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Research Article

System Approach Towards the Creation of Secure and Resilient Information Technologies in the Energy Sector

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ABSTRACT:

As the nexus between sustainability, economic efficiency and energy security becomes closer, the creation of reliable and accessible power systems becomes critical. This study seeks to find, analyse and synthesize information from various sources to assess the structure of electricity generation in order to create information technology for diversification and optimization of the energy portfolio/mix. This is essential in order to ensure electricity supply (generation) stability and reliability, guarantee power quality for the end users of electricity. With the goal of optimising and managing the structure of electricity generation mix for electricity providers, our research focuses on combining different electricity generation technologies, maximising the value of the portfolio, e.g. ensuring energy security, and minimising the portfolio's environmental footprint. One of the major findings is that the most effective and optimal scenario for energy mix development does not always coincide with the policies of the governments and companies' strategies. The paper presents also the difference between the current and future optimal mix.

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Introduction

The development of smart power systems is aimed at providing resilience, reliability, stability, and security of power supply. This is challenged by complexity of the power systems, aging of the equipment fleet coincided with a rapid introduction of the innovative energy technologies, activities on modernization/automation of the technical processes, etc. All this represents a decision-making process within multiple tasks, insufficient structuring and increasing volume of input data, need for considering potential cyber threats and addressing cybersecurity.[1]

Since the energy enterprises belong to critical infrastructure (CI),[2] innovative applications of information technology to support and monitor their sustainability and manageability are key to economic stability and national security of the country.

Thus, creating an effective energy mix – the structure of electricity generation capacity of the power plants (i.e. distribution (diversification) of generation capacities (GCs) by types of technologies for producing electricity) - is a central issue for governments of the countries. Accordingly, a number of tasks that need to be solved to provide the process of automation of the intellectual decision-making process for the generation of electricity are currently in the focus.

The purpose of this article is to study the peculiarities of the creation of information technology (IT) of decision support to the optimization of the electricity generation capacities of the energy companies. The IT is intended to facilitate the assessment of the electricity generation capacities of the power stations through systematization, formalization and consistent aggregation of information about their operation.

Despite the vast amount of research, the use of IT in relation to strategic planning of the structure of generation capacities is not sufficiently covered. IT for the optimization tasks in the energy industry started to develop in the late 60s of the last century, when there were created a number of high-level modelling systems, model generators, optimization and simulation software tools. Given that modern versions of these software tools have a predominantly macroeconomic approach, the representation of the energy sector in them is simplified and data input is not flexible.[3, 4]

Smart grid technology promoted development of the new approaches to manage diverse energy resources in a safe and efficient manner. Current research seeks to solve non-formalized and weakly structured problems in the energy sector. Given the limitations of resources and unstable energy market, this would help to understand to what degree electricity generating companies are able to achieve their goals while identifying crucial cases for power system stability.

The research is based on the combination of widely-used approaches for the optimization of electricity generation structure such as Multi-Criteria Decision Making (MCDM) techniques,[5, 6] Markowitz Mean-Variance Portfolio (MVP) analysis,[7, 8] risks level evaluation and application of integrated, scenario-based modelling LEAP (Long-range Energy Alternatives Planning System) [9] into a single information technology. That was not widely applied in the previous research. Another distinction of the current study is that it focuses not on one but different countries and companies.[10, 11] The current research builds on findings presented previously.[12, 13]

Methods

The model of the study comprises of the following four components. First, given the importance of choosing (giving priority) to the most appropriate energy technology, which is determined by a set of certain factors and conditions, the approach of multi-criteria decision-making is applied. Given the need to balance the advantages and disadvantages of using a particular set / configuration of energy technologies the modern portfolio theory (MPT) is considered. Since MPT takes into account mainly financial risks and in practice there is a need to re-evaluate the composition of the energy portfolio in terms of other possible dangers, an assessment of the strategic alignment of the energy portfolio is carried out. Additionally, the analysis of the risks inherent in various sources of electricity generation and their possible impact is studied. Finally, the study applies LEAP within the strategic planning of an optimal diversified electricity generation mix.

