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Energy risk management in urban projects management

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ABSTRACT

BACKGROUND AND OBJECTIVES: In general, one can assert that energy security risks are global and significantly affect (negatively, positively) the state and development of the national and world economy. The purpose of the paper is the formation of methodical-practical foundations of energy risk management in the energy sector.

METHODS: The matrix method was used in building the energy security risk assessment matrix. Economic-mathematical modeling was used. Depending on the characteristics of the dynamic series and the available information, the methods of analytical alignment, smoothing using the moving average, the average absolute increase, and the average coefficient of change were applied.

FINDINGS: The energy security risk assessment matrix was created. The development of a strategy for the behavior of subjects of market relations in the electricity market should be based not only on the results of risk identification and assessment and the developed risk management plan, but also on the risk response plan and the method of their control (monitoring). The coefficient of use of the installed energy capacity was in the range of 32–26% in Poland in 2021. Calculations of average annual growth rates for each of the dynamic series give reason to state that the highest growth rates of dependence on energy imports were characteristic of coal (+4.17%) and the lowest ones — of oil (+0.35%) during 1990–2021. Considering the forecast values for 2030, a certain decrease in the growth rate of dependence on the import of energy resources (for coal and oil) and an increase- for gas are expected.

CONCLUSION: As a conclusion, the method of forecasting the total final energy consumption of the country was improved for forecasting the amount of energy resources in order to use it for building an energy policy that considers such variables as the economic situation and the political situation in the country. The formation of a risk response plan should be based on management plans and documentation of risk manifestations, intellectual and organizational assets of the economic entity (generalized risk management experience, management strategies, templates, etc.).

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INTRODUCTION

Harmonious development of the economy is impossible without energy supply, which requires the formation of a complementary economic policy in the energy sector. In the world economic system energy is considered as the most important factor of its security, growth and development. The demand for energy resources has a clearly expressed tendency to growth even in the conditions of the implementation of energy saving programs, which is especially characteristic of economies with high rates of development (China, India, and Brazil). At the same time, according to the International Energy Agency (IEA), the provision of modern energy technologies in the conditions of uneven territorial distribution of energy resources and their limitations is a priority for the governments of many countries seeking to overcome poverty (Lee *et al.,* 2017). According to the studies of the U.S. Chamber of Commerce's Institute for 21st Century Energy, energy security is primarily related to the geopolitical location of key energy resources, since a significant part of the world's explored reserves of oil, gas and other fossil energy resources are located in a limited number of countries (Liu and Zeng, 2017). At the same time, many of these countries are in a state of permanent social-political disturbances. Another factor influencing the energy security of the world economic system is the insufficient level of development of the logistics network, since in many cases the transportation of energy resources is complicated by the lack of communication routes between producers and consumers of energy resources (Fera *et al.,* 2017). Therefore, the level of energy security depends significantly on the reliability and efficiency of international trade in energy resources. Separately, it should be noted that the existence of local sources of instability in the global economic system can significantly affect fluctuations in demand and, accordingly, prices for energy resources in other countries, even self-sufficient in terms of the supply of energy resources (Gallagher *et al.,* 2018). It is especially relevant for energy-dependent countries. Under the conditions of the transition to market relations, the liberalization of the electricity market, a significant number of stakeholders (subjects of these relations) pursuing different (sometimes non-complimentary, radically opposite) interests are involved in the processes of management and decision-making regarding its development (Zare *et al.,* 2016a, Zare *et al.,* 2016b). A large number of subjects of energy relations, provided that each of them assumes a certain part of the risk, leads to the emergence of a general (systemic) risk factor (Ho *et al.,* 2019), because the failure of at least one of them to fulfill the obligations assigned on them will lead to the emergence of undesirable, negative events, threats due to violation of a clear energy supply regime, etc. (Child *et al.,* 2018). When developing and implementing energy strategies, it is advisable for energy market subjects to rely on the risk management methodology and carry out systematic research and analysis of risks. These processes require coordinated actions in the management of energy risks at all temporal and hierarchical levels of the organizational management structure, and the task of creating an effective risk management system becomes urgent. The need for risk management is due to objective reasons caused primarily by the uncertainty of the state and trends in the development of the energy market, as well as subjective reasons that arise directly during the justification and adoption of management decisions. The purpose of this study is the formation of methodical-applied principles of energy risk management in the energy sector. The set goal made it necessary to solve such tasks: to develop the structure and content of the energy risk management system; to develop a model of compatibility (coherence) of the energy infrastructure with other components of the critical infrastructure (institutional and technological) of the country; to improve the method of forecasting the total final energy consumption of the country for planning the volume of energy resources. The study was conducted in Poland during 2019-2021. Hybrid threats are becoming an increasing challenge for the energy security of Poland and the countries of Central and Eastern Europe. They are mainly concentrated around strategic projects in the Baltic Sea region (liquefied gas terminal, oil port, etc.) and on border territories (so-called interconnectors) (Bielski *et al.,* 2021). Due to the multifaceted nature of the subject, these threats concern not only conventional actions (army, paramilitary groups, special services), but also risks in the information and cyber spaces. Critical infrastructure is not protected from hybrid or asymmetric threats in Poland. Critical infrastructure is not protected from hybrid or asymmetric threats in Poland. One can say about especially significant

risks in the case of coastal or marine projects. The factor of hybrid threats in the Baltic Sea also affects the operator of electric power grids- the company Puget Sound Energy (PSE) (Saługa *et al.,* 2020). It is about the cable connecting Poland to Sweden, which helps the Polish system to keep its balance in difficult situations. Let's add that in the perspective of 2023, the risk of a blackout in Poland due to a lack of electricity will be quite high, which is associated with the need to close old coal-fired thermal power plants (which is 60% of all currently operating power plants) and the late start of the construction of new conventional capacities (Wagner *et al.,* 2016).

