European Data Quarterly

Zaslavskiy V, Krasovska K, Pasichna M.
European Data Q. 2016; 1(1): 3-20
https://doi.org/10.11610/edq.01101

ISSN

***datajournals.eu*: The European Open Data portal**

Data Paper

Towards the Creation of a Competitive, Diversified Energy Portfolio for Electricity Generating Companies in EU Energy Market Conditions

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ABSTRACT:

Leading electricity generating enterprises in the European Union (EU) diversify their energy portfolio. This study aims to deliver ranking of the set of possible electricity generation sources. The energy sector is one of the sectors of critical infrastructure (CI), and competitive, secure and sustainable delivery of electricity is one of the main objectives of the Energy Community. To achieve this, companies need to prioritise between different electricity generation sources, which is the focus of this paper.

The study utilizes the method of Analytic Hierarchy Process (AHP), which allows explaining which alternative best meets the needs of the companies from both an expert point of view and through the mechanism of quantitative assessment. Moreover, a system of the main factors, which have to be considered when evaluating a choice among electricity sources, is being created. The procedures performed in the study create the basis for analysing the feasibility of using the source of electricity generation for diversification of the energy portfolio at corporate level.

ARTICLE INFO:

Received: 30 Aug 2016
Revised: 05 Nov 2016
Accepted: 10 Dec 2016
Online: 14 Feb 2017

KEYWORDS:

Information Technologies, System Analysis, Decision Making Theory, Analytic Hierarchy Process, AHP, Hierarchy, Electricity Generation Source

Overview

This paper presents a study on the problem of diversification of the energy portfolio at the leading electricity generation enterprises in the European Union through the application of the Method of Analytic Hierarchy Process (AHP) by Thomas Saaty. The energy sector belongs

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to the so-called critical infrastructure (CI), where the economic stability and security of society depend on reliability, safety and efficiency of such systems.[1] The structure of the energy portfolio of the power generating companies is one of the indicators of effectiveness of the critical infrastructure. Depending on the composition of the energy or fuel mix at the level of major energy generation companies, it can be possible to indicate the level of country's dependence on specific fuels, level of technical progress, trends in resource depletion, CO2 and other greenhouse gas (GHG) emissions. On the other hand, the composition of the energy mix allows the companies to understand where they are in the market and what needs to be done.

Given the complexity of CI industry, its study should be carried out meticulously, correctly identifying importance of the criteria, reliability of critical components that ensure its functioning. To assess risks and maintain the security of CI it is necessary to apply the principles of systems analysis, mathematical models and algorithms for qualitative and quantitative assessment of systems efficiency.

The AHP set of tools as multi-factor decision-making process helps to solve such problems. In the field of energy sector, AHP has been used within the context of rational evaluation and basis for fixation of the alternatives in meeting energy demand, taking into account the limited supply.[2]

In recent years, approaches with the application of AHP to the energy sector were considered by a number of researchers. In 2011, much attention was paid to reliability theory and risk analysis, conducting reliability analysis and assessment of risks of energy systems and their components such as thermal power plants or nuclear power plants.[3] In 2015, the attention was focused on the issue of rational placement of CI objects within the task of coherent location of the power stations.[4]

Since the current acute problem of depletion of natural resources is one of the most important issues for energy systems, of increased relevance are studies on the choice among the alternative energy sources and finding new ones. The approaches to planning of the energy supply in the regions using renewable energy sources[5] and the problem of choosing alternative sources using AHP,[6] while addressing the modernization of the national energy system, are currently under research.[7]

Finding a solution on planning of the rational use of natural resources requires a systematic approach, systematization and quantitative assessment in order to obtain a holistic understanding and increase the effectiveness of strategic planning in the energy sector in account of resource constraints.

This article analyzes the problems of rational use of resources in the energy sector, taking into account different types of criteria (economic, technical, social and environmental), and in relation to power generation companies that work with various sources of electricity generation in different EU Member States (France, Germany, Belgium, Italy, Sweden, and Finland). From this point of view the problem of rational use of resources has not been considered yet. This makes the issue of diversification of the portfolio of electricity generation sources relevant. The study applies AHP while choosing the source of electricity generation, followed by numerical calculations.

The research design starts with identification of the goal, criteria and factors, influencing the choice which the energy companies are facing while determining their portfolio of electricity generation sources. Based on that, the hierarchy of the research task is being built. Next, mathematical calculations in order to make ranking and weighting of the elements (sources of electricity generation, criteria of choices among them) are being conducted. At the end, ranking of the electricity sources, which better meet the priorities of both producers and customers, is delivered.

By design, our research utilises both quantitative and qualitative approaches. The qualitative component of AHP is associated with so called "motivation research" aimed at discovering the underlying motives (criteria and factors) of electricity generating companies, which lead to changing the structure of their energy mix portfolio. The quantitative component of the AHP consists in quantification of the relative importance of criteria, factors and alternatives of the hierarchy in a multi-criteria decision problem.

Methods

The research adhered to the following *course of action*:

- Selection of the energy companies to be included in the focus group of the research;
- Identification and selection of electricity generation sources to be considered;
- Identification of the criteria and factors which determine selection of the electricity generation sources at the level of the energy company;
- Applying mathematical methods to classify and rank the electricity generation sources and the criteria influencing them.