The research presents analysis of the development and optimization of the current energy generation mixes for Ukraine and seven EU member states (Germany, France, Belgium, Italy, Spain, Sweden and Finland). The selection of EU countries is justified by the fact that they are headquarters to the leading EU energy companies and their energy policies have impact on the global energy market.

The general scheme of information technology for diversification and optimization of the structure of generation capacities can be represented through the following context diagram (Fig. 1).

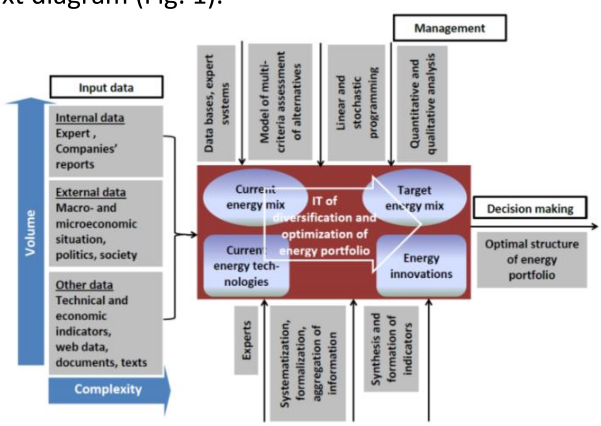

Figure 1: Conceptual structure of information technology components for diversification and optimization of the electricity generation structure.

The general scheme of algorithms for solving problems and procedures for diversifying and optimizing the structure of electricity generation capacities is as follows (Fig. 2).

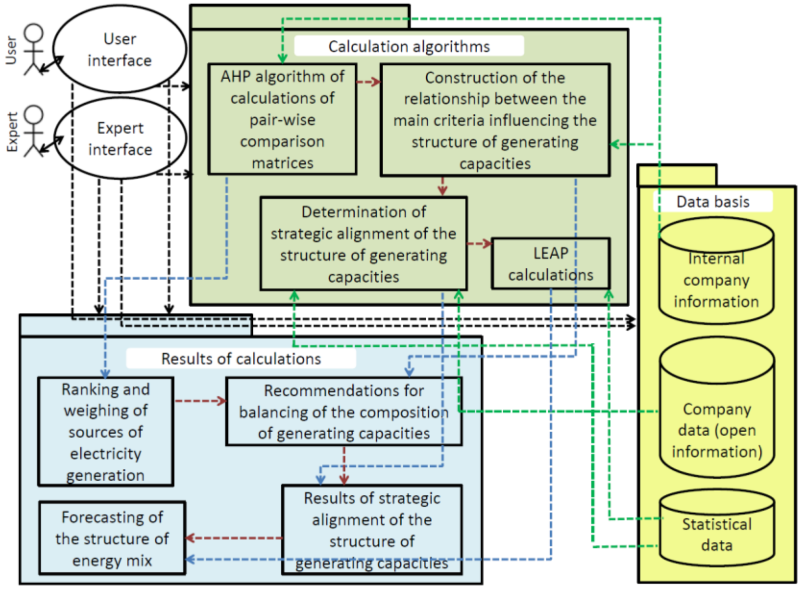

Figure 2: Software architecture for diversification and optimization of electricity generation structure.

The first component of the proposed IT – AHP (analytical hierarchy process) [6] – is based on subjective expert assessments about the criteria and factors that are crucial for energy companies in choosing the technologies (alternatives) for generation electricity. Based on the existing set of alternatives, criteria and factors, a hierarchy is constructed and appropriate calculations are carried out to evaluate elements of the hierarchy.

The purpose of the AHP hierarchy (Fig. 3) is the ranking of sources of electricity generation (the first level of the hierarchy), influenced by a number of criteria $F_1 - F_8$ and their corresponding groups of factors $F_{11} - F_{82}$ (second and third level of the hierarchy, respectively). The number of sources of electricity generation $Z_1 - Z_7$ (alternatives to the hierarchy) is the fourth level of the hierarchy.