LITERATURE REVIEW

Generally, one can state that energy security risks are global and significantly affect (negatively, positively) the state and development of national and world economies (Krishnan, 2016). Before starting to consider the methodological foundations of macro-energy risk assessment and management, let's dwell on the concept of risk, its functions and tasks, as well as the typology of risk. It is considered an event that may or may not occur with a potentially negative (threats) or positive (opportunities) impact on the economic system (Jacobson *et al.,* 2017). At the same time, risks are associated with the potential level of danger regarding the achievement of the goal of the development of the economic system, given the objective impossibility of using complete, relevant, reliable, timely information about the state of the external and internal environment (Cergibozan 2022). Scientists pay considerable attention to the definition of the term "risk". According to Shahsavari and Akbari (2018), with "a causal approach to considering the content and classification of risk, the most significant feature all other risk features depend on and follow from are the causes of the uncertainty of the conditions under which the business activities of the economic entities are carried out, i.e. sources of risk". Regarding the morphology of the concept of "risk" in the modern economic literature, which concerns the theoretical basis of risk, there is a significant list of varieties of definitions of the term "risk". This indicates that there is still no single and agreed approach to the semantic description of this concept, its content, characteristics, etc. Moreover, different authors give different interpretations and characteristics of the content of risks that have the same essence, or use the same concepts in different ranges of values (Duan *et al.,* 2018). In opinion of the authors, here is one of the clearest interpretations of risk: "Risk is an economic category in the activities of economic entities, which is associated with overcoming uncertainty, conflict in situations of assessment, management, inevitable choice" (Radovanović *et al.,* 2017). The essence of risk is manifested in the functions it performs, namely: analytical, protective, regulatory, innovative and health-improving ones. As for the concept of energy security risk, based on the analysis of the corresponding sources, it can be asserted that it has no unambiguous and consensus interpretation (Ho and Chuah, 2021). To a large extent, it is explained by the complexity of the process of functioning of the energy market, which is determined by the variety and number of its constituent elements, and their relationships. In addition, the interests of the parties interacting in the energy market can be both complementary and contradictory, which can negatively affect the achievement of the goals of the development of the energy sector. Let's consider this definition of the concept of risk in the electric power system (Marzi *et al.,* 2019): "The risk in the power industry is an objective-subjective category related to the probability of occurrence of undesirable events (threats) in conditions of uncertainty and conflicting interests of various groups of energy market entities and reflects the extent of their losses (losses) from violation of a reliable electricity supply regime as a result of uncoordinated actions of these entities". Such a definition can be considered one-sided, as it reflects only potential threats without considering the positive impact of unforeseen opportunities. That is, the concept of "risk" in the energy sector should be understood as an objective-subjective category that is inextricably linked with the probability of the occurrence of undesirable events (threats), as well as potential opportunities under conditions of uncertainty, conflicting interests of groups of entities of the energy market of the country. The risk reflects the degree (level) of their losses (damages) due to the violation of a reliable energy supply regime (due to uncoordinated actions of these entities) or the level of potential additional income (due to the emergence of unforeseen opportunities) (Steffen, 2018). According to this classification, it can be considered (Thomson *et al.,* 2018) that the energy enterprises of the country are prone to pure risks

(technological, production, management) and specific risks due to branch affiliation and the features of the energy process. The classification of energy market risks contributes to the development and effective functioning of the risk management system of economic entities, which purposefully affects the object of management to reduce the negative consequences of the manifestation of risks, as well as to optimize the effect of potential opportunities (Schittekatte *et al.,* 2021; Jehan *et al.,* 2020). Despite the significant contribution of scientists to the formation of methodological bases for the analysis of the energy market of a country, the conceptual, theoretical-methodological and methodical bases for the formation of complementary economic and energy policies of a country in the conditions of European integration on the basis of harmonious development remain insufficiently substantiated and formed. Providing all areas of the economy of a country with various types of energy and fuel is one of the most important tasks of the management system and economic policy of the country, a necessary condition for its successful and harmonious development.

MATERIALS AND METHODS

Scientists singled out an attempt to stimulate the use of renewable energy sources in electricity, which contradicts cross-subsidization (Moser *et al.,* 2017). The problem is also that energy management issues at the institutional level are distributed among a significant number of central executive bodies of the country. Identified risks are subject to evaluation and ranking. Quantitative risk analysis involves (Mazzucato and Semieniuk, 2018): selection of a system of risk assessment indicators; justification of the choice of the evaluation method; formation of management decisions regarding response to risks; selection of priority decisions. Quantitative assessment of risk is carried out based on indicators of the probability of risk and possible losses from the manifestation of risk using subjective or objective (statistical) methods (Healy and Barry, 2017). Subjective methods are based on assessments and criteria based on the experience of managers, the advice of consultants, and the conclusions of experts. With subjective analysis, it is believed that the risk manager can establish the probability of risk occurrence and the scale of losses without analyzing similar events in the past or conducting statistical experiments (Algieri and Leccadito, 2017). According to objective methods, the probability of an event burdened with risk is determined by the frequency of its occurrence in the past. To determine the amount of possible losses, it is advisable to use the following quantitative methods (Kim, 2017): statistical analysis, econometric modeling; simulation modeling; theory of games and statistics solutions; graphoanalytical methods; building a "decision tree"; construction of impact diagrams, etc. Quantitative risk analysis requires considerable time, the involvement of highly qualified risk managers, and the use of special software (Liu *et al.* 2017). Let's consider the methods of statistical risk analysis in more detail. If one considers Y as a discrete random variable, using Eq. 1.

