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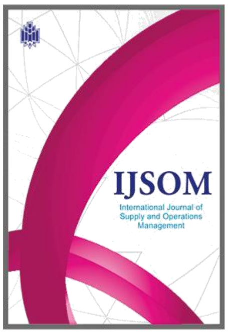

Alternative energy sources and their analysis as investment opportunities: A case of the Czech Republic

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Abstract

Alternative energy sources and their efficient usage are currently a significant and widely discussed problem in all countries. The paper deals with the analysis of possible energy sources and their evaluation using multiple criteria decision making (MCDM) methods in specific conditions of the Czech Republic. The analysis aims at decision what alternative energy sources are suitable best for possible investments. The analysis uses TESES (technical, economic, social, ecological, strategic) classification of criteria. The total number of criteria considered in evaluation is 16, and five alternative renewable sources are defined. The evaluation is based on the crisp data set that describes the current situation in the Czech Republic. The most often applied MCDM methods (analytic hierarchy process, TOPSIS, and PROMETHEE class method, and the weighted sum approach) are used to compare the results. The differences in the obtained results by all methods are compared and discussed in detail. The main contribution of the study consists of a demonstration of applicability various decision-making techniques in the analysis of alternative energy sources. The results can be generalized not only for the specific conditions of the Czech Republic.

Keywords: alternative energy sources; analytic hierarchy process; multiple criteria decision making; investment

1. Introduction

The expanding world population (Smith, 2013) and increasing living standard in many world countries lead to a higher demand of energies (Chatzimouratidis and Pilavachi, 2012). Fossil fuels traditionally cover this demand, but their increasing use decreases these sources (Pilavachi et al., 2009). Besides, the environmental impact of their usage cannot be ignored, and it is still more and more accented. Therefore, more environmentally friendly forms of energy are deployed to use to reduce the negative impacts of traditional sources.

The Czech Republic is a member of the European Union (EU). According to EU documents, the increased share of energy from alternative sources is necessary. The Czech Republic is bounded by the directive to increase the total energy consumption from alternative sources to 15 % in 2030 and at least 30 % in 2050. The state energy conception must take into account the most promising sources for the specific social conditions of the Czech Republic. This study contributes to the discussion about energy conception and its adjustments.

In the Czech Republic, there are five real renewable energy sources concerning natural conditions. There can be identified five primary alternative energy sources as an addition to the traditional ones (coal, water, and nuclear power plant stations). They are wind power stations, see, e.g. (Talinli et al., 2011, Madhuri et al., 2017, and Ahmad and Tahar, 2014), photovoltaic power stations (HakimiAsl et al., 2016, Madhuri et al., 2017, Ahmad and Tahar, 2014, Ghasempour et al., 2019, Sueyoshi and Goto, 2014, and Mai et al., 2018), geothermal power stations (Satapathy, 2019), hydro-electric power stations (Barros, 2008, Ahmad and Tahar, 2014, and Mattmann et al., 2016), and biomass energy stations (Li et al., 2018, Madhuri et al., 2017, and Ahmad and Tahar, 2014). There are several other alternative sources (e.g. energy of sea waves), but they cannot be considered due to the Czech conditions.

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Evaluation of alternative energy sources is a complex multiple criteria decision-making (MCDM) problem with a relatively small number of alternatives and a high number of criteria. For the analysis, TESES (technical, economic, social, ecological and strategic) classification of criteria is used. This classification was formulated in Beranovsky (2002). The similar classification is applied in paper Talinli et al. (2011), where technical, economic, environmental and socio-political classes are considered for wind power farms evaluation, and in Madhuri et al. (2017), where renewable energy sources are evaluated by technical, economic, ecological and geographical aspects. Ahmad and Tahar (2014) considered four main criteria: technical, economic, social and environmental for evaluation of hydropower, solar, wind and biomass energy sources with respect to 12 sub-criteria.

The technical criteria describe the technical obstacles of single technologies, technical parameters of produced electricity and if the technology enables efficient usage of produced warm, and coefficient of hazard in the building-up season. Economic criteria describe the project from the investors' point of view that is conclusive for the project realization or rejection. Social criteria cover the social project implications and their benefit for solving social and socio-economic problems of the regions and states. Ecological criteria describe the particular benefits of a unique technology for environment components, and strategic criteria evaluate the long-term project effect for the power industry in the Czech Republic and the situation in further fields of the national economy, for example, political goals, and geographical areas.