Let $Z_1 - Z_m$ be the set of alternative variants of power generation sources $(m = 7)$, which consists of elements: coal (Z_1), natural gas (Z_2), hydropower (Z_3), wind energy (Z_4), solar energy (Z_5), biomass use (Z_6), nuclear energy (Z_7). Let $F_1 - F_8$ - 8 complex multi-type criteria and $F_{11} - F_{13}$; $F_{21} - F_{22}$; $F_{31} - F_{32}$; $F_{41} - F_{43}$; $F_{51} - F_{52}$; $F_{61} - F_{62}$; $F_{71} - F_{73}$; $F_{81} - F_{82}$ – are 19 relevant

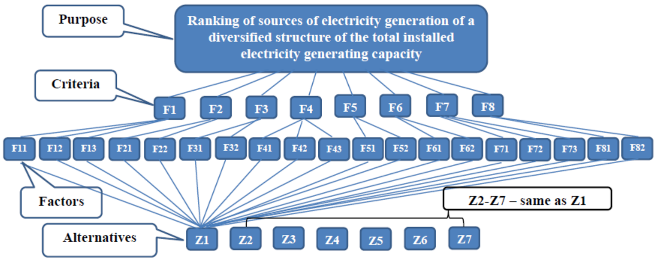

Figure 3: The multi-level hierarchical structure for evaluating electricity generation sources.

factors influencing decision-making in companies regarding the set of alternatives. Thus, the task of AHP is described by the system of the following equations - a matrix of pair-wise comparisons of general form:

$$A^k = \begin{pmatrix} a^k{}_{11} & \dots & a^k{}_{1n} \\ \dots & \dots & \dots \\ a^k{}_{n1} & \dots & a^k{}_{nn} \end{pmatrix}, \tag{1}$$

in which the elements of the matrix A^k must satisfy the properties of the inverse symmetry $a_{ij} = \frac{1}{a_{ji}}$, and on the diagonal of the matrix there are 1.

For each matrix of judgments, it is determined the normalized vector of local priorities $a^k_{norm} = (a^k_1, a^k_2 \dots a^k_n),\ k = \overline{1,28}$ which is calculated by three known methods, such as: (a) the method of the priority vector:

$$A^k a^k_{norm} = \lambda^k_{max} a^k_{norm}, \tag{2}$$

where $\lambda^k_{max}$is the maximal Eigen value of the matrix A^k;

(b) the method of the average geometric element of each of the rows of the matrix A^k:

$$a^k_{norm\_i} = \frac{\sqrt[n]{\prod_{j=1}^n a^k_{ij}}}{\sum_l^n(\sqrt[n]{\prod_{j=1}^n a^k_{lj}})},\ i = \overline{1,n}\,, \tag{3}$$

(c) the method of averaging over normalized columns of the matrix A^k:

$$a^k_{norm\_ij} = \frac{a^k_{ij}}{\sum_{l=1}^n a^k_{lj}},\ a^k_{norm\_i} = \frac{\sum_{j=1}^n a^k_{norm\_ij}}{n}, \tag{4}$$

Normalized vectors of judgment matrix were calculated for obtaining global alternatives priorities:

$$b^{Z_m} = \sum_{i=1}^{8} \sum_{j=1}^{19} b^{N_0} \cdot b^{N_{F_i}} \cdot b^{N_{F_{ij}}}, m = \overline{1,7}\,, \qquad (5)$$

where n – dimension of the matrix; a_{ij}^k – element of i raw of the matrix (each of the matrices of pair-wise comparisons corresponds to the vector $a^k, k = \overline{1,28}$); b^{Z_m} – vector of alternative priorities; b^{N_0}– a normalized vector of priorities of pair-wise comparisons matrix relative to the main goal; $b^{N_{F_i}}$ - normalized vector of priorities of pair-wise comparisons matrix of factors with respect to complex criteria; $b^{N_{F_{ij}}}$ – the normalized vector of the priorities of matrix of pair-wise comparisons of alternatives with respect to the factors. The matrix consistency estimation was calculated as:

$$CR = \frac{CI}{RI}, \qquad (6)$$

where CI – index of matrix coherence, which is determined as:

$$CI = \frac{\lambda_{max}^k - n}{n-1}, k = \overline{1,28}, \qquad (7)$$

RI - estimate of random coincidence for a random matrix of dimension $n \times n$. The calculations were carried out using matrix algebra and developed software in the MATLAB environment.