$$Y = \{y_1, y_2, y_3\} \quad (1)$$

Where, y_1, y_2, y_3 – possible consequences of the event according to optimistic, moderate and pessimistic estimates, and the probability of their occurrence, using Eq. 2.

$$V = \{v_1, v_2, v_3\} \quad (2)$$

The mathematical expectation F(Y) of the possible consequences using Eq. 3.

$$F(Y) = \sum_{i=1}^{3} v_i y_i; \sum_{i=1}^{3} v_i = 1 \quad (3)$$

The mathematical expectation F(Y) can be thought of as the risk expected on average. An important absolute indicator of risk is also the standard deviation (mean squared deviation) p(y), as a measure of dispersion of possible losses around the average value of F(Y), using Eq. 4.

$$p(y) = \sqrt{\sum_{i=1}^{m} v_i [y_i - F(Y)]^2} \quad (4)$$

The relative risk indicator is the coefficient of variation W calculated, using Eq. 5.

$$W = \frac{p(y)}{F(Y)} \quad (5)$$

Conceptually, when calculating absolute and

relative risk indicators, any deviation from the average value is considered undesirable. According to the neoclassical theory of risk, only unfavorable deviations are considered (Chowdhury *et al.,* 2018). At the same time, the risk is assessed using the modified indicators: the absolute value of semivariance (SV) — as an analogue of the mathematical expectation *F(Y)*); the absolute value of the semi-squared deviation (SSV) — as an analogue of the standard deviation *p(y)*; the relative value of semivariance (KSV) — as an analogue of the coefficient of variation *W*. The use of the given absolute and relative indicators makes it possible to quantitatively assess the level of risk, thereby establishing the directions of a targeted response (influence) to it. In order to clearly understand the degree of influence of a certain risk (negative, positive) on the achievement of energy security goals, each economic entity should be oriented on the appropriate (typical/individual) risk assessment scale, which combines qualitative and quantitative gradations (Wang *et al.,* 2019). Table 1 shows the developed scale for assessing the negative consequences (one-sided scale) of the impact of risk on achieving these goals: stability of energy supply, safety of operational activities, financial and economic effectiveness of activities.

To rank risks according to two criteria (probability/impact), the energy security risk assessment matrix is used (Table 2).

The relative coefficient of partial risk (*Tr*) is calculated using Eq. 6.

$$T_r = v \times w \quad (6)$$

Where, v — probability of risk; w — risk impact value.

In the built matrix, risk areas are identified, belonging to which is determined by the value of the *Tr* coefficient: low risk area — up to 0.08; medium risk area- $Tr \in [0.08; 0.24]$; high risk area — 0.24 and more. The energy market is a complex and dynamic economic system, the study of which requires the use of adequate methods for the purpose of identifying a set of factors (internal, external) influencing the functioning of the market, as well as establishing the main trend of its development for ensuring the energy security of the country (Mihić *et al.,* 2018). Considering the high level of risk inherent in this market, the system of market forecasting and taking it into account in the formation of the country's energy policy, as well as ensuring a high level of energy (and therefore economic and national) security acquire

Table 1: Scale for assessing the negative impact of risk on achieving energy security goals

Impact of risk on energy security	Qualitative/quantitative assessments of risk impact				
	Very low, LL 0.05	Low, L 0.10	Medium, M 0.20	High, H 0.40	Very high, HH 0.80
Unstable energy supply	Barely noticeable	Up to 5%	By 5-10%	By 10-20%	Above 20%
Operational risk	Insignificant	It requires planned and preventive	It requires operative	It requires confirmation of	The activity loses its
Deterioration of financial and economic	Imperceptible	Up to 5%	By 5-15%	By 15-40%	Above 40%

Table 2: Energy security risk assessment matrix

Probability	Impact level				
	Very low, LL 0.05	Low, L 0.10	Medium, M 0.20	High, H 0.40	Very high, HH 0.80
0.9	0.05	0.09	0.18	0.36	0.72
0.7	0.04	0.07	0.14	0.28	0.56
0.5	0.03	0.05	0.10	0.20	0.40
0.3	0.02	0.03	0.06	0.12	0.24
0.1	0.01	0.01	0.02	0.04	0.08

a great importance. Energy security should be aimed at achieving uninterrupted, effective supply of the economy with energy products (resources). In the absence of a universal generally accepted typology of energy market study methods, we will distinguish the following groups of methods (Cai *et al.,* 2019): intuitive — subjective, heuristic, expert, etc.; formalized — economic and mathematical modeling, extrapolation, simulation modeling, factor analysis, etc.; combined — formed by combining procedures of qualitative analysis and formalized algorithms of logical transformations and numerical calculations. Expert methods of individual and group assessment make it possible to reveal the behavior of the energy market as an economic system based on the use of professional knowledge and competences of researchers, their ability to generalize acquired own experience and adapt borrowed experience (De Amorim *et al.,* 2018). Formalized (quantitative) methods are based on the extrapolation of the established main trend of changes in the object of study in the past to future periods of time, provided that the structure and weight of factors affecting the functioning of the energy market are unchanged (constant) (Krane, 2017). The development trend can be considered as the evolution of the energy market, which is described by an economic and statistical model, using Eq. 7.