2. Problem formulation

Our study evaluates five alternatives (alternative energy sources) with respect to five main sets of criteria. Each set of criteria contains several sub-criteria. Their total number is 16. As the most suitable analytical tool for our purposes analytic hierarchy process (AHP) was chosen. AHP belongs among the most popular MCDM techniques. Except for AHP, several other MCDM methods have been applied for comparison purposes.

AHP is a prevalent decision-making technique that has been applied in numerous case studies in the past. Chatzimouratidis and Pilavachi (2007) have evaluated the non-radioactive emissions from power plants using AHP. They have used a four-level hierarchy tree with five types of emissions. In their study, authors have focused on ten power plants, not only with alternative renewable energy sources. The hydro-electric power station was finally ranked as the second. At the top, there was the nuclear power station and the difference between these two power plants was very tiny - overall evaluation for hydro-electric was 13.30 % and for nuclear 13.34 %. The geothermal power station was the third with evaluation 13.29 %, wind power station the fourth (13.04 %), photovoltaic power station the sixth (10.77 %), and biomass power station as the worse among alternative sources (7.23 %).

The same authors have published the paper focused on the impact on the living standard from power plants (Chatzimouratidis and Pilavachi, 2008). In this study, the authors have used AHP method for evaluation of ten types of power stations. With respect to quality of life (with weight 75 %) and socio-economic aspects (25 %), all five types of energy power stations have ranked as the best – geothermal power station (15.0 %), wind power station (13.12 %), biomass power station (11.71 %), photovoltaic power station (11.61 %) and hydro-electric power station (9.7 %). The nuclear power station was ranked in the sixth position. The similar problem with a different set of criteria, and also sensitivity analysis with four alternative scenarios, were presented in (Chatzimouratidis and Pilavachi, 2009a), and (Chatzimouratidis and Pilavachi, 2009b).

The AHP was also used for the analysis of the hydrogen fuelling systems for transportation (Winebrake and Creswick, 2003), the evaluation of liquid biofuels (Papalexandrou et al., 2008) and the hydrogen energy technology (Lee et al., 2008). Pilavachi et al. (2009) have used AHP for the evaluation of hydrogen production methods, Talinli et al. (2011) for wind power farms and Ahmad and Tahar (2014) for analysis of hydropower, solar, wind and biomass energy sources. Solar, biomass, and wind energy are compared by AHP in (Madhuri et al., 2017).

The AHP is probably the most popular but not only method for solving MCDM problems and (Barahona et al., 2014). TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), and PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) class methods belong to tools with numerous applications also. They have been used in many other studies, e.g. (Wang et al., 2014), (Tavana et al., 2013), (Vego et al., 2008), (Beynon and Wells, 2008), (Iskin et al., 2012) and (Li and Sun, 2009). The AHP method is developed into fuzzy AHP – FAHP (Nazam et al., 2015, and HakimiAsl et al., 2016) and combined with other MCDM methods such as TOPSIS (Ghasempour et al., 2019).

There also exist various recent studies on alternative energy sources based on other methodological approaches – such as data envelopment analysis (Amini et al., 2016, Amini and Alinezhad, 2017, and Khalili and Alinezhad, 2018), linear regression models (Dombi et al., 2014), panel data analysis (Inglesi-Lotz, 2016), vector autoregressive models (Reboredo and Ugolini, 2018), quantiles analysis (Troster et al., 2018), portfolio optimization (Neto et al., 2017) or classical decision models (Wang et al., 2010).