With regards to the second component of the proposed IT the task for balancing of the structure of electricity generation is formulated. Taking into account Markowitz modern portfolio theory and the peculiarities of its application to the electricity generation sector, an assessment of the structure of generation capacities is being studied. It searches for such a set of electricity generation structure that is able to provide the lowest level of risk (or fluctuation of generation costs) for the specified return level (or electricity output per unit of cost) or maximize the expected return at an acceptable level of risk.

For this purpose, an analysis of the structure of electricity generation capacities was carried out within the quadratic optimization problem under linear constraints, and an efficiency frontier (EF), indicating the Sharpe ration, was constructed.

This modelling is defined by the following main variables: (a) expected electricity generation portfolio return:

$$E_{R_p} = \sum_{i=1}^{m} w_i E_{R_i}, \qquad (8)$$

where m - the set of alternative variants of power generation sources ($\mathrm{m} = 7$); (b) standard deviation (σ_ρ), or aggregate risk of the electricity generation portfolio:

$$E_{\sigma_p} = \sqrt{\sum_{i=1}^{m} w_i^2 \sigma_i^2 + 2\sum_{i=1}^{m-1}\sum_{j=i+1}^{m} w_i w_j \sigma_i \sigma_j \rho_{ij}}, \tag{9}$$

where w_i – share of i-th sources of electricity generation in the structure of generating capacityi; E_{R_i} - expected returns of the i-th source of electricity generation (the physical output of the electricity per unit of value); σ_i and σ_j - standard deviations in the costs of electricity generation by i-th and j-th sources of electricity generation respectively; ρ_{ij} - correlation coefficient (takes values from -1 to +1). Sharpe ration is calculated as:

$$\frac{E_{R_p} - r_0}{E_{\sigma_p}}, \tag{10}$$

where r_0- no risk factor. At the same time, the optimization problem is as follows:

$$\begin{gathered} \min E_{\sigma_p} = \sqrt{\sum_{i=1}^{m} w_i^2 \sigma_i^2 + 2\sum_{i=1}^{m-1}\sum_{j=i+1}^{m} w_i w_j \sigma_i \sigma_j \rho_{ij}}, \\ \sum_{i=1}^{n} w_i = 1, \\ w_i \geq 0, \\ i = 1, \ldots, n, \end{gathered} \tag{11}$$

and

$$\begin{gathered} \max E_{R_p} = \sum_{i=1}^{m} w_i E_{R_i}, \\ \sigma_p^2 = \sum_{i=1}^{n}\sum_{j=1}^{n} w_i w_j \sigma_{ij} \leq \sigma^2, \\ \sum_{i=1}^{n} w_i = 1, \\ w_i \geq 0, \\ i = 1, \ldots, n, \end{gathered} \tag{12}$$

The calculations were carried out using matrix algebra and developed software in the MATLAB environment.

In the third component of the suggested IT in order to explore the strategic alignment of the energy companies it is analysed how changes in their electricity generation capacity reflect the goals stated in the strategies of the companies. At the same time, taking into account a variety of different types of risks inherent in different sources of electricity generation, their classification is constructed and the absolute magnitude of the risk (absolute loss level) for each source of electricity generation Z_m $(m = 7)$ is calculated:

$$W_m = p_m x_m, \quad (13)$$

where p_m and x_m - probability of occurrence of the event of losses and the size of possible damage from it, respectively.

The model analysis in LEAP (fourth component of the IT) has been built around a series of integrated modules, namely Key Assumptions, Demand, Transformation and Resources (Fig. 4).

Key assumptions cover levels of GDP (Gross Domestic Product), income and population, number and size of private households (PHHs). Demand module covers four energy end-use sectors: PHHs, industry, transport and services. The transformation module includes natural gas losses during transmission and distribution of electricity. Coal, natural gas, hydropower, wind energy, solar energy, biomass and nuclear energy are taken for primary energy resources, diesel, gasoline and electricity - for secondary energy.

The timeline of the analysis is 2015 (base year) to 2030. Forecast includes the “Reference scenario” (RS), the “European” and “Optimum” scenarios.