Methods of data collection. Library and field methods of data collection were engaged. Whereas the first is based on analysis of the literature and accessible documents, the latter is conducted through the interviews.

Library research covers the review of the literature and reports of the companies which are publicly available. Specifically, the relevant information contained at the official web sites of the companies as well as at such tools, as Science Direct, Web of Science, Google Scholar, etc. were examined. The historical timeframe in the analysis of the trends in power mix portfolios is 2007-2015, which is distinguished by increased attention towards low-carbon economy in the light of the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol and, thus, enhanced focus on the advancements in conventional energy and deployment of renewable energy sources.

Library research covered the following types of sources:

1. Reports on the companies' activities (performance indicators' reports; sustainability, corporate social responsibility (CSR), annual reports; presentations; other) and information published on companies' websites and websites of official conference (if any);
2. Studies related primarily to energy transformation, technological change, sustainable entrepreneurship, innovation systems, diffusion of technologies;
3. Articles published in peer-reviewed journals;
4. Press releases published on companies' websites.

The selection of sources was restricted to studies available in the English, Russian, or Ukrainian languages; and reviewed publications that have an abstract and are available in full text.

Field research was added to test the suitability and completeness of the information summarized from the literature against real practice and trends. The field research (survey of experience) is based on the interviews with representatives of the energy companies – both semi-restrictive, open-ended interviews were conducted and closed, fixed-response questionnaires were filled in.

The interviews were conducted in two stages. First, the importance of criteria and factors through the method of direct assessment was evaluated by the group of experts on a scale from "1" to "5." The experts were also invited to add and/or remove criteria/factors if deemed necessary. Since having too many criteria makes pair-wise comparisons complex and time-consuming, it is desirable to reduce the number of criteria. In this regard, the criteria and factors for the assessment with marks "3" and above have been taken into account.

As a result, the conducted assessment was used to reduce the initial 9 criteria, involving 29 sub-criteria, to 8 criteria and 20 sub-criteria (Table 2). The criterion "specifics of the electricity source" (which comprises such factors as "emission reduction potential of the energy technology," "energy-efficiency potential of the energy technology," and "ability of the energy technology to respond to a peak demand") was considered to be irrelevant.

Second, questionnaires on pair-wise comparisons were prepared to ask the experts to compare the selected criteria. While conducting pairwise comparisons it is necessary to answer the following questions: which of the two compared elements is more important, has a greater impact, is more evident. While comparing the criteria, the expert is usually asked which of them is more important; when comparing alternatives regarding the criteria he or she is usually asked which of the alternatives is better or most likely.

The interviews were conducted in the period from April to August 2015.

Method of data processing. The research applies the AHP Method – mathematical set of tools for system analysis, which is used to solve a variety of decision making challenges. The method was developed at the University of Pennsylvania by the American scientist Thomas Saaty in 1972-1973.[8]

The solution of a research problem requires ranking on a set of options of sources of electricity generation, taking into account the diversity of these elements. The AHP method allows to determine not only the intensity of the action (priority) of specific factor (criterion) on the functioning of the system and ranking of specific optional solutions (alternatives), but also the weight of criteria regardless of their nature. Thus, it is possible to quantify how much each item is more/less important than another one.

It should be noted that the "ideal" option, that is best for all the selected criteria underlying the classical tools for decision making, is difficult to achieve. Therefore, it is necessary to find a compromise among the various hypothetical decisions that must focus on the alternative that is "justified" and can be "non-optimal."[9]

The research procedures included four steps:

Step 1. At this step the main target (ranking of the sources of electricity generation of diversified energy portfolio of the companies), finite set of different types of alternative sources of electricity generation, evaluation criteria of electricity generation sources are defined and a hierarchy of a problem to be solved is constructed.

Let $\mathrm{Z}_1 - \mathrm{Z}_\mathrm{m}$ is a set of alternatives of the sources of electricity generation. In this case, $\mathrm{m} = 7$ and a set of alternatives consists of the elements: coal (Z1), natural gas (Z2), hydropower (Z3), wind power (Z4), solar power (Z5), biomass (Z6), nuclear power (Z7).

Figure 1, based on the existing set of alternatives, criteria and factors, represents the constructed hierarchy, which consists of four levels. Level I − objective: ranking of the sources of electricity generation of diversified energy portfolio of the companies. Level II and level III: criteria and corresponding groups of factors that affect the importance of sources of electricity generation. Level IV: diversified set of alternative sources of electricity generation.

Thus, the objective, a set of alternatives $Z_1 - Z_7$, eight complex diverse criteria $F_1 - F_8$ and 19 parent factors $F_{11} - F_{13}$; $F_{21} - F_{22}$; $F_{31} - F_{32}$; $F_{41} - F_{43}$; $F_{51} - F_{52}$; $F_{61} - F_{62}$; $F_{71} - F_{73}$; $F_{81} - F_{82}$ are defined.