2.1 Alternatives

The set of alternatives correspond to available alternative energy sources in the conditions of the Czech Republic. The data set is obtained from real projects running in 2018. They were gained from the firm that is focused on energy audits. At present, the data for power stations based on non-photovoltaic renewable energy sources are practically unavailable in the Czech Republic, and they are law-protected. Therefore, in our paper, one power station from each group of energy sources is analyzed. The list of alternatives is as follows - in parenthesis is presented the total output of the station in kW, expected service life in years, and total costs of construction in a million CZK (1 EUR = 26 CZK approx.):

- *Wind power station* – a wind farm with four wind power stations (2300 kW, 20 years, 367 million CZK).
- *A photovoltaic power station* (373 kW, 15 years, 30 million CZK).
- *A geothermal power station* (300 kW, 30 years, 23 million CZK).
- *A hydro-electric power station* (103 kW, 20 years, 10 million CZK).
- *A biomass energy* power station (1500 kW, 20 years, 170 million CZK).

In 2010, almost 13 thousand photovoltaic power stations were installed in the Czech Republic, in comparison with about one hundred hydro-electric power stations, about 50 wind power stations with approximately 150 turbines, five biomass power stations and only a few small geothermal power stations.

Eight years later (in 2018), more than 28 thousand photovoltaic power stations were installed, and this number is more than doubled comparing to 2010. Small hydro-electric power stations development was very fast in the last eight years, and the number increased to more than 1600 hydro-electric power stations. There are installed about 70 wind power stations, five biomass power stations and one new sizeable geothermal power station in the Czech Republic.

2.2 Criteria

The evaluation of the five above described alternatives is performed according to TESES (technical, economic, social, environmental, strategic) classification of criteria. The main criteria and sub-criteria are expressed as follows:

Technical (Tx)

Technical criteria express various aspects of the alternative energy sources with respect to the production of energy, service life, and other technical factors. The study takes into account the following ones:

- *T1:* Relative utilization of installed energy output – a ratio of the energy production per period and theoretical (or rather expected) energy production in this period [%, maximize]. For illustration, the value 100.9 % in Table 1 means that the real energy production of the wind power plant exceeds expectations by 0.9 %.
- *T2:* Relative expected loss of the energy due to the weather conditions, device errors, and services [%, minimize].
- *T3:* Expected service life of the power station [years, maximize].
- *T4:* Complexity of the project rated in points in the scale from 0 to 100 [points, minimize]. Higher values express higher complexity.

Economic (Fx)

The set of economic criteria describes how the projects are evaluated using several traditional economic indicators:

- *F1:* Net present value (NPV) of the financial flow of the project [thousands of CZK, maximize].
- *F2:* Internal *rate* of return (IRR) of the financial flow [%, maximize].
- *F3:* Recovery time objective (RTO) measures the time needed for reaching the full service level after plant disaster [years, minimize].
- *F4:* Recovery of investment (ROI) is a ratio of expected returns to the investments [%, maximize].
- *F5:* Net profit (NP) [thousand of CZK, maximize].

Social (Sx)

The group of social criteria is related to measuring of impacts of the projects on living conditions in surrounding of the power plants:

- *S1:* The number of new job positions measured relatively in points from 0 to 100, higher values express a higher number of new positions [points, maximize].
- *S2:* User's comfort, quality and complexity of the project evaluated by points from 0 to 100, higher values express a higher user's comfort [points, maximize].

Environmental (Ex)

Environmental criteria are currently one of the most important factors taken into account in decisions about the building of new power plants. In our study, the following ones are considered:

- *E1:* Decreasing of carbon dioxide comparing to the current situation [kg/kWh, maximize].
- *E2:* The level of influence of the scenery by the building of the plant - in points from 0 to 100, higher values mean stronger undesirable impact on the environment [points, minimize].
- *E3:* Other environmental impacts such as undesirable noise, and dustiness - evaluated by points from 0 to 100, higher values are assigned to stronger undesirable impact on the environment [points, minimize].

Strategic (Gx)

- *G1:* Accessibility of the area for the plant measured in points from 0 to 100, higher values express an easier accessibility to the plant [points, maximize].
- *G2:* The level of diversification of energy sources, i.e. the level of increase of various sources - points from 0 to 100 [points, maximize].

Table 1. Data set for the analysis.