$$l(t) = n(t) + d_t \quad (7)$$

Where, $l(t)$ — the level of the dynamic series during the time interval t; $n(t)$ — a deterministic component that describes the main tendency (trend) of changes in an economic indicator $l(t)$ over time; d_t — a random component.

To extrapolate the patterns of the development of the energy market, depending on the characteristics of the dynamic series $l(t)$ and the available information support, it is possible to use the methods of analytical alignment, smoothing using the moving average, the average absolute increase, and the average coefficient of change, etc. Given the complexity of the energy market as an object of study, one can describe its operation using a number of economic indicators (demand and supply of energy products, product price, production volumes of energy products by their types, primary energy supply, final energy consumption, energy consumption structure, etc.). And based on the experience of developed countries in its research, it is considered expedient to use the methods of analytical alignment of the dynamic series for the purpose of determining the patterns of market changes (Jenkins and Taebi, 2019). The system of forecasting economic processes has a significant number of types of growth curves. To correctly select the optimal growth curve for the purpose of forecasting and modeling of economic phenomena, it is necessary to know the specifics of each of the types of these curves. Most often, scientists use polynomial, exponential, and S-shaped growth curves to forecast economic processes (Deller, 2018). In the economy, most dynamic processes are characterized by the "saturation" effect, i.e., the rate of increase/decrease of indicators slows down over time and stabilizes, and eventually their level approaches a certain limit, or at first, they grow quite slowly, then accelerate sharply, and then their growth rate is reduced again, approaching the limit. To model these processes, it is common to use the so-called "S-shaped" growth curves, among which it is advisable to highlight the Gompertz curve, which is divided into 4 segments (sections): 1- function increase is insignificant; 2- increase is growing; 3- increase is nearly constant; 4- the rate of increase is reduced, the function approaches a certain value indefinitely. As a result of the specified combination of the dynamic process, the configuration of the curve of this function resembles the Latin letter "S". "S-shaped" curves simulate two consecutive processes (with acceleration of development, with a slowdown in the pace of development and the transition to full saturation). The inflection point will determine the culminating moment of this development, while the asymptote is the limit of the process development. Energy market modeling with the help of S-shaped curves can be an example of the successful use of combined methods, using Eq. 8.

$$l(t) = b + \frac{(c-b)\times t^k}{g + t^k}, b,c,g > 0; c > b, k > 1 \quad (8)$$

Where, b,c,g,k - desired parameters of the model or econometric models with dummy variables, using Eq. 9.

$$l(t) = f(h_{it}; t) + d_t \quad (9)$$

Where, h_{it} - dummy variables reflecting the effect of external and internal factors on the functioning of the energy market. The information base of the study are the works of scientists on the problems of managing the energy sector in Poland, the formation of economic policy in the energy sector, European integration processes in this area; normative acts regulating the energy sector of the economy; the law of the European Union in the energy sector; annual reports of the International Energy Agency; statistical reporting and statistical data of Polish energy companies.

RESULTS AND DISSCUSSION

A risk may exist or arise throughout the entire life cycle of an energy market entity at any phase of its activity. The tasks of risk management are as follows: detection of risk sources, setting the level of potential threats (possibilities), identification, documentation of risks, development of measures to optimize them (reduction of negative impacts, maximum use of favorable opportunities when risks occur, etc.). It is advisable to divide the process of energy risk management into the following stages: risk management plan creation, risk identification, risk analysis (quantitative and qualitative), risk response planning, risk control and regulation, and follow the sequence of their implementation. A risk management plan is a document that covers the methodology, list of tasks, information sources, management system tools, risk breakdown structure (RBS), distribution of areas of authority and responsibility of risk managers, description of the degree of influence of potential risks, measures for tracking (monitoring), control, regulation of risks (Table 3).

The formation of a risk management plan is carried out on the basis of information about the main goal, goals subordinate to it, resource supply of

Table 3: Tasks that arise during the formation of a risk management plan (Parpairi, 2017: Wei *et al.,* 2017: Campisi *et al.,* 2018)