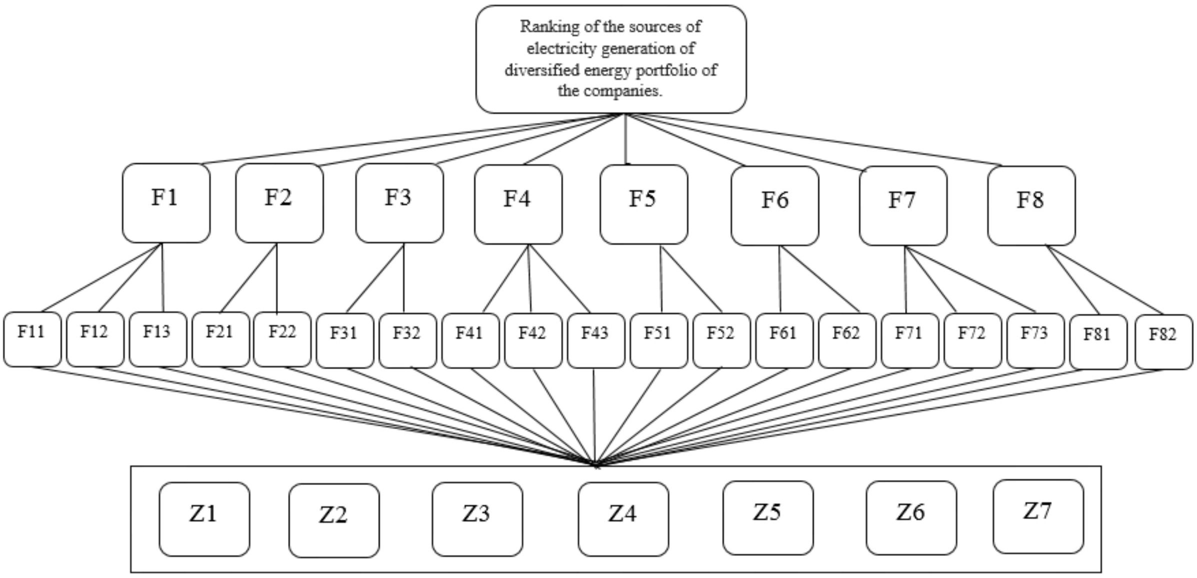

Figure 1: The multi-level hierarchical structure for evaluating sources of electricity generation.

Step 2. At this step AHP requires construction of the matrices of judgments (pair-wise comparisons) and prioritization of all the elements of the hierarchy. Below is a general view of the matrix (1):

$$A = \begin{pmatrix} a_{11} & \dots & a_{1n} \\ \dots & \dots & \dots \\ a_{n1} & \dots & a_{nn} \end{pmatrix} \quad (1)$$

According to AHP, the elements of the matrix A must satisfy the inverse symmetry properties (2):

$$a_{ij} = \frac{1}{a_{ji}}. \quad (2)$$

Diagonal of the matrix consists of 1, thus $a_{11} = 1, a_{22} = 1 \dots a_{nn} = 1$.

To construct the matrices of pair-wise comparisons the method of questionnaires was used. The experts who participated in the study were asked to fill in three forms:

- Pair-wise comparison of complex criteria with relation to the objective;
- Pair-wise comparison of factors with relation to parent criteria;
- Pair-wise comparison of alternatives with relation to factors.

The scores were given by the experts in accordance to well-known AHP scale which allows assessment of the relative importance of the elements of hierarchy.[10]

As a result of the questionnaires 28 matrices of pair-wise comparisons were built (with dimension of $n \times n = 2 \times 2 - 19 \times 19$). Matrix N_0, survey result on the first questionnaire, matrices $N_{F_1} - N_{F_8}$ – second questionnaire, and matrices $N_{F_{11}} - N_{F_{13}}$; $N_{F_{21}} - N_{F_{22}}$; $N_{F_{31}} - N_{F_{32}}$; $N_{F_{41}} - N_{F_{43}}$; $N_{F_{51}} - N_{F_{52}}$; $N_{F_{61}} - N_{F_{62}}$; $N_{F_{71}} - N_{F_{73}}$; $N_{F_{81}} - N_{F_{82}}$ of the third questionnaire respectively that are the evaluation of the method of pair-wise comparisons of alternatives regarding 19 factors with regards to complex criteria.

For example, matrix N_0 is presented in Table 1.

Matrices of judgments to assess the factors and alternatives are constructed similarly.

Table 1. Matrix N_0.

Criteria	F1	F2	F3	F4	F5	F6	F7	F8
F1	1	2	5	1/6	3	2	1/2	1/3
F2	1/2	1	4	1/4	2	2	1/2	1/3
F3	1/5	1/4	1	1/7	1/2	1/4	1/5	1/6
F4	6	4	7	1	6	5	2	1
F5	1/3	1/2	2	1/6	1	1/4	1/5	1/6
F6	1/2	1/2	4	1/5	4	1	1/3	1/5
F7	2	2	5	1/2	5	3	1	1/7
F8	3	3	6	1/2	8	5	7	1

After the pair-wise comparisons are conducted and matrices are built, the vector of local priorities was determined (3). For each matrix of judgments, the normalized vector of local priorities was calculated $a^k = (a_1^k, a_2^k \dots a_n^k), k = \overline{1,28}$ with the following components[11]

$$a_i^k = \sqrt[n]{\prod_{j=1}^{n} a_{ij}}\,, i = \overline{1, n}\,, \tag{3}$$

where n – dimension of matrix; a_{ij} – element of i row of the matrix. Thus, each of the 28 matrices of judgments has a vector $a^k, k = \overline{1,28}$.