Criterion	Measurement unit	Type	Wind	Photovoltaic	Geothermal	Hydro-electric	Biomass
T1	%	max	100.9	9.3	79.9	59.3	85.6
T2	%	min	8.0	9.7	4.0	17.8	14.4
T3	points	max	20	15	30	20	20
T4	points	min	75	40	95	80	60
F1	CZK	max	119.6	1.0	94.7	7.0	366.9
F2	%	max	11.5	8.0	40.7	15.7	30.7
F3	year	min	8.5	8.5	2.5	6.5	3.5
F4	%	max	203.4	152.9	1109.0	215.8	67.1
F5	CZK	max	386.5	28.4	103.7	11.408	86.8
S1	points	max	65	40	75	70	55
S2	points	max	70	80	75	75	55
E1	kg/kWh	max	2.917	0.268	2.310	1.715	2.475
E2	points	min	80	75	50	60	60
E3	points	min	40	25	10	50	40
G1	points	max	40	85	25	40	75
G2	points	max	65	70	90	45	60

A complete data set for the analysis of investments into considered alternative power plants is presented in Table 1. The values in Table 1 are mostly technical or economic parameters that can be exactly measured, or estimations obtained by expert evaluation (data in points).

3. Methodology

MCDM problems can be solved and analyzed in detail using various methodological approaches. The most suitable method for our case study is the AHP. The results of this method are compared with the recommendations obtained by other approaches – TOPSIS and PROMETHEE class methods and weighted sum approach (WSA). In the following sub-sections, the main features of the methods applied in our study are briefly described.

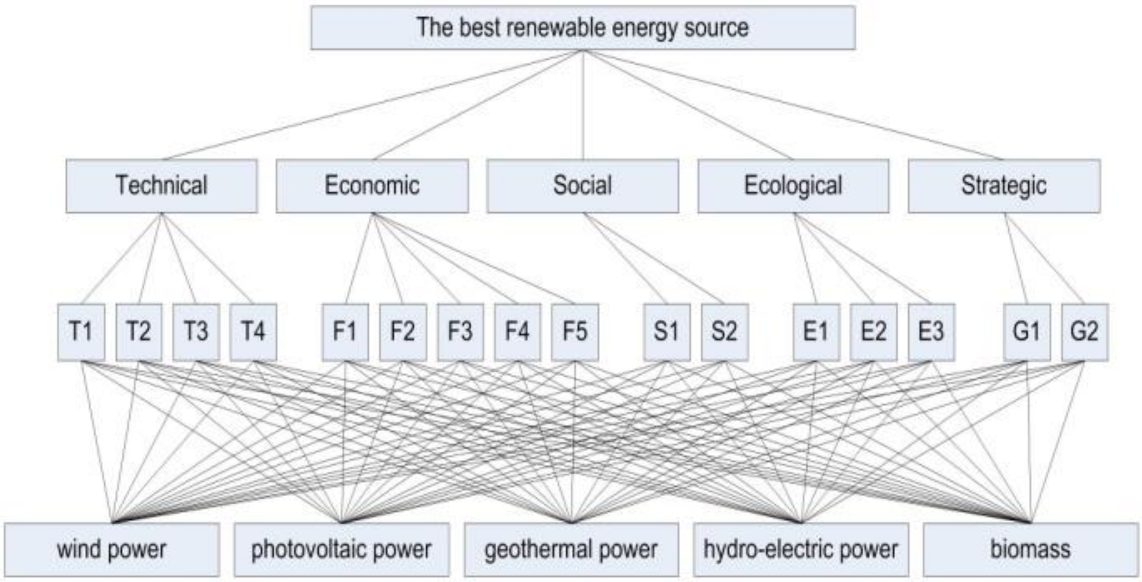

Figure 1. AHP model for evaluation of alternative energy sources.

3.1 Analytic Hierarchy Process

The AHP (Saaty, 1990) is a methodology for solving of MCDM problems. This method uses a tree structure to simplify complex decision-making problems and structure them into several sub-problems that can be solved more easily. Our case can be expressed as a four-level AHP hierarchy, as presented in Figure 1.
The hierarchy in Figure 1 contains four levels:

- *The goal of the evaluation* – analysis of alternative (renewable) energy sources and selection of the best one.
- *Criteria* that have been described in the previous section of the paper.
- *Sub-criteria*, and
- *Alternatives.*

The main principle of the AHP is based on pairwise comparisons of the elements on a particular hierarchy level with respect to an element of the level above. In this way, the importance of the elements on the second level of the hierarchy (weights of the criteria) is derived. Similarly, the importance indices on the third level (weights of the criteria) can be computed. Pairwise comparison of all alternatives with respect to all sub-criteria allows deriving preference indices of the alternatives with respect to all sub-criteria. Finally, their synthesizing leads to deriving of global preferences of all alternatives that allow their ranking.