Task	Task content
Selecting an energy security risk management methodology	From the set of methodological approaches to risk management, the most appropriate one is selected, considering its tools and the necessary information support
Distribution of roles and responsibilities of risk managers	The roles and responsibilities of managers are distributed during the risk management process
Setting the amount of resources necessary for energy risk management	Formation of reserves to cover probable losses and the management reserve. Development of procedures for the use of reserves
Determination of time parameters of risk management processes	Setting the terms and frequency of risk management actions
Formation of the structure of energy security risks	Formation of a risk category based on own experience or based on the results of analyzing the types of potential risks in the formats of a list of categories (types) or RBS. RBS makes it possible to consider in detail the totality of risk sources in the process of their identification. Risk categories can be formed based on the following characteristics: risk source; the area affected by the risk; budget; area of responsibility; reason, etc.
Determining the probability of risk occurrence and the degree of its impact on energy security	Defining general ratios of the impact of risks on the achievement of goals (negative impacts, positive impacts). Typical scales can be used
Formation of the "probability/impact" matrix	The matrix contains the probabilities of occurrence of risk events and their impact on project goals. Determining a qualitative value of the "probability/impact" ratio depends on the individual perception of risk by each organization
Determining the attitude of stakeholders to energy security and their risk appetite	The attitude of stakeholders to the organization (favorable, neutral, negative) can change over time. The risk appetite of the most important stakeholders is recorded in the risk management plan with an indication of the individual perception of the quantitative limit (threshold) of the permissible risk in relation to the goals
Defining risk management reporting formats	The reporting formats are designed for ordering the documentation of the risk management process. The requirements for the content and forms of risk registration, as well as for reporting
Monitoring of risk management processes	The procedure for registration (documentation) of all risk management (management) actions, as well as the conditions and methods of audit of risk management processes are established

the energy market entity and the effect of external environmental factors. The identified risk should be perceived as a manageable project parameter, the occurrence of which can and should be influenced in order to reduce adverse consequences (threats) and maximize the use of favorable opportunities. Internal sources of energy risks generate operational risks related to the technical condition of the equipment, the safety of personnel, the efficiency of energy production and transmission, the availability of an insurance reserve of energy resources, the protection of production processes and information, the qualifications of personnel, etc. The consequences of the manifestation of operational risks may be unproductive growth of production costs, financial losses related to the violation of energy supply obligations, emergency stops of operational activities, deterioration of the reputation of the responsible energy producer, consumption of fixed assets and resource stocks, etc. The consequences of the manifestation of risks generated by external sources may be losses of energy sales markets, financial and economic losses associated with the deterioration of trading conditions, changes in energy prices, manifestations of corruption and fraud, credit conditions, etc. According to the results of a group expert evaluation of the impact of risks on the energy security of Poland, the main types of risk and qualitative assessments of the probability of their occurrence and the level of impact (low, medium, high) were identified. According to research, the main risks that affect the stability and safety of the energy system include: operational risks (O), management risks (C), consumption risks (S), interaction risks (Z), currency risks (V), price risks (P), financial risks (F), legal risks (Leg), political risks (Pol) and natural risks (V). Interaction and political risks have the greatest impact on the security of the energy system. The highest probability is characteristic of price and operational risks. Risk positioning in 2–4 quadrants confirms the existence of a potential threat to the energy security of Poland. The emergence of operational (technological) risks is associated with the probability of failures (interruptions) of the main equipment of energy enterprises in Poland, since their structure looks like this in terms of the level of wear and tear: equipment that exceeded the limit of physical wear and tear — 34.8%; equipment that exceeded the limit resource — 28.4%; equipment that exceeded the estimated resource — 27.4%; equipment that is within the limits of standard operational capabilities- 9.4%. The coefficient of use of the installed capacity of the units was within 32–26% (for comparison, in 1990, this indicator was 67.8%) in 2021. The emergence of management risks (C) is related to the fact that in the process of functioning of the wholesale electricity market, sudden changes in electrical regimes may occur, the adaptation of the energy system to which will require an urgent review of the system of criteria and adequate emergency management. Attempts at unauthorized external interference in the operation of the energy system can also pose a significant threat. Consumption risks (S) are caused by a change in the purchasing power of money and lead to an increase in the number of receivables, since the payment for the actually consumed electricity is essentially made on credit, and moreover, it is not always on time. Research and analysis of energy risks gives reason to assert that a certain legal irregularity of the process of stakeholder interaction in the conditions of energy market liberalization and the presence of conflict of interests of various groups of energy market subjects can serve as the basis for the emergence of interaction risk (Z), which can be confirmed by manifestations of systemic corruption and fraud. Additionally, they include state administration bodies and local governments, as well as external investors. The essence of the interests of various groups of energy market subjects is given in Table 4.

The main parties of interaction, participants of the energy market are as follows: producers of electric energy (energy companies with vertically integrated organizational structures, generating companies, independent producers of electricity); suppliers of electric energy (energy companies with vertically integrated organizational structures), organizations that provide transportation (transmission) of electric energy, distribution companies that provide the distribution of electric energy, energy distribution organizations; independent "businessmen", brokers who act as intermediaries in the processes of concluding contracts (agreements), dealers (organizations that buy/resell electricity). In our opinion, according to their function, it is appropriate to group them as "energy market intermediaries"; electricity consumers of various groups and categories; authorities regulating the electricity

Table 4: Characteristics of Polish energy market stakeholder interests

Energy market subjects	Energy market subject interests
Producers, sellers of electricity, entities providing electricity services on the wholesale electricity market	Maximization of profits as the final result of activity.
Electricity consumers	High level of electricity quality, reliability, uninterrupted power supply, minimization of electricity tariffs.
State administration bodies	Maximization of revenues to the budgets of the relevant levels, minimization of the negative environmental impact of electric power facilities, ensuring a high level of energy security.
Foreign and domestic investors	Minimization of terms of return of capital invested in electric power facilities, maximization of dividends.
Intermediaries	Reliable functioning of the energy market, maximizing the level of profits by increasing the number of contracts, resale of electricity.
International organizations	Monitoring the fulfillment of obligations in the energy sector (in particular, minimization of the negative environmental impact of electric power facilities, ensuring a high level of energy security).