Vectors $b^k = (b_1^k, b_2^k \dots b_n^k), k = \overline{1,28}$ – are the results of normalization of the vectors a^k in accordance to formula (4) for each 28 matrices of judgements and represent a contribution (priority) of criteria to achieve the goal:

$$b_i^k = \frac{a_i^k}{\sum_{i=1}^{n} a_i^k}\,, k = \overline{1,28}\,. \tag{4}$$

For each vector b^k there is the following (5):

$$\sum_{i=1}^{n} b_i^k = 1\,, \tag{5}$$

where n – dimension of matrix; b_i^k – component of vector b^k.

Step 3: The idea of this step is to assess the consistency of expert judgments.

After the local vectors of priority are calculated, the consistency of the matrix of judgments should be assessed. Consistency of the matrix in general shows that given the primary data set all other data can be logically deduced from them. The acceptable threshold of consistency is 10 %. If the consistency grade is higher than the threshold, the quality of judgment needs to be improved by testing expert evaluations,[12] specification of the questions which were put for the experts. The consistency assessment shows irrationality of expert judgment, or whether the so called "smoothing" of the judgments that may be accepted or not depending on the conditions of the problem.

In order to calculate the consistency, it is necessary to find the following $\lambda^k_{max}, k = \overline{1{,}28}$ - eigenvalues of the matrices (N_0; $N_{F_1} - N_{F_8}$; $N_{F_{21}} - N_{F_{22}}$; $N_{F_{31}} - N_{F_{32}}$; $N_{F_{41}} - N_{F_{43}}$; $N_{F_{51}} - N_{F_{52}}$; $N_{F_{61}} - N_{F_{62}}$; $N_{F_{71}} - N_{F_{73}}$; $N_{F_{81}} - N_{F_{82}}$), calculated by the formulas (6), (7):

$$\lambda^k_i = \sum_{i=1}^{n} a_{ij} \times b^k_i, k = \overline{1{,}28}, \quad (6)$$

$$\lambda^k_{max} = \sum_{i=1}^{n} \lambda^k_i. \quad (7)$$

To calculate the consistency the RI – values of random index of consistency for random matrix of dimension $n \times n$ (Table 2) are used.

Table 2. Random Index values.

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Consistency ratio in AHP is calculated according to the following formula (8):

$$CR = \frac{CI}{RI}, \quad (8)$$

where CI – consistency index of the matrix to be calculated according to the formula (9):

$$CI = \frac{\lambda^k_{max} - n}{n-1}, k = \overline{1{,}28}, \quad (9)$$

where λ^k_{max} is the maximum eigenvalue of the matrix; n – dimension of matrix.

As mentioned before, if CR ≤ 0,1 (above-mentioned threshold of 10 %), then the value of consistency is considered acceptable; if CR ≥ 0,1, then matrix of judgements is considered inconsistent and the expert judgments should be revised.[13]

Step 4. After checking consistency of the judgment matrix, the synthesis of global priorities is conducted. For obtaining the global priorities of the alternatives the normalized vectors of the matrices of judgments are used and convolution of criteria is done in accordance to the formula (10):

$$b^{Z_m} = \sum_{i=1}^{8} \sum_{j=1}^{19} b^{N_0} \cdot b^{N_{F_i}} \cdot b^{N_{F_{ij}}}, m = \overline{1{,}7}, \quad (10)$$

where b^{Z_m} – vector of priorities of the alternatives; b^{N_0}– normalized vector of priorities of the matrix of judgements against the main objective; $b^{N_{F_i}}$– normalized vector of priorities of the matrix of judgements of the factors against complex criteria; $b^{N_{F_{ij}}}$ – normalized vector of priorities of the matrix of pair-wise comparison of alternatives against factors.

Step 5. The last step consists of the ranking of a set of alternatives. Graphically the AHP process is presented at Figure 2.

Data records

Following the course of actions described above, the following data were collected.

The focus group of the research was represented by eight global energy companies: EDF, RWE, Vattenfall, E.On, GDF Suez, Enel, Iberdrola and Fortum. The most important selective criterion was that the energy companies have energy generation business in European Union Member States. Additionally, the location of the headquarters on the European continent and active position in the area that can depart from at least one of the following: (1) operation in more than one country or even continent; (2) diversified energy mix; (3) referenced in media as leading players in the energy realm.