In each stage of application of AHP model, the decision-maker expresses his/her preferences in the scale from 1 to 9 where 1 means that the *i*-th and the *j*-th element are equally important and 9 means that the *i*-th element is absolutely more important than the *j*-th element, and creates one or several pairwise comparison matrices. Let us denote the pairwise comparison matrix $\mathbf{A} = \{a_{ij} | a_{ji} = 1/a_{ij}, a_{ij} > 0, i, j = 1, ..., k\}$, where k is the number of elements in the particular level of the hierarchy. Saaty (1990) suggests deriving the local priorities v_i, $i = 1, \dots, k$, as the eigenvector belonging to the largest eigenvalue of matrix A. Due to the computational difficulties several approximation methods for deriving priorities are recommended. Logarithmic least square method is the most popular among them.

3.2 Weighted sum approach (WSA)

WSA is one of the methods based on utility functions. Original criterion values y_{ij}, $i = 1, \dots, n$, $j = 1, \dots, k$, where n is the number of alternatives and k the number of criteria, are transformed using linear utility function to r_{ij} values from the interval [0, 1], where 0 corresponds to the worse alternative and 1 to the best one.

The overall utility of an alternative a_i, $i = 1, \dots, n$, is derived easily as the weighted sum of partial utilities, i.e.

$$u(a_i) = \sum_{j=1}^{k} v_j r_{ij}$$

where v_j, $j = 1, \ldots, k$, is the weight of the j-th criterion.

The alternatives can be ranked according to the descending values of overall utilities, and the alternative with the highest value can be considered as the best.

3.3 TOPSIS method

TOPSIS method (Hwang and Yoon, 1981) is based on minimization of the distance from the ideal alternative and maximization of the distance from the basal alternative. The first step of the algorithm is the normalization of the criterion matrix as follows:

$$r_{ij} = \frac{y_{ij}}{\sqrt{\sum_{p=1}^{n} y_{pj}^2}}, i = 1, \ldots, n, \; j = 1, \ldots, k.$$

In the second step, the weighted decision matrix $\mathbf{W} = (w_{ij} = v_j r_{ij}, i = 1, \ldots, n, \mathrm{j} = 1, \ldots, k)$ is calculated. Let H_j is its highest (ideal) value of the j-th criterion over all alternatives, i.e. $H_j = \max_i (w_{ij})$, and similarly, D_j is the lowest (basal) value, i.e. $D_j = \min_i (w_{ij})$. Euclidean distances of all alternatives from ideal and basal values are computed in the following way:

$$d_i^+ = \sqrt{\sum_{j=1}^{k} (w_{ij} - H_j)^2}, \qquad i = 1, \ldots, n,$$

$$d_i^- = \sqrt{\sum_{j=1}^{k} (w_{ij} - D_j)^2} \qquad i = 1, \ldots, n.$$

Finally, the measure

$$c_i = \frac{d_i^-}{d_i^- + d_i^+}, \quad i = 1, \ldots, n,$$

is computed. It is a measure that generates the final ranking of alternatives (higher values are better).

3.4 PROMETHEE class methods

PROMETHEE methods have been introduced by Brans et al. (1986). It is a class of several outranking methods that allow partial or complete ranking of alternatives. These methods compare each pair of alternatives a_i and a_j with respect to each criterion using preference functions. This comparison leads to deriving a level of preference of the alternative a_i over the a_j with respect to the h-th criterion p_{ij}^h (partial preference index) – it is the value from 0 (no preference) to 1 (maximum preference of a_i over a_j). One of the following three relations may occur:

- $p_{ij}^h > 0 \wedge p_{ji}^h = 0$, i.e. a_i is preferred over a_j at a certain level,
- $p_{ij}^h = 0 \wedge p_{ji}^h > 0$, i.e. a_j is preferred over a_i at a certain level,
- $p_{ij}^h = 0 \wedge p_{ji}^h = 0$, i.e. there is indifference between this pair of alternatives.

