AHP-Based Comparative Analysis of Electricity Generating Portfolios for the Companies in EU and Ukraine: Criteria, Reliability, Safety

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Abstract. The article presents a model for evaluating different electricity generating sources at the leading electricity production companies in the EU and Ukraine as well as the main criteria, which have to be considered when taking decisions on diversification of the energy portfolio. The objective of this approach is to improve understanding of how to diversify, and, thus, increase reliability of the energy portfolio in order to follow the process of transformation of the energy sector. The study utilizes the method of Analytic Hierarchy Process (AHP), which allows explaining which energy technology best meets the needs and preferences of the companies from both an expert point of view and through the mechanism of quantitative assessment.

Keywords. Energy Portfolio, Diversification, Reliability, AHP.
Key Terms. Decision Support, Mathematical Modeling, Industry.

1 Introduction

Problem statement. Introduction of innovative energy-generating technologies and the creation of reliable and secure structure of electricity generation are based on diversification of the energy portfolio (mix), that is the structure of electricity generation broken down by fuel type. The deficiencies in analyzing energy portfolio, which is supposed to contain both conventional and renewable energy sources (RES), can delay the development of countries and regions.

The European Union (EU), whose share in the global demand for energy accounts for almost 14% [1], is one of the main participants in the transformation of the global energy system. For Ukraine, as one of major strategic partners of the EU, modernization of its energy industry is one of the key measures to reduce vulnerability in energy supply.

Given that energy supply system refers to the critical infrastructure (CI) [2,3], Ukraine should have a thorough understanding of the European practices of its protection and reliability, as the threat to its functioning is a threat to national security.

The article presents a model for evaluating different electricity generating sources (technologies) within the energy portfolios of the leading electricity production companies in EU and Ukraine. Understanding of these trends would contribute to an optimal trade-off between different energy technologies or creation of an optimal electricity generation portfolio, aimed to maximize the value of the portfolio, e.g. ensure energy security and minimize its environmental footprint.

Literature review. Given that energy planning is to be delivered as finding the optimal solutions based on several (either conflicting or synergetic) criteria and under certain restrictions, Multi-Criteria Decision Making (MCDM) techniques are very popular. These days the combinations of different methods are gaining popularity. In 2015 the research utilizing MESSAGE model combined with Multi-Criteria Model Analysis (computing a Pareto-efficient solution) was conducted to assess the role of nuclear power against seven criteria [4]. In 2016 there was a study on a grey based MCDM for the evaluation (not planning) of the RES for Turkey which integrates three MCDM methods - Decision Making Trial and Evaluation Laboratory, Analytic Network Process and Multi-Criteria Optimization and Compromise Solution [5].

AHP is one of the most popular set of MCDM tools. In 2014-2016 AHP was applied for conducting the reliability and risk assessment analysis of energy systems and their components at the nuclear power plants [6,7]. In 2015-2016, there were researches on the rational choice for the location of power stations [8,9,10]. The problem of choosing an alternative electricity generation source and ensuring economic security of energy enterprises through AHP application while addressing the modernization of Ukraine's energy system are currently under research [11,12].

Novelty and future use of the research. Although the use of AHP is not new, the comparison of its application to both EU and Ukrainian energy generation systems has not been covered before. The findings of the research can be used by electricity utilities in other countries and/or regions while taking decisions on the energy portfolio, by the governments while developing energy and environmental strategies.

The paper is organized into three sections, elaborating on methods of the research, its results and conclusions.

2 Application of AHP for Evaluation of the Electricity Generating Sources

A general description of AHP model. The AHP model by T. Saaty [13] has been applied. Its course of action contains the following: 1. Formulation of the problem – weighting and ranking of the electricity generating sources of diversified energy portfolio of the companies; 2. Selection of electricity generating sources to be considered as alternatives or focus of the research; 3. Identification of the criteria and factors which determine selection of the electricity generation sources at the level of the energy company; 4. Construction of AHP hierarchy and evaluation of its components.

Methods of data collection. Library and field methods of data collection were engaged. Whereas the first is based on analysis of the relevant academic literature and companies' annual, financial and Corporate Social Responsibility (CSR) reports, the latter is conducted through expert interviews.

The reports (that cover the period 2007-15) from eight leading EU electricity production companies and one leading Ukrainian energy company were considered. The energy experts interviewed were from three leading EU energy companies (and different countries) and one from the leading energy company in Ukraine; they were senior level managers with engineering degree and from 15 to 30 years of experience in energy area. Semi-restrictive, open-ended interviews were conducted and closed, fixed-response questionnaires were filled in. The interviews were conducted in the period from April 2015 to March 2017.