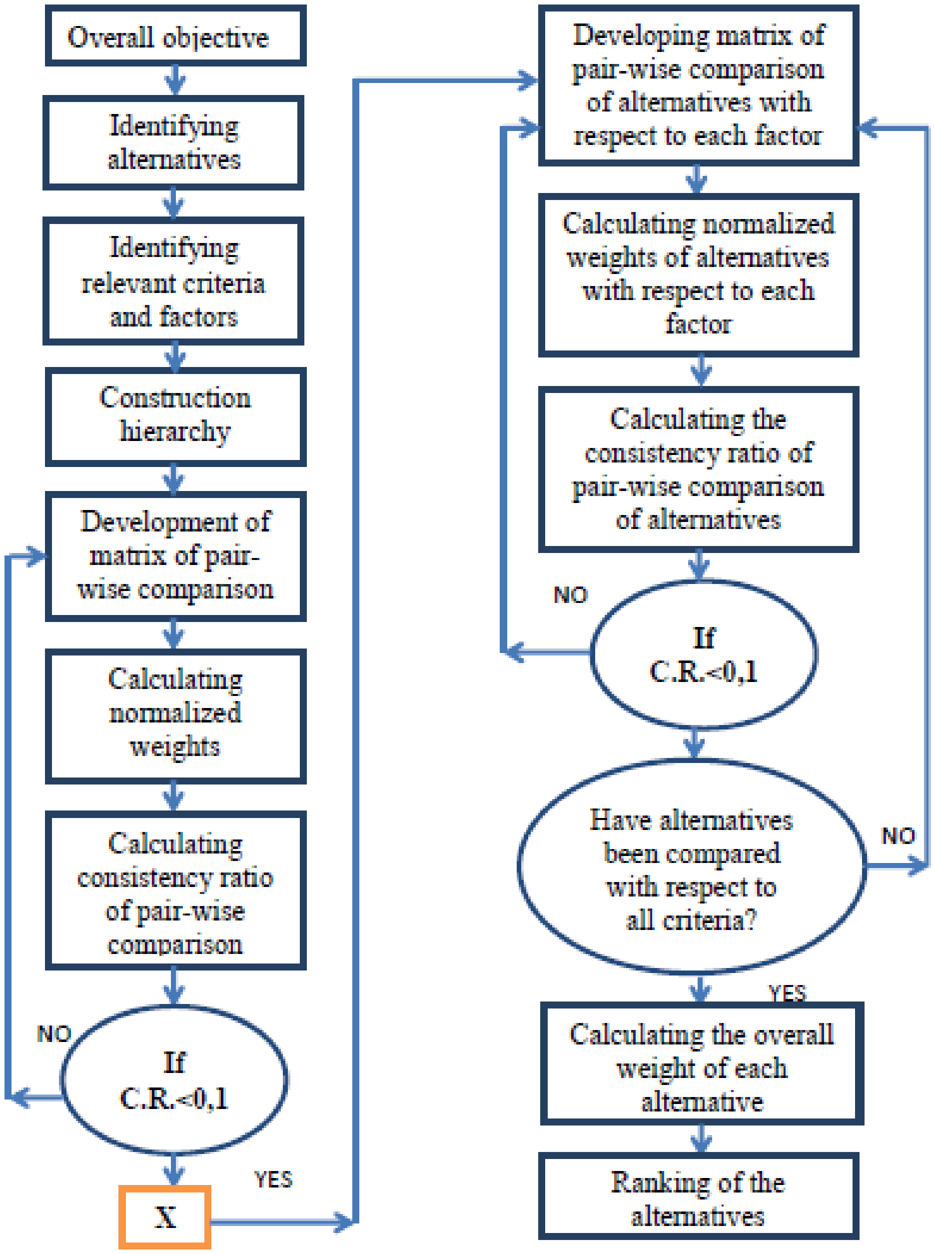

Figure 2: The flow of AHP method (adapted from Mahalingam and Krishnamoorthy[14]).

These companies are among the leading energy generating companies in Europe in accordance to Forbes 2014 ranking,[2] and other sources (Vattenfall Annual Report, 2012: 14[3]; RWE Facts and Figures Report 2015[5]; Thomas, 2007[4]). Together with other utilities, they represent a market share of almost half of the power generation in the EU-27 in 2014.[5]

Seven electricity sources, with which energy companies are primarily dealing, were taken as alternatives for companies' energy mix diversification: coal (lignite), natural gas, hydro, wind, solar, biomass, and nuclear. The share of these sources accounted for 97 percent of electricity production in the EU-27 in 2014.[1]

Based on the literature review with regards to *identification of the criteria and factors*, which drive diversification of the energy generation portfolio at the corporate level, eight criteria, involving 20 factors were identified. Composing a sufficient set of criteria requires choosing the "right" level of details. The criteria selected were based on a general understanding of the trends influencing the development of the energy sources, thus not specifying all the possible considerations which appeared to be relevant to the development of the energy source/technology.

The *experts interviewed* were representatives of the energy companies under examination, who had a long working experience (at least 10 years) in the energy area, and whose positions were among the top-management (board members, directors, managers). The representatives of the energy companies (experts) were contacted using professional-oriented social network (LinkedIn) on a subject of being interviewed with regards to the research questions of the study. Those of them, who agreed to contribute, were interviewed personally. Of the 10 inquiries distributed, three agreed to be interviewed (response rate of 30 %).

Table 2 presents the set of the most important criteria and relative factors that were selected as a result of the expert analysis.

The results of the comparisons from the pair-wise questionnaires were used for creation of the matrices of judgement and relevant calculations following the AHP method of data processing.

The matrices and calculations connected to them are presented by Excel files. The results of the calculations, comprising of the ranking of the criteria, factors and alternatives are presented in Tables 3, 4, and 5, while Table 6 reveals the percentage contribution of each factor to the final ranking of the sources of electricity generation.

Results presented in Table 5 show that the renewables are the highest priority sources of energy for power generation portfolio in terms of the defined criteria and factors. Coal (lignite), natural gas and nuclear energy are placed at the end of the ranking.

Further on these criteria and factors are used in the method of pair-wise comparisons.

Pair-wise comparisons spreadsheets are represented by word files and look like the following (Figure 3).

Table 2. Criteria for evaluation of electricity generation sources and their evaluation.