Depending on the nature of the criterion, the decision-maker chooses for calculation of partial preference indices one of the six types of preference functions and their parameters (usual function, quasi function, linear preference function, level function, linear preference with indifference area function, and Gaussian function). More about these preference functions can be found in (Brans et al., 1986).

The partial preference indices are synthesized using weights of the criteria and global preference indices p_{ij} are defined as follows:

$$p_{ij} = \sum_{h=1}^{k} v_h p_{ij}^h \in [0,1].$$

The higher are the values p_{ij}, $j = 1, \ldots, n$, the better is the alternative a_i evaluated. On the contrary, the higher are the values p_{ij}, $i = 1, \ldots, n$, the worse is the alternative a_j in its evaluation. Therefore, PROMETHEE method computes so-called positive and negative flows. They are defined as the averages of particular row values and column values p_{ij} respectively, i.e.

$$F^+(a_i) = \frac{1}{n-1}\sum_{j=1}^{n} p_{ij},$$

$$F^-(a_j) = \frac{1}{n-1}\sum_{i=1}^{n} p_{ij}.$$

The net flow is defined as the positive minus the negative flow:

$$F(a_i) = F^+(a_i) - F^-(a_i).$$

PROMETHEE I method offers to decision-makers just partial ranking of alternatives. According to this method, the alternative a_i is preferred over the alternative a_j if $F^+(a_i) \geq F^+(a_j)$ and $F^-(a_i) \leq F^-(a_j)$, and there is no equality between both flows. Otherwise, the pair of alternatives is incomparable or indifferent. PROMETHEE II method fully ranks all alternatives according to the values of their net flows.

4. Computational experiments and results

Alternative energy sources can be evaluated in various aspects. The main aim of this study is their evaluation considered the preferences of the investor that has a higher emphasis on economic and technical criteria. Except this, we compare the results of the investor's analysis with the results that have a higher emphasis on ecological and social criteria.

The first step of application of the AHP consists in the estimation of weights of the criteria (second level of the hierarchy – Figure 1). An expert energy investor created the pairwise comparison matrix – it is presented in Table 2. The matrix is consistent – its consistency index is 0.033, which is lower than a threshold value of 0.1. The last column of Table 2 contains weights of the main groups of criteria derived using eigenvalue method. The weight vector is calculated as the right eigenvector belonging to the largest eigenvalue of this matrix.

Table 2. Weights of the main groups of criteria

	Technical	**Economic**	**Social**	**Ecological**	**Strategic**	v_j
Technical	1	1/3	4	4	8	0.2701
Economic	3	1	7	6	9	0.5306
Social	1/4	1/7	1	1	3	0.0806
Ecological	1/4	1/6	1	1	3	0.0831
Strategic	1/8	1/9	1/3	1/3	1	0.0356

Table 3. Weights of the criteria – investor aspect

Main criteria	Weights	Criterion	Weights
Technical	0.2701	T1	0.1480
		T2	0.0573
		T3	0.0224
		T4	0.0424
Economic		F1	0.1523
		F2	0.1327
	0.5306	F3	0.0578
		F4	0.0875
		F5	0.1003
Social	0.0806	S1	0.0135
		S2	0.0671
Ecological		E1	0.0119
	0.0831	E2	0.0356
		E3	0.0356
Strategic	0.0356	G1	0.0305
		G2	0.0051

Similarly, the weights of the groups of criteria are split into sub-criteria. The final results, i.e. the final weights of all sub-criteria with the emphasis on the investor aspect, are included in Table 3.

A similar procedure is applied for estimation of the criteria and sub-criteria weights with the emphasis on the ecological aspect. In this case, the pairwise comparison matrices were created by an expert environmental researcher. Table 4 presents the weights of the main criteria and corresponding sub-criteria.