market; investors (foreign and domestic ones). The transition of the energy sector of Poland to market relations, the liberalization of the energy market led to the fact that during the implementation of planning, organization and other management functions, the results of which are managerial decisions regarding the development of the energy system, a significant number of participants in this process are involved. As a result, this leads to a conflict of interests of each of the participants, representatives of different parties to this process. There is also a high level of probability of the occurrence of physical (technological) risks, which are associated with the probability of failures and/or interruptions in the operation of the main equipment of energy companies. It is forecasted that qualitatively new financial and economic risks may arise, which will be determined by the interaction of formed groups of subjects in commercial relations during the operation and development of the energy system according to new principles. Price risks (P) in the electricity market are caused by the dynamics of prices for oil and other energy resources (natural gas, coal), as well as the reform (liberalization) of the energy market and changes in pricing principles. During the existence of natural monopolies, energy prices were determined exclusively by the level of costs for its production and transportation. Today, the price level in the free energy trade sector is set based on the results of annual auctions. "Spot" contracts (providing for the supply of energy the day after the payment is made), the contracts in which the term of energy supply can be changed throughout the year are quoted on them. A significant number of subjects of market relations in the energy sector became exposed to financial risks, which are primarily related to commercial aspects of activity. The emergence of qualitatively new (so-called "modern") financial risks (F) as a result of fluctuations in the price level of fuel and material resources is due to the formation of various groups of subjects of energy relations on the energy market. These risks (P, F) include currency risks (V) caused by changes in the exchange rate of foreign currencies. The stability of the energy system of Poland directly depends on weather conditions (state of the environment), which affect the occurrence of natural and climatic risks (W), thereby — the emergence of abnormally uneven loads. The development of a strategy for the behavior of the subjects of market relations in the Polish electricity market should be based not only on the results of risk identification and assessment and the developed risk management plan, but also on the risk response plan and the method of their control (monitoring). Response to risks (partial, general) should be timely, adequate, understandable for stakeholders and effective. The purpose of risk response is to define and implement measures for reducing the level of potential threats, the rational use of opportunities, as well as decreasing the amount of costs for the occurrence of certain risk events. The formation of a risk response plan should be based on management plans and documentation of risk manifestations, intellectual and organizational

assets of the economic entity (generalized risk management experience, management strategies, templates, etc.), characteristics of the risk appetite of top managers and the most important stakeholders. The implementation of a risk response plan is accompanied by the update of energy market subjects' activity management plans and the introduction of appropriate changes to the risk management plan. The main types of risk response strategies include: response strategies to potential risks accompanied by opportunities or threats; response strategies to events that seem to serve as "triggers" and cause losses only when certain conditions, for example, weather, occur. The implementation of a risk response plan is aimed at reducing individual threats, increasing partial opportunities and reducing risk. The risk response plan implementation tools include: expert methods; information system of the decision-making process; energy system management methods. To select a risk response strategy, you can use the method of risk positioning in the single square (graphic model of the risk matrix). Since risk has two characteristics (probability of occurrence and degree of impact), each identified and assessed risk can be represented as a point in two-dimensional space (Fig. 1).

Risk control (monitoring) as a management function covers procedures for monitoring identified risks, identifying new risks through analysis, evaluating the effectiveness of planned measures to respond to risk manifestations, as well as adjusting management decisions. The content of control is the timely and adequate response of risk managers to potential changes in the parameters of market processes, modes of operation of energy market subjects, the risk management plan and the risk register. The general sequence of the risk control process is given on Fig. 2.

Data analysis methods, audits, sessions of working groups and councils (seminars, symposia) attended by the most influential stakeholders serve as tools for analyzing input data on risk management. At the adjustment stage, changes are made to the risk management plan, the risk register, the assets of the organization's processes are updated (templates used to form the risk management plan, risk structure, etc.), and experience in energy risk management is accumulated. The development of innovations used in the energy risk management system is closely related to the development of the stock market structure. The formation of the energy markets of Poland should activate this process, which has been quite slow throughout the country's independence. Against the background of the development of the stock market, the subjects of the Polish energy market should become active initiators of the development and use of new financial mechanisms in the risk