Criteria and factors		Mark*
Governmental support and regulation in place	**F1**	**4**
Presence of a clear and stable legislation and regulation, aimed at the development or new construction of the power stations	F11	4
Presence of a clear and stable legislation and regulation, aimed at the increase in energy efficiency, emissions reduction and other environmental protection measures	F12	5
Presence of a clear and stable legislation and regulation, aimed at the development or new construction of the power stations and is not limited by environmental protection measures (e.g. biodiversity protection)	F13	3
Stable national economy	**F2**	**4**
Economic growth in the country, characterized by GDP growth, stable electricity prices and stable electricity demand	F21	4
Resistance to high CO_2 and fuel prices (with, at the same time, stable economic situation in the country: GDP growth, stable demand, etc.).	F22	5
Internal policy of the company aimed at diversification of energy portfolio	**F3**	**3**
Ambitious energy efficiency and emission reduction policy of the company	F31	3
Companies are practicing mergers and acquisitions, as well as divestments of the power plants	F32	3
Competitive costs to generate electricity	**F4**	**5**
Relatively low costs of the new technologies for electricity generation	F41	3
Relatively low costs of modernization of existing technologies for electricity generation	F42	3
High profitability of the projects	F43	5
Social acceptance and cooperation with stakeholders	**F5**	**3**
Support of the energy projects by public and NGOs (non-governmental organizations)	F51	3
Cooperation with stakeholders (international organizations, industry, academia, etc.) and different levels of the government	F52	4
Reliable fuel suppliers for electricity generation	**F6**	**4**
Relatively low costs for fuel supply for electricity generation	F61	5
Stable fuel supply for electricity generation	F62	3
Satisfaction of the electricity customers	**F7**	**4**
The source of power generation is known to consumers and meets all the necessary requirements	F71	3
Relatively low price for electricity generated by the energy source	F72	5
Reliable, uninterrupted supply of electricity from the energy source	F73	3
Security and safety of electricity generation	**F8**	**4**
Operation of the power station has strict and unlimited liability in case of accidents or malfunctions of the station	F81	4
The ability to assess the reliability of the power plant (power plant meets all the requirements of safety at work, and its staff is highly qualified and able to assess the possibility of malfunctions / failures)	F82	4

*1- not relevant, 2 – unsatisfactorily, 3 - moderate, 4 - good i 5 – excellent

F82. With regards to the fact, that ability to assess reliability of the plant operation (whether the plant follows all the safety requirements and its personnel has enough experience to evaluate the probability of any breakdown/accident) is important for the energy company, given the current situation, which source of the electricity generation would be more preferable for the company to invest in / develop?

	A	absolute								equivalent								absolute	B
64	Coal&Lignite	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Natural gas (CC)
65	Coal&Lignite	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Large-scale hydro
66	Coal&Lignite	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Wind (mainly on-shore)
67	Coal&Lignite	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Solar (utility scale PV)
68	Coal&Lignite	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Biomass (biomass CHP)
69	Coal&Lignite	9	8	7	6	5	**4**	3	2	1	2	3	4	5	6	7	8	9	Nuclear
70	Natural gas (CC)	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Large-scale hydro
71	Natural gas (CC)	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Wind (mainly on-shore)
72	Natural gas (CC)	9	8	7	6	5	**4**	3	2	1	2	3	4	5	6	7	8	9	Solar (utility scale PV)
73	Natural gas (CC)	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Biomass (biomass CHP)
74	Natural gas (CC)	9	8	7	6	5	**4**	3	2	1	2	3	4	5	6	7	8	9	Nuclear
75	Large-scale hydro	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Wind (mainly on-shore)
76	Large-scale hydro	9	8	7	6	5	**4**	3	2	1	2	3	4	5	6	7	8	9	Solar (utility scale PV)
77	Large-scale hydro	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Biomass (biomass CHP)
78	Large-scale hydro	9	8	7	6	5	**4**	3	2	1	2	3	4	5	6	7	8	9	Nuclear
79	Wind (mainly on-shore)	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Solar(utility scale PV)
80	Wind (mainly on-shore)	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Biomass (biomass CHP)
81	Wind (mainly on-shore)	9	8	7	6	5	**4**	3	2	1	2	3	4	5	6	7	8	9	Nuclear
82	Solar (utility scale PV)	9	8	7	6	5	4	3	2	1	2	3	**4**	5	6	7	8	9	Biomass (biomass CHP)
83	Solar(utility scale PV)	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Nuclear
84	Biomass (biomass CHP)	9	8	7	6	5	**4**	3	2	1	2	3	4	5	6	7	8	9	Nuclear

No	Elaboration on factors of criteria F4
F41	Decisions on investments into new electricity source are driven mainly by the costs of the projects (capital costs, operation and maintenance costs, fuel and CO2 costs, R&D costs, etc.).
F42	Decisions on investments into expansion of the electricity source are driven mainly by the costs of modernization of the existing technologies.
F43	The investment into electricity source generate earnings as compared to its expenses and other relevant costs.

Figure 3: Extracts from a pair-wise survey spreadsheet.

Table 3. Values of priorities of criteria and their ranking.