Table 4. Weights of the criteria – ecological aspect

Main criteria	Weights	Criterion	Weights
Technical	0.0853	T1	0.0467
		T2	0.0181
		T3	0.0071
		T4	0.0134
Economic		F1	0.0152
		F2	0.0133
	0.0530	F3	0.0058
		F4	0.0087
		F5	0.0100
Social	0.2175	S1	0.0363
		S2	0.1812
Ecological		E1	0.0667
	0.4697	E2	0.2015
		E3	0.2015
Strategic	0.1745	G1	0.1495
		G2	0.0250

Tables 3 and 4 contain two sets of weights that are used as inputs for MCDM methods briefly described in the previous section. As mentioned above, four MCDM methods with algorithms based on different principles are applied. AHP requires to construct pairwise comparison matrices that compare each pair of alternatives with respect to a sub-criterion. There is in total 16 sub-criteria, i.e. the decision-maker has to construct 16 matrices of rank 5. It is 160 pairwise comparisons. This process is quite time-demanding, but the method itself is more flexible and accurate than the other ones. WSA and TOPSIS methods do not require any additional information (except weights of the criteria). PROMETHEE II method needs knowledge of one of the six types of preference functions and their parameters for each criterion or sub-criterion. A linear preference function with indifference area for each sub-criterion was chosen. Their parameters have been set after the discussion with experts. The results of the evaluation for both sets of weights (investor and ecological aspect) are presented in Table 5. The utility values obtained by the first three methods (AHP, WSA and TOPSIS) are normalized for better comparability of the results. The values for the PROMETHEE II method in Table 5 are net flows that may be negative. The best alternative(s) identified by all methods are bolded.

Table 5. Results obtained by MCDM methods

Methods	**Wind**	**Photovoltaic**	**Geothermal**	**Hydro-electric**	**Biomass**
investor's point of view					
AHP	0.206	0.124	**0.330**	0.094	0.246
WSA	0.212	0.098	**0.313**	0.122	0.255
TOPSIS	0.237	0.091	0.269	0.108	**0.295**
PROMETHEE	0.099	-0.406	**0.424**	-0.354	0.237
ecological point of view					
AHP	0.142	0.217	**0.315**	0.147	0.179
WSA	0.150	0.206	**0.295**	0.164	0.185
TOPSIS	0.109	0.203	**0.324**	0.157	0.207
PROMETHEE	-0.165	-0.013	**0.353**	-0.151	0.024

All calculations have been performed the specialized software tool for multiple criteria evaluation of alternatives *Sanna* that was developed at the Department of Econometrics, University of Economics, Prague. *Sanna* is an add-in MS Excel application that allows solving problems with up to 200 alternatives and 30 criteria. More information about it can be found in (Jablonsky, 2014).

It is interesting that (almost) all methods lead to identical conclusions, i.e. geothermal power station is the best alternative with respect to both investor and ecological aspects. Only TOSIS method accenting investor preferences prefers biomass power station. The two worse alternatives reflecting more investor aspects are hydro-electric and photovoltaic stations. It is quite surprising because especially photovoltaic power stations are very popular among investors in the real conditions of the Czech Republic. The reason consists probably in an exceptional governmental unacceptable support of this kind of energy in the last years which is not included in the available data set. Ecological point of view prefers geothermal power station – all applied methods identify this option s the best. Different results are obtained on the opposite side of ranking. The two worse power stations with reflecting the ecological aspects are small hydro-electric power stations and wind power parks in this case.

Table 6. Contribution of criteria to the power station – investor aspect

Power station	**Geothermal**	**Biomass**	**Wind**	**Photovoltaic**	**Hydro-electric**
Total evaluation	**32.99%**	**24.54%**	**20.62%**	**12.42%**	**9.37%**
T1	3.30%	3.58%	6.04%	0.48%	1.63%
T2	2.98%	0.37%	1.20%	1.03%	0.22%
T3	1.38%	0.26%	0.26%	0.10%	0.26%
T4	0.18%	0.95%	0.44%	2.36%	0.36%
F1	1.71%	9.71%	2.07%	0.86%	0.86%
F2	7.27%	3.51%	0.80%	0.66%	0.99%
F3	2.78%	1.94%	0.24%	0.24%	0.55%
F4	5.88%	0.70%	0.72%	0.72%	0.72%
F5	1.13%	0.98%	6.60%	0.71%	0.61%
S1	0.52%	0.11%	0.28%	0.04%	0.39%
S2	1.50%	0.22%	0.81%	2.75%	1.50%
E1	0.26%	0.28%	0.48%	0.04%	0.13%
E2	1.75%	0.76%	0.13%	0.19%	0.76%
E3	1.99%	0.30%	0.30%	0.84%	0.16%
G1	0.11%	0.86%	0.19%	1.33%	0.19%
G2	0.25%	0.05%	0.06%	0.07%	0.02%

