of production capacities with an increase in the share of RES and costs.

For the energy mix of the local community, it is necessary to define criteria for assessing its quality. No models were found in the literature that simultaneously calculated all the following optimization parameters:

- Energy efficiency of energy generation/distribution,
- Exergy efficiency of energy generation/distribution,
- Coefficient of exergy quality of energy generation/distribution,
- Specific investment cost per total installed capacity of energy generation/distribution, €/kW,
- Specific cost of energy generation in energy generation/distribution, per kWh of energy, €/kWh,
- CO_2 emissions due to the consumption of renewable and non-renewable energy sources to obtain 1 kWh of energy, kg/kWh,
- Stochastic for RES,
- Storage factor,
- Technology life cycle.

Listed parameters are universal and can be applied to the mathematical description of the energy mix of any local community or region. It is also necessary to consider the state of the current energy mix used by the local community and the energy mix that it strives for and wants to achieve.

Multi-criteria optimization is the only appropriate way to fully create a realistic picture of the currently optimal energy mix, considering both the necessary and enough criteria with which to describe this problem. Such an approach gives the universality of the application of the given concept for the calculation of the listed parameters. In the analyzed literature, authors have generally given priority to minimizing generation costs, neglecting the simultaneous observation of defined, energy, technical, environmental, stochastic parameters. All this indicates that, to find the optimal variant of the energy mix of the local community/state, it is necessary to apply one of the methods of multi-criteria optimization.

MCDM methods have been used to address multiple conflicting criteria to arrive at better solutions. The authors present papers that include deterministic (ELECTRE, REGIME, WSM, AHP, VIKOR, etc.), stochastic (DEMATEL, SMAA, SAHA, SAHP, STOPSIS, SVIKOR, etc.) and fuzzy MCDM (fuzzy AHP, fuzzy ANP, fuzzy TOPSIS, fuzzy VIKOR et al.) methods. In the analyzed literature, there are few papers that used the VIKOR optimization method to optimize the energy mix of the local community. However, the real reason why this method is potentially good in solving the problem of selecting 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 precise results. After modeling the real energy current state at the level of the observed local community/state, a real insight into the current state of that locality is got, which, according to the VIKOR methodology, includes a precisely defined redistribution of the share of individual components of energy supply and distribution. By combining the VIKOR and similar methods with objective weighting methods like Entropy, MEREC etc., a powerful mathematical tool can be obtained, which can very reliably calculate precise information on the optimal energy mix from the observed optimization matrix.

The Entropy or MEREC methods can be used to calculate objectively the criteria weights in the optimization process and therefore can be applied in this problem. When it comes to the energy mix, the entropy method did not have a significant application in the analyzed literature in this area. However, there are newer methods for this application. With appropriate assumptions and restrictions, different scenarios are to be developed to know exactly what the observed local community should do to reach the optimal energy mix. The control and calibration method for the entropy method can be used by AHP method (or some kind of subjective methods) to determine the weights of the criteria.

This review paper can provide a better understanding of MCDM techniques for future academics and practitioners in making appropriate decisions, especially in the part related to the selection of the energy mix optimum during the energy transition. It is difficult to answer the following questions: how to choose the optimal energy mix in some country, region, local community, company? How to manage production, but also consumption of energy (electrical and thermal) in real time?

Experiences with multi-criterial (Multi-criteria Decision Modelling – MCDM) tools indicate that they could serve as a basis for the realization of such a system. MCDM enables the selection of appropriate criteria (technical, economic, ecological, social, political...) and the appropriate allocation of weighting elements (priorities) to the individual criteria at any moment in time to obtain an optimal energy mix for given conditions, at a given moment of time. The concept of new research direction is simple, and starts from the premise that if the systems based on MCDM are designed and supplied with adequate data in real time, obtained results can be used for optimization and management of the complex energy supply and consumption system, that is, it would be possible to make a tool that does it. This paper suggests that in the process of optimization of the energy mix with the help of MCDM methods, more research should be done in this area, with all the previous suggestions.

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