Criteria	Priority	Rank
F4. Competitive cost to generate electricity	0,2800	1
F8. Security and safety of electricity generation	0,2795	2
F7. Satisfaction of the electricity customers	0,1346	3
F1. Governmental support and regulation in place	0,0978	4
F2. Stable national economy	0,0794	5
F6. Reliable fuel suppliers	0,0674	6
F5. Social acceptance and cooperation with stakeholders	0,0351	7
F3. Internal policy of the company aimed at diversification of energy Portfolio	0,0262	8

Table 4. Values of priorities of the factors and their ranking.

Factors	Global weight	Rank
F81. Operation of the power station has strict and unlimited liability in case of accidents or malfunctions of the station	0,2236	1
F43. High profitability of the projects	0,2026	2
F72. Relatively low price for electricity generated by the energy source	0,0895	3
F12. Presence of a clear and stable legislation and regulation, aimed at the increase in energy efficiency, emissions reduction and other environmental protection measures	0,0606	4
F22. Resistance to high CO_2 and fuel prices (with, at the same time, stable economic situation in the country: GDP growth, stable demand, etc.).	0,0595	5
F61. Relatively low costs for fuel supply for electricity generation	0,0562	6
F82. The ability to assess the reliability of the power plant (power plant meets all the requirements of safety at work, and its staff is highly qualified and able to assess the possibility of malfunctions / failures)	0,0559	7
F41. Relatively low costs of the new technologies for electricity generation	0,0541	8
F71. The source of power generation is known to consumers and meets all the necessary requirements	0,0311	9
F11. Presence of a clear and stable legislation and regulation, aimed at the development or new construction of the power stations	0,0278	10
F52. Cooperation with stakeholders (international organizations, industry, academia, etc.) and different levels of the government	0,0263	11
F42. Relatively low costs of modernization of existing technologies for electricity generation	0,0233	12
F21. Economic growth in the country, characterized by GDP growth, stable electricity prices and stable electricity demand	0,0198	13
F73. Reliable, uninterrupted supply of electricity from the energy source	0,0140	14
F31. Ambitious energy efficiency and emission reduction policy of the company	0,0131	15
F32. Companies are practicing mergers and acquisitions, as well as divestments of the power plants	0,0131	16
F62. Stable fuel supply for electricity generation	0,0112	17
F13. Presence of a clear and stable legislation and regulation, aimed at the development or new construction of the power stations and is not limited by environmental protection measures (e.g. biodiversity protection)	0,0094	18
F51. Support of the energy projects by public and NGOs (non-governmental organizations)	0,0088	19

Table 5. Values and ranking of priorities of the alternatives.

Alternatives	Priority	Rank
Z4. Wind energy	0,1979	1
Z5. Solar energy	0,1785	2
Z3. Hydro energy	0,1643	3
Z6. Biomass energy	0,1634	4
Z1. Coal (lignite)	0,1278	5
Z2. Natural gas	0,1266	6
Z7. Nuclear energy	0,1071	7

Conclusion

Ranking the sources of electricity generation using AHP reveals that the wind energy best meets all the criteria and judgments, and is slightly ahead of solar, hydro and biomass with the rest of electricity sources falling behind (Table 5).

As can be seen from Table 6 in regard to wind and solar energy ranking, the factor of high profitability of the projects (F43), which reached as much as 6 %, was crucial. This is partly a result of the recent cost reductions and efficiency improvements which enabled a great number of onshore wind and PV projects to be built without subsidies. Furthermore, the high ranking of wind and solar energy is a result of the legislation and regulation, which promotes the expansion of existing and building new renewable power plants, advocates energy efficiency, emission reduction and other environmental protection measures.

For hydropower, the most important factor in making investment decisions is the unlimited liability of the power plants in case of accidents or malfunctions (F81 – 3.74 %), the relatively low cost of new technologies (less costly compared to natural gas technologies) with F41 equalling 2.35 %, and resistance to higher prices for carbon and fossil fuels (F22 – 1.25 %).

Biomass CHP ranks fourth mainly due to the high profitability of the projects – particularly in Italy IRR can reach 20 % with an average level of this indicator for biomass projects at the level of 9.7 %.[15] Another factor that is crucial for such projects is the high level of liability of the power stations in case of accidents or malfunctions (F81 – 3.63 %).

F81 ("Operation of the power station has strict and unlimited liability in case of accidents or malfunctions of the station") together with F72 ("Relatively low price for electricity generated by the energy source") result in the highest weights for coal power plants (5.44 % and 3.15 % respectively). However, the coal-based power plants have the lowest weights in such important factors as the profitability of the projects, the cost of new coal technologies, and the existence of legislation and regulation that promotes their development.

Natural gas as a source of electricity generation occupies the next to the last position, mainly as a result of high price of upgrades of gas systems, significant costs for fuel supply, and instability in gas supply.

For nuclear power, which occupies the last position of the ranking, the most important factor in making decisions on its further use is the strict and unlimited liability in case of accidents or malfunctions of the nuclear power station operation, and the low price of electricity generated. Such decisive factors as possibility to assess the reliability of the station (F82), the profitability of projects (F43), support from the government (F11) and general public resulted in low importance (F51), with 0.24 %, 0.58 %, 0.15 % and 0.02 % respectively.

With regards to the eight criteria, shown in Table 3, competitive cost of electricity generation and security and safety of electricity generation are the most important criteria in selecting sources of electricity generation. As the data show, these criteria are twice as important for business than customer satisfaction from the generated electricity – a criterion that takes the third place in the ranking. Regarding the criteria that received low ranks, it should be noted that the internal policy of the company is almost three times less important than support from the government and the economic stability in the country.