The obtained results by the AHP method can be analyzed in more detailed. The following analysis considers investor aspects. The percentage contribution of all end-node criteria to each type of power station gained by AHP method is displayed in Table 6. In this table, we can easily find that geothermal power station is the best alternative under nine criteria (T2, T3, F2, F3, F4, S1, E2, E3 and G2). It is strong mainly in financial criteria, especially F2 – internal rate of return with 7.27% and F4 – recovery of investment with 5.88%. However, it is also ecologically accepted concerning criteria E2 – scenery derogation (1.75%) and E3 – other environmental impacts (1.99%).

The second alternative from the investor point of view is surprisingly biomass energy power station. Table 6 shows an explanation. Biomass energy is very well investment taking into account financial criteria, especially F1 – the net present value (9.71% is the best value for all types of power stations) and F2 – internal rate of return (3.51%). It is also good evaluated under T1 – annual utilization of installed output (3.58%), and it is the best alternative concerning ecological criterion E1 – decreasing of carbon dioxide.

The third rank is placed by wind power station that is the best alternative namely in economic criterion F5 – net profit (6.60%) and technical criterion T1 – annual utilization of installed energy output (6.04%). Probably the highest net profit increases the interest of investors in this alternative.

The photovoltaic power stations surprisingly place the fourth rank. The Czech investors choose this alternative in more than 90% cases, and we suppose the photovoltaic power station can be the winner. The data in Table 6 shows that this assumption was mistaken. The photovoltaic power station is the best alternative with regard to T4 – investment costs, S2 – user's comfort and G1 – accessibility of suitable areas criteria. Unfortunately, the rest of the numbers is not as good as we assume. In real investment probably accessibility of suitable areas (for example farmlands in the Czech Republic) is the key feature and the reason for favour of this type of investment.

The last alternative is a small hydro-electric power station – the second often alternative energy source in the Czech Republic. This alternative is not the best-evaluated alternative concerning any criterion. It has only 1.63% for T1 – annual utilization of installed energy output and 1.50% for S2 – user’s comfort. All other values are lower. According to our data set, this alternative is worse without any doubts.

5. Conclusions

Alternative (renewable) energy sources integration may be the critical element of new energy policy not only in the Czech Republic because it improves the stability and reliability of the energy system, minimizes environmental impact and significantly saves sources of limited and not ecological fossil fuels.

The first place of the geothermal power station is not surprising. It has a maximal expected lifetime and also a minimal time of recovery. Also, other economic criteria as the recovery of investment and internal rate of return are the best compared to other sources. Expected dissipation of energy is minimal. Both social criteria are very good evaluated. The environmental impact of geothermal power stations is small because they are placed underground. This power station also increases the number of energy mix sources. The problem with the installation of the geothermal power station is with the accessibility of suitable areas for this kind of energy (G1 criterion). In the Czech Republic, there are minimal accessible, and suitable areas for this kind of renewable energy sources and that is why probably this kind of power stations does not belong to the most significant sources of energy in the Czech Republic in the future.

The primary methodological tool for multiple criteria evaluation of alternatives used in our study is the AHP. The AHP model was applied for the estimation of weights of criteria and finally for ranking of alternatives. The remaining MCDM methods used AHP weights as inputs for their calculation of utilities of alternatives. The results of all methods are comparable even though there are slight differences in the final rankings of alternatives.

Energy policy is a significant strategic issue in all countries. The presented research prove that MCDM methods may be a helpful tool in solving complex decision-making problems. Future research will be focused on the evaluation of various energy strategic decisions and a comparison of their outcomes in EU countries. Future research steps can be extended by other methodological approaches and a more detailed sensitivity analysis of results. One of the research directions consists in application of data envelopment analysis models in analysis of strategic decisions in energy and environment.

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