The RS provides for such an economic development that would follow the past trends. The European scenario shows more ambitious targets in terms of economic development, increased energy efficiency, accelerated retirement of fossil- and nuclear-based generation, transformation towards the use of RES, etc. The European scenario differs from the RS in terms of higher GDP growth, a steep drop in the use of electricity in PHHs, decline in coal consumption and growth in the consumption of natural gas, solar energy, biomass and electricity in industry, growing share of electrical vehicles.

In order to find the Optimum scenario for the development of energy generating capacities, that takes into account generation costs, necessity to meet the required demand, fluctuations in the daily loadings of the grid, and the GHG emissions, the linear programming of the LEAP OSeMOSYS (Open Source Energy Modelling System) was applied.[8] Standard LEAP calculation algorithm was used.

Results

Ranking of Electricity Generation Sources. The calculation of the ranking of elements of the AHP hierarchy according to three methods of calculating the priority vector were delivered. According to the most closely approximated result, the ranking of sources of electricity generation is presented (Fig. 5). It can be seen significant difference between the regions which can be explained

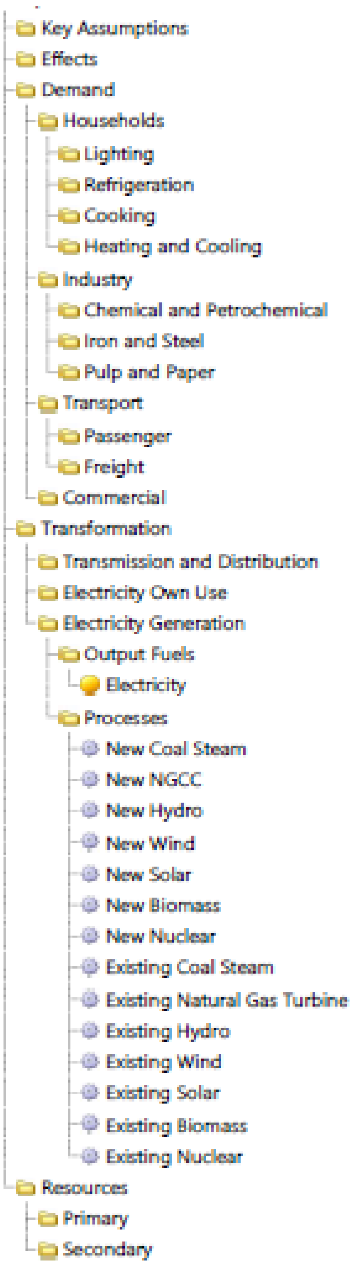

Figure 4: EAP hierarchical tree with modules and corresponding branches.

by the difference in ranking of the criteria which are influencing the final ranking of the alternatives (Fig. 6). At the same, such factors as F4 – Competitive costs to generate electricity and F8 – Security and safety of electricity generation are ranked first and second respectively in both regions.

Balancing of Electricity Generation Sources. The construction of an efficiency frontier of the structure of electricity generation capacities as a proxy for balancing energy portfolio risk and return confirms that the most efficient energy portfolios are those that are more diversified and where the predominant share is the electricity source with a lower level of fluctuation in LCOE.[1]

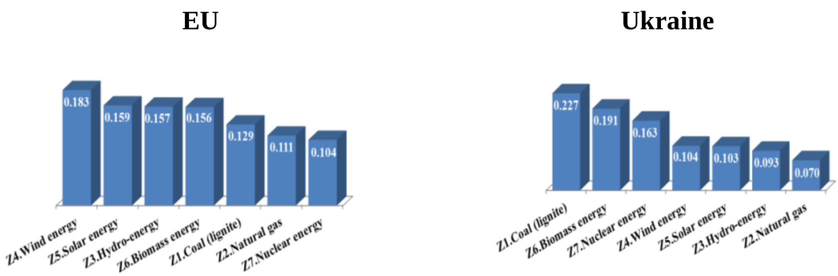

Figure 5: Weights and ranking of alternatives of the electricity generation sources for the energy portfolio of the energy company.