With regards to the factors (see Table 4) it becomes evident that for the companies the profitability of the projects appears to be two times more important than the price of electricity charged to the customers and much more important than the costs of electricity generation. This also indicates that the costs of the energy investment projects can be too high and profitability − negligible. This also justifies the importance of governmental support for electricity producers. Going into details, the study shows there can be inconsistencies among the regulation that addresses climate change and the one which has to create favourable conditions for the development of energy technologies. The first is of higher importance for the energy companies.

It is also important to note that factor F21 “Economic growth in the country” got relatively low score and appears to be almost three times less important for the energy utilities than factor F12 “Presence of a clear and stable legislation and regulation, aimed at the increase in energy efficiency, emissions reduction and other environmental protection measures.” This can be explained by the fact that not only economic growth, but also economic recession could lead to the surplus of generation capacity. Thus, the companies have to be careful with such trends as in the long run “excessive” capacities might be closed and the companies would face losses. Companies, therefore, should not take AHP results for granted in longer term, and need take into account for the evolving state of affairs.

Validation

In total 28 matrices were built in the research. They were built upon the expert judgements. To check their consistency, the Consistency Ratio was calculated. Among 36 matrices only one showed the inconsistency – the value of 19,25 given the limit of 0,1. The rest of the matrices appeared to be consistent with CR value of up to 0,1 (0,04; 0,06; 0,07; etc.). To check the inconsistent matrix, the same questions were put to the experts to clarify the pair-wise comparison.

Use and potential reuse

This study was conducted for the energy companies, but the developed alternatives, criteria and AHP hierarchy can be applied to other companies, and the energy system as a whole.

The process of calculations confirms that the presence of too many criteria makes AHP application difficult and time consuming process, thus the tasks require simplification and reduction in the number of criteria is desirable.

Table 6. The percentage contribution of each factor to the final ranking of the sources of electricity generation, %.

Factors	Electricity sources and their weights, %						
	Wind energy, 18,6%	Solar energy, 16,8%	Hydro-energy, 15,4%	Bio-mass energy, 16,34%	Coal/ lignite, 12%	Natural gas, 11,9%	Nuclear energy, 10%
F11. Presence of a clear and stable legislation and regulation, aimed at the development or new construction of the power stations	0,74	0,78	0,18	0,48	0,05	0,24	0,15
F12. Presence of a clear and stable legislation and regulation, aimed at the increase in energy efficiency, emissions reduction and other environmental protection measures	1,62	1,94	0,48	1,02	0,11	0,30	0,21
F13. Presence of a clear and stable legislation and regulation, aimed at the development or new construction of the power stations and is not limited by environmental protection measures (e.g. biodiversity protection)	0,25	0,30	0,07	0,16	0,02	0,05	0,03
F21. Economic growth in the country, characterized by GDP growth, stable electricity prices and stable electricity demand	0,59	0,43	0,18	0,37	0,06	0,18	0,06
F22. Resistance to high CO_2 and fuel prices (with, at the same time, stable economic situation in the country: GDP growth, stable demand, etc.).	1,03	1,03	1,25	1,25	0,19	0,32	0,52
F31. Ambitious energy efficiency and emission reduction policy of the company	0,35	0,42	0,10	0,22	0,02	0,07	0,05
F32. Companies are practicing mergers and acquisitions, as well as divestments of the power plants	0,32	0,37	0,21	0,24	0,03	0,03	0,04
F41. Relatively low costs of the new technologies for electricity generation	1,35	1,19	2,35	1,07	1,14	3,49	0,64
F42. Relatively low costs of modernization of existing technologies for electricity generation	0,57	0,03	0,16	0,31	0,25	0,36	0,50
F43. High profitability of the projects	6,03	4,34	1,87	3,75	0,65	1,79	0,58
F51. Support of the energy projects by public and NGOs (non-governmental organizations)	0,14	0,14	0,36	0,10	0,02	0,05	0,02
F52. Cooperation with stakeholders (international organizations, industry, academia, etc.) and different levels of the government	0,42	0,42	1,07	0,30	0,05	0,15	0,05
F61. Relatively low costs for fuel supply for electricity generation	1,41	1,41	1,41	0,11	0,17	0,14	0,61
F62. Stable fuel supply for electricity generation	0,02	0,02	0,24	0,10	0,29	0,09	0,29
F71. The source of power generation is known to consumers and meets all the necessary requirements	0,60	0,60	0,60	0,60	0,10	0,19	0,21
F72. Relatively low price for electricity generated by the energy source	0,51	0,51	0,51	0,51	3,15	1,75	1,45
F73. Reliable, uninterrupted supply of electricity from the energy source	0,19	0,19	0,19	0,19	0,19	0,19	0,19
F81. Operation of the power station has strict and unlimited liability in case of accidents or malfunctions of the station	0,85	0,85	3,74	3,63	5,44	2,21	4,27
F82. The ability to assess the reliability of the power plant (power plant meets all the requirements of safety at work, and its staff is highly qualified and able to assess the possibility of malfunctions / failures)	0,83	0,42	0,97	0,97	0,83	0,97	0,24

On the other hand, the results generated by the AHP method cannot be taken by granted without accounting for specifics of a situation, for which the study was conducted.

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