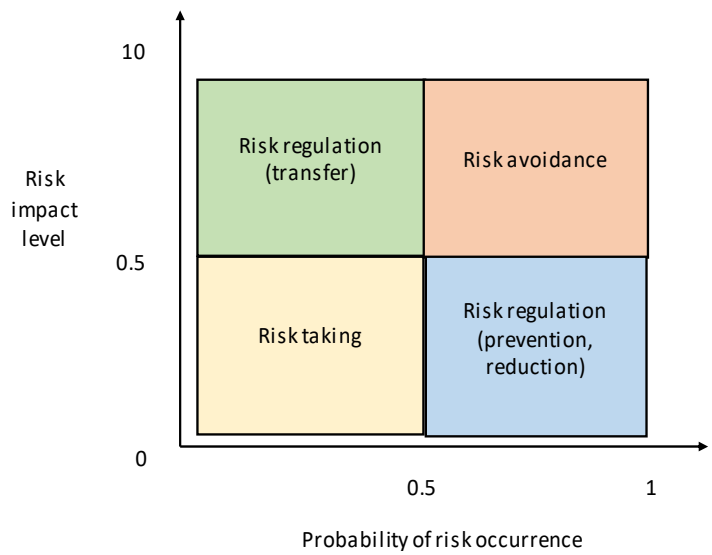

Fig. 1: Graphic model of the risk matrix

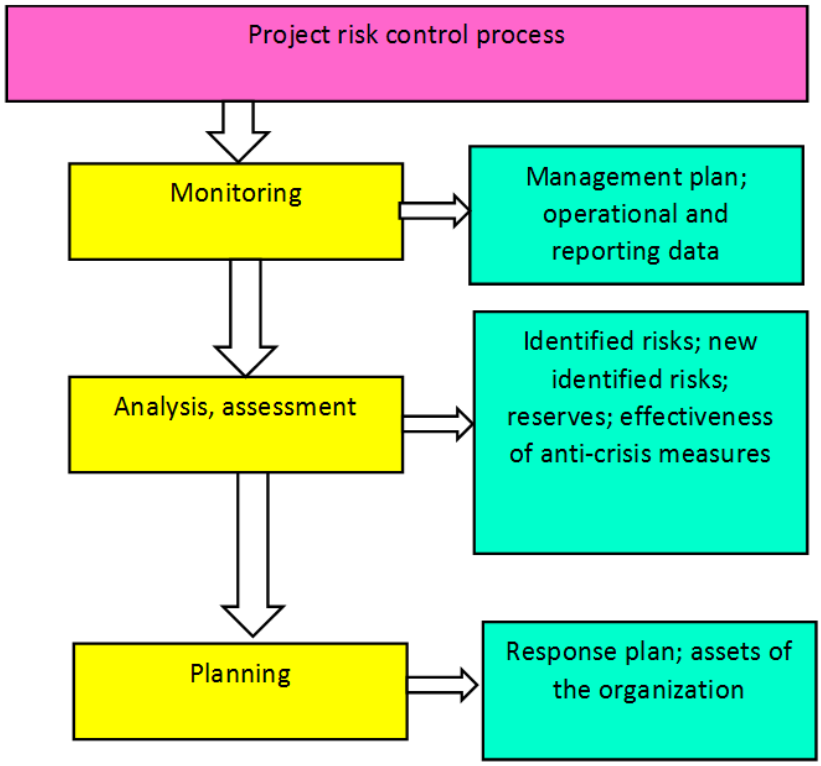

Fig. 2: Project risk control process

management system. The main areas of reducing the level of risk and increasing the level of energy (and economic) security of Poland should be as follows: increasing the level of energy efficiency of the Polish economy (decrease in the share of cost of energy resources per unit of GDP); exploration, expansion of already proven reserves, increase in production volumes of own energy resources; substitution of expensive imported energy resources (oil, natural gas, etc.) for other types of fuel; diversification of the use of energy resources by expanding both types of energy resources (especially renewable, alternative resources) and sources of supply; countering fluctuations in the level of prices for energy resources (prevention and countermeasures against monopolization of the energy market, development of market infrastructure, creation of reserves of energy resources, preservation of a sufficient level of state influence on the fuel and energy complex, on the market of energy resources, etc.); introduction and further development of market principles of responsible interaction of stakeholders in the country's electricity industry, development of the management system in this area. The authors examine the trends in the development of the energy product market for EU countries, considering the forecast values of a number of indicators for 2025 and 2030.

Information about the dependence of the EU economy on the import of energy products is given in Table 5.

First, we will analyze the dynamic series of the dependence of the EU economy on energy imports for the period from 1990 to 2021. Calculations of the average annual growth rates for each of the dynamic series presented in Table 5 give grounds for asserting that the highest growth rates of dependence on energy imports were typical for coal (+4.17%), and the lowest for oil (+0.35%) for the period from 1990 to 2021. Considering the forecast values for 2030, a

Table 5: Dependence of the EU economy on energy imports, in 1990–2030.

Year	Dependence on imports (%)			
	Coal	Oil	Natural	Average value
		1990–2021		
1990	18	81	48	45
2000	30	77	50	47
2010	39.4	84.4	62.1	52.7
2012	42.2	86.4	65.8	53.4
2021	44.2	87.4	65.3	53.2
Average annual growth rate for 1990-2021, %	+4.17	0.35	+3.14	0.76
		1990–2030		
2025*	50	86	75	62
2030*	66	88	81	67
Average annual growth rate for 1990–2030, %	3.3	0.2	17	0.1
Comparative change in the average annual growth rate (%)	–0.87	–0.15	0.3	–0.66

** – expert evaluation*
Note: created by the author based on EEII, (2020).

certain decrease in the growth rate of dependence on the import of energy resources (for coal and oil) is expected, and an increase — for natural gas. However, in general, there is a trend towards increasing dependence of the EU economy on energy imports, as the average annual growth rates for coal, oil and natural gas are positive values. The availability of forecast data (expert estimates) for 2025 and 2030 and the established nature of changes in dynamic series make it possible to apply a combined method to describe the development trend of the European energy markets of coal, oil and natural gas using a power law model (Eq. 8). To build the model, it is necessary to find the numerical values of the parameters b,c,g,k. We will find them for the energy resource "natural gas". The economic content of the parameters b and c is transparent: b - minimum function value I(t) in the range of definition, c - maximum value. Considering that the minimum level of dependence of the EU economy on gas imports is I_{1990} = 48%, and the maximum level is I(t) = 90%, we automatically obtain the values of the two desired parameters: b = 48, c = 90. To find the parameters g,k we will build a system of two nonlinear equations with two unknowns considering expert estimates I^*_{2021} = 75% and I^*_{2030} = 81%. The system acquires this form, using Eq. 10.