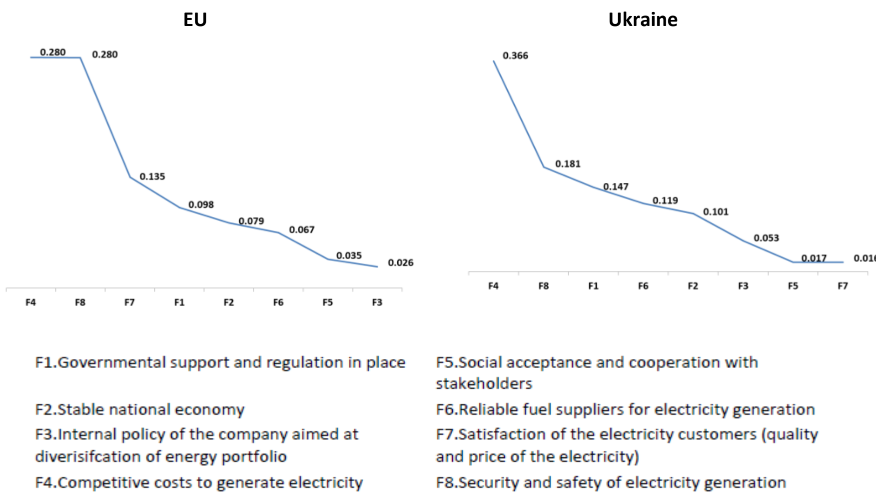

Figure 6: Weights and ranking of criteria for evaluation of the electricity generation sources of the energy company.

[1] LCOE – Levelized cost of generating (producing) electricity.

Strategic Alignment of the Structure of Electricity Generation Sources. A qualitative analysis of the dynamics of changes in the composition of the generating capacities of the companies in recent years indicates that, despite their statements about the transition towards renewable energy, their operations in traditional and nuclear energy sectors remain active. The analysis of the absolute values of risks obtained indicates that sources of electricity generation with a lower level of LCOE are characterized by lower levels of other risks.

Optimal Structure of the Energy Mix. Given the projected demand a LEAP model predicts the following optimum structure of the electricity generation (Fig. 7) for the year 2030 (only two regions are presented).

As a result, the Optimum scenario in the EU differs considerably from both other scenarios and shows very moderate increase of capacities; the increase, if any, concerns mainly natural gas and hydro, the Optimum scenario also favours nuclear energy (existing nuclear power plants are kept compared to the European and Reference scenarios). For Ukraine the increase in capacities results in expansion of hydro facilities.

Given all the above-mentioned it can be summarized that according to the company's goals, and also taking into account the trends of the energy market, the optimal structure of power generation capacity would depend on the economic and political availability of fuels for the next decade (decades), the predictability of the price for the electricity generated, as well as from the support of the state.

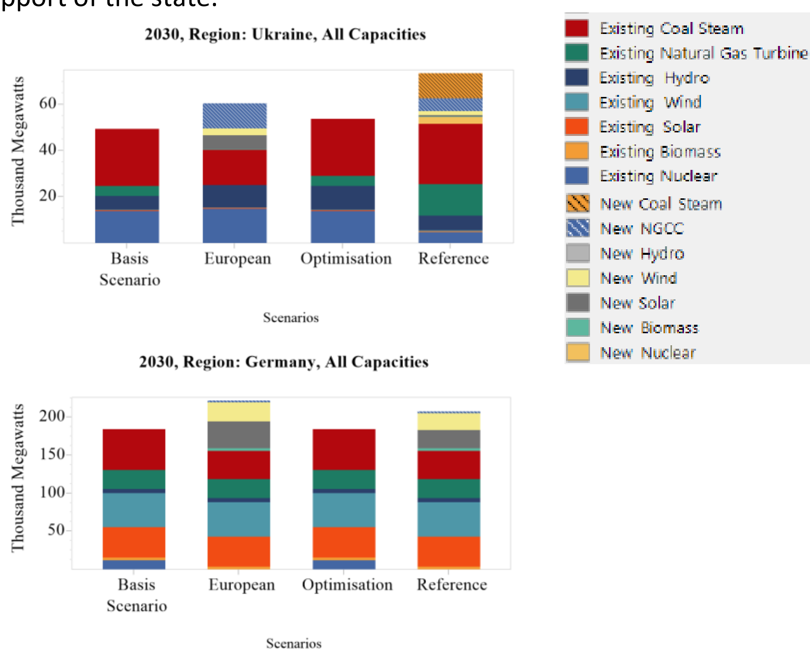

Figure 7: Forecasts of installed capacity for Ukraine and EU member states for 2030; Basis scenario – situation for the year 2015.