Seven electricity generating sources were considered, which are responsible for 97% of generated electricity in EU-27 in 2014 [14]. 8 assessment criteria and 19 relevant factors were determined to make evaluation of the electricity sources.

To sum up, Table 1 below presents which data from the literature, company reports and surveys were necessary for application AHP in accordance with T. Saaty for evaluation of the electricity generating sources and how it was collected.

Table 1. Input data required for AHP application and sources of these data

Input data	Source
List of criteria, factors and alternatives for AHP hierarchy	See references [15,16,17,18]; Annual, financial and sustainability reports of the companies for 2007-2015 [19,20,21,22,23, 24,25,26]; Information from the interviews
Pair-wise comparison values for AHP	Assessment by energy experts
RI values	Values from [13]

Data processing. The constructed by authors (and in accordance to T. Saaty) AHP hierarchy (Fig. 1) consists of four levels (top to down): 1. Objective; 2. Criteria ($F_1 - F_8$); 3. Criteria-relative factors ($F_{11} - F_{82}$). 4. Sources of electricity generation or alternatives ($Z_1 - Z_7$).
Given that $\mathrm{Z}_1 - \mathrm{Z}_m$ – a set of alternatives, $m = 7,$ consisting of: coal (Z_1), natural gas (Z_2), hydro-energy (Z_3), wind energy (Z_4), solar energy (Z_5), biomass energy (Z_6), and nuclear energy (Z_7). And given that $\mathrm{F}_1 - \mathrm{F}_8$ are eight complex multi-type criteria and $\mathrm{F}_{11} - \mathrm{F}_{13};\ \mathrm{F}_{21} - \mathrm{F}_{22};\ \mathrm{F}_{31} - \mathrm{F}_{32};\ \mathrm{F}_{41} - \mathrm{F}_{43};\ \mathrm{F}_{51} - \mathrm{F}_{52};\ \mathrm{F}_{61} - \mathrm{F}_{62};\ \mathrm{F}_{71} - \mathrm{F}_{73};\ \mathrm{F}_{81} - \mathrm{F}_{82}$ are their 19 parent factors then AHP is presented by a set of the following equations - *matrix* A *of paired-wise comparisons*:

$$A^k = \begin{pmatrix} a_{11}^k & \dots & a_{1n}^k \\ \dots & \dots & \dots \\ a_{n1}^k & \dots & a_{nn}^k \end{pmatrix}, \qquad (1)$$

where k – number of matrix, $k = \overline{1{,}28}$ *;*

calculation of vector of local priorities:

$$\mathrm{a}_\mathrm{i}^\mathrm{k} = \sqrt[\mathrm{n}]{\prod_{\mathrm{j}=1}^{\mathrm{n}} \mathrm{a}_{\mathrm{ij}}}\,,\ \mathrm{i} = \overline{1, \mathrm{n}}, \qquad (2)$$

calculation of b_i^k *- normalized vector of* $\mathrm{a}_\mathrm{i}^\mathrm{k}$*:*

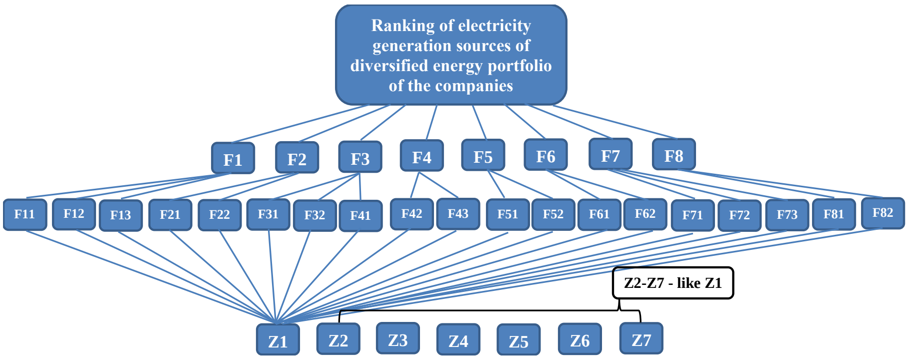


Fig. 1. The multi-level hierarchical structure for evaluating electricity generation sources

$$b_i^k = \frac{a_i^k}{\sum_{i=1}^n a_i^k}; \quad \sum_{i=1}^n b_i^k = 1, \tag{3}$$

calculation of $\lambda_{\max}^{k}$ - *eigenvalue of matrices:*

$$\lambda_{\max}^{k} = \sum_{i=1}^{n} \lambda_i^k; \; \lambda_i^k = \sum_{j=1}^{n} a_{ij}^k b_j^k, \tag{4}$$

checking CR *- consistency of matrices* ($\leq 0{,}1$)*:*

$$CI = \frac{\lambda_{\max}^{k} - n}{n-1}; \qquad CR = \frac{CI}{RI}, \tag{5}$$

where CI- consistency index of the matrix; RI – values of random index of consistency for random matrix of dimension $n \times n$ [13].