$$\begin{cases} 75 = 58 + \dfrac{52 \times 41^k}{g + 41^k} \\ 81 = 58 + \dfrac{52 \times 51^k}{g + 51^k} \end{cases} \quad (10)$$

The solution will be g =3474, k =2.5454. Thus, the general model for the energy resource "natural gas" takes using Eq. 11.

$$I(t) = 58 + \frac{42 \times t^{2.5454}}{3474 + t^{2.5454}} \quad (11)$$

As it can be seen, I(t) = 58, and $\lim_{t \to \infty} I(t) = 90$, and therefore the initial conditions are fulfilled.

With the help of built models of primary energy supply and final energy consumption, forecasting the needs of the economy for energy resources is significantly simplified, which will contribute to their effective planning during the implementation of the economic policy in the energy sector. So, to sum up, it must be stated that it is innovation in the energy industry, diversification of energy resource flows, supply channels for Poland that will contribute to increasing the level of energy efficiency of industry and the economy as a whole, will reduce the level of dependence on external energy sources and will ultimately lead to an increase in the level of economic security, as well as the level of national security.

Identification of existing security controls should be undertaken to avoid unnecessary works and expenses. In addition to the evaluation of the security control measures already used in the company, the control measures planned for implementation should also be analyzed (Croutzet and Dabbous 2021). During the analysis, existing and planned control measures should be recognized as ineffective or unreasonable. If a certain measure is unreasonable or does not consider a certain risk, it must be checked again to determine the need to exclude it, replace it with another one, or preserve it (Hu *et al.,* 2018). If security controls are ineffective or do not work as they should, this can transform into a vulnerability (Sovacool *et al.,* 2016). The existing control measures are implemented through a number of company actions (Ragosa and Warren, 2019): document analysis through verification of the implementation/ execution of risk management plans; verification of implementation of measures (control measures that have been implemented to ensure the effectiveness of the risk management process); an on-site analysis (it is necessary to analyze the implemented control measures for effectiveness and efficiency, to compare the probability of the occurrence of risk before the implementation of the policy and after its implementation); checking/analysis of audit results through the use of a checklist to determine compliance with ISO31000 recommendations. The expansion strategy is selected when the threat level exceeds the risk manager's ability or authority to resolve it (Garschagen *et al.,* 2018). In this case, the resolution of the problem is transferred to a higher level of management of the energy sector. Avoidance is a strategy that is preferred in the event of the possibility of a threat (man-made, social, financial, organizational, etc.) of a critical or catastrophic level with a high degree of probability. Such a threat can be avoided by eliminating the cause that generates it, or by changing the mode of operation of the energy market subject (Agustia *et al.,* 2020). The risk-taking strategy means awareness (a risk will inevitably occur) of a threat and active (reservation, limitation) or passive (observation) response (Nakano and Lau, 2020). Reservation is one of the main ways of managing the overall energy risk. The specifics of reservation is the impossibility for the subject to transfer the energy risk to the insurer/guarantor by means of insurance/guarantee, or to stock market participants by means of hedging carried out using derivatives (Atanga, 2020). Along with the financial reservation, an important role is played by the physical reservation of energy resources (stocks of natural gas, oil, coal, etc.) for ensuring the stability of the operation of energy market subjects. The threat reduction strategy involves reducing the probability or reducing the consequences of its occurrence by preventing the occurrence of risk or diversifying it (Rehman and Anwar, 2019). Risk prevention involves the implementation of preventive procedures aimed at preventing risk events or minimizing the probability of their occurrence. Diversification consists in the distribution of energy production between several organizations that are not directly related to each other, or in attracting funds (resources) from many sources. Diversification is one of the ways of reducing the overall energy risk exposure by expanding the suppliers, paths and types of energy. Other forms of diversification include changing the structure of energy production and attracting funds (including energy resources) from different sources that are weakly dependent on each other (Yang and Lee, 2020). It should be noted that risk diversification reduces only unsystematic (specific) risk, and not systematic risk caused by market conditions of business. The strategy of transfer is that the rights to the threat are transferred to a third party for a certain reward. Risk transfer methods include (Tang *et al.,* 2021): insurance; contracts with a detailed description of the rights and obligations of the parties in the event of certain circumstances; exchange agreements (hedging). The transfer of risk is beneficial for both the transferring and receiving parties since: possible large project losses for the transferring party may

be insignificant for the receiving party; the receiving party has a better mechanism for reducing the level of losses and a system for controlling them than the transferring party. In the electricity sector edging involves reducing the level of risks of fluctuations in the price level of energy resources (for example, electricity) under conditions of free trade, as well as the risk of negative events.

So, let's identify the main mistakes during the integration of a risk-oriented approach at the enterprise, regardless of the industry of the national economy (Wang 2019):

- The claim that systemic risk management is a solution exclusively for large businesses. Unsystematic risk management.
- Incomplete risk identification. If you only identify the event or only the impact and do not identify the weak points, risk management will be