Conclusions

To sum up, due to the consideration of many factors the developed general scheme of information technology for diversification and optimization of the structure of electricity generation allows a sufficiently complete description of the object of evaluation and its comprehensive assessment.

A comparative analysis of the results of the application of the developed information technology for different countries points to the existing differences in the adoption and implementation of effective managerial decisions on energy mix management. The most effective and optimal scenario for the development of energy mix in accordance with the proposed modelling does not always coincide with the policy of the governments of the countries and strategic plans of the energy companies.

The presented model delivers an assessment of different scenarios for energy planning. Detailed insight into final energy demand is an important determinant for the forecasting. Given the trends, demand management (especially smart houses) and energy storage deserve more attention in terms of its potential for further reductions in energy consumption and peak loading.

References

[1] Dagoumas Athanasios, "Assessing the Impact of Cybersecurity Attacks on Power Systems," *Energies* 12 (2019): 1996-1073, https://www.mdpi.com/1996-1073/12/4/725/pdf.

[2] Volodymyr Zaslavskyi and Vladislav Ievgiienko, "Risk analyses and redundancy for protection of critical infrastructure. Monographs of System Dependability" (Oficyna Widawnicza Politechniki Wroclawskiej 2010), 161-173.

[3] Olexandr Dyachuk, "Practical Use of MARKAL/TIMES Models for Modeling, Forecasting and Analysis of Energy Systems Development," *Economic Analysis* 12, no. 1 (2013): 98-103.

[4] Bernard Bonin, Henri Safa, and Axel Laureau, "MIXOPTIM: A Tool for the Evaluation and the Optimization of the Electricity Mix in a Territory," *European Physical Journal Plus* 129 (2014): 1-15.

[5] Mariliis Lehtveer, Marek Makowski, and Fredrik Hedenus, "Multi-Criteria Analysis of Nuclear Power in the Global Energy System: Assessing Trade-offs between Simultaneously Attainable Economic, Environmental and Social Goals," *Energy Strategy Reviews* 8 (2015): 45-55.

[6] Mahbud Shahriar, Diego Viesi, Sara Cattani, and Luigi Crema, "An Innovative Multi-objective Optimization Approach for Long-Term Energy Planning," *Applied Energy* 208 (2017): 1487-1504.

[7] Simon Awerbuch and Yang Spencer, "Efficient Electricity Generating Portfolios for Europe: Maximising Energy Security and Climate Change Mitigation," *EIB Papers* 12, no. 2 (2007): 8-37.

[8] Joachim Lang and Reinhard Madlener, "Portfolio Optimization for Power Plants: The Impact of Credit Risk Mitigation and Margining," Institute for Future Energy

Consumer Needs and Behavior (FCN), E.ON ERC, RWTH Aachen University, Aachen, 2010.

9 LEAP, https://www.energycommunity.org, accessed May 19, 2019.

10 Madlener Reinhard, Barbara Glensk, and Günther Westner, "Applying Mean-Variance Portfolio Analysis to E.ON's Power Generation Portfolio in the UK and Sweden," E.ON Energy Research Center, RWTH Aachen University, 2009.

11 Federica Cucciella, "Modeling Optimal Investments with Portfolio Analysis in Electricity Markets," *Energy Education Science and Technology Part A: Energy Science and Research* 30, no. 1 (2012): 673–692.

12 Volodymyr Zaslavskyi and Maya Pasichna, "Optimization Techniques for Modelling Energy Generation Portfolios in Ukraine and the EU: Comparative Analysis," *Advances in Intelligent Systems and Computing* 761(2018): 545-555.

13 Volodymyr Zaslavskyi and Maya Pasichna, "Strategic Evaluation of Electricity Generation Structure in the European Union and Ukraine: Geographical Focus," Dependable Systems, Services and Technologies, thesis of conference reports, (2018): 555-560.

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