calculation of b^{Z_m}*- global priority vectors of the alternatives*:

$$b^{Z_m} = \sum_{i=1}^{8} \sum_{j=1}^{19} b^{N_0} \cdot b^{N_{F_i}} \cdot b^{N_{F_{ij}}}, m = \overline{1{,}7}, \tag{6}$$

where 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.

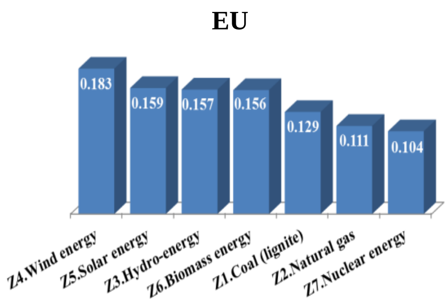
3 Results of AHP Application to Evaluate Electricity Sources

Ranking of criteria, factors and alternatives. Conducted interviews and matrix calculations derived from the constructed AHP hierarchy have provided the following set and rankings of criteria, its relative factors and alternatives (Table 2, Fig.2-5).

From Table 2 the visible differences are observed within the prioritization of the factors of criteria F1, F4, F6-F8. It reveals that EU company has long-term outlook for its generation capacity and Ukrainian company is more interested in short-term developments (e.g. whereas EU company prioritizes low-cost new technologies, Ukraine company prefers low-cost modernization of the existing capacities).

Table 2. Criteria and factors for evaluation of electricity generating sources; ranking of 19 factors (ranked "1" is the most important) for EU and Ukraine's (UA) companies

Criteria and factors	Ranking	
	EU	UA
F1.Clear and stable governmental support and regulation in place:		
F11.Lgislation and regulation, aimed at the development or new construction of the power stations	10	3
F12.Lgislation and regulation, aimed at the energy efficiency, emissions reduction and environmental protection	4	10
F13.Legislation and regulation, aimed at the development or new construction of the power stations and is not limited by environmental protection measures	18	15
F2.Stable national economy:		
F21.Economic growth in the country, characterized by GDP growth, stable electricity prices and stable electricity demand	13	7
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.).	5	6
F3.Internal policy of the company aimed at portfolio diversification:		
F31.Ambitious energy efficiency and emission reduction policy	15	8
F32.Practice on mergers and acquisitions, divestments of the power plants	16	16
F4.Competitive costs to generate electricity:		
F41.Relatively low costs of the new energy technologies	8	12
F42.Relatively low costs of modernization of existing energy technologies	12	5
F43.High profitability of the projects	2	1
F5.Social acceptance and cooperation with stakeholders:		
F51.Support of the energy projects by public and NGOs (non-governmental organizations)	19	18
F52.Cooperation with stakeholders (international organizations, industry, academia, etc.) and different levels of the government	11	13
F6.Reliable fuel suppliers for electricity generation:		
F61.Relatively low costs for fuel supply for electricity generation	6	11
F62.Stable fuel supply for electricity generation	17	4
F7.Satisfaction of the electricity customers:		
F71.Electricity source is known to consumers and meets their requirements	9	19
F72.Relatively low price for generated electricity	3	14
F73.Reliable, uninterrupted supply of electricity	14	17
F8.Security and safety of electricity generation:		
F81.Operation of the power station has strict and unlimited liability in case of accidents or malfunctions	1	9
F82.The ability to assess the reliability of the power plant (power plant meets all the requirements of safety at work, its staff is highly qualified and able to assess the possibility of malfunctions / failures)	7	2



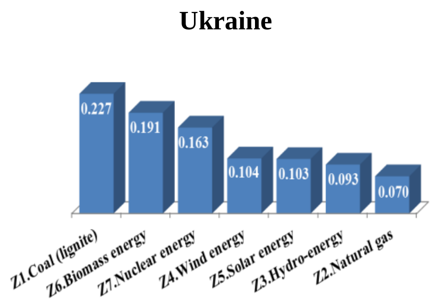


Fig. 2. Weights and ranking of alternatives for energy company

Fig. 3. Weights and ranking of alternatives for energy company

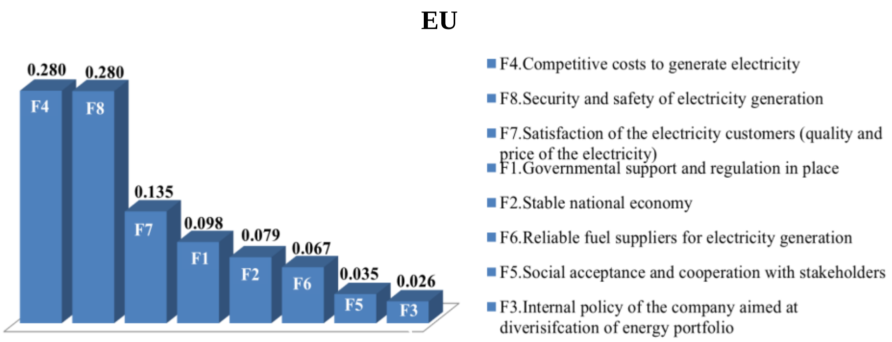


Fig. 4. Weights and ranking of criteria for energy company

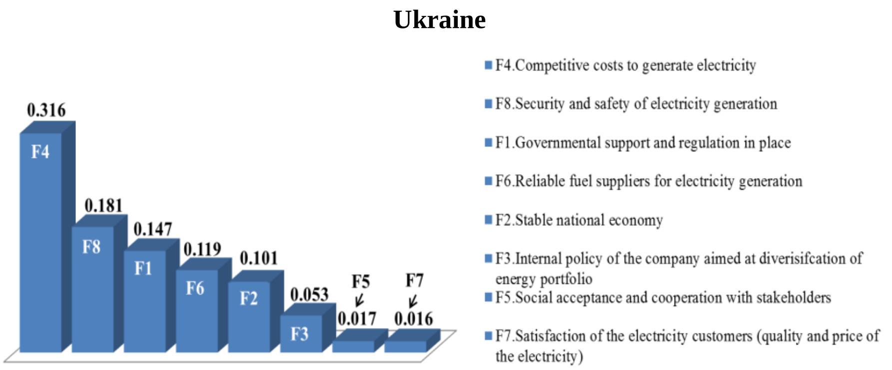


Fig. 5. Weights and ranking of criteria for energy company

Ranking for the electricity generation sources indicate that RES have the highest value for the portfolio within EU with nuclear energy and natural gas taking the last positions (Fig. 2). By contrast, for Ukraine coal, biomass and uranium have the highest priority, leaving the RES and natural gas far behind (Fig. 3).

For both EU and Ukraine's energy company the cost and safety of electricity generation are the most important criteria in selecting sources of electricity generation (Fig. 4-5). Whereas for the EU these two criteria are equally important, for Ukraine the cost is twice as important as security and safety of electricity generation. For the EU company "the satisfaction of the customers" is the third important criterion, for Ukraine company this criterion is ranked the last. Support from the state and the economic stability are in the middle of the ranking for both regions with the governmental support being more important than the economic stability.

Discussions on improving reliability and safety through diversity. The abovementioned set of criteria and factors are aimed to account for different aspects of delivering a common goal - electricity product of the company. Since it is usually argued that different components in a system improve its redundancy and reliability, thus avoiding common-cause failure, it is important to understand the optimal diversity of the components, e.g. to what extent the diversity should be integrated into energy portfolio and for which companies and/or countries it can be beneficial.

On the other hand the "optimal" energy portfolio is a complex issue as it is mainly driven by the electricity production costs over the timeframe. Thus, it should be a clear understanding of the implications of reliance on alternative energy sources and whether there is a fuel diversity and not the diversity of the attributes inherent in usage of specific fuel that improves reliability and safety of electricity generation.

4 Conclusions

The presented model shows the prioritization of the electricity generation sources against different aspects of portfolio decision process. Comparison of two regions – EU and Ukraine - reveals a number of differences in decision making process at the corporate level. This can be explained by slow path of energy reforms in Ukraine, presence of ineffective state-owned enterprises, low level of competition and energy services for the consumers, etc.

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. It is recommended to make an insight into the optimal level of diversity within energy portfolio, e.g. the optimal shares of different electricity generation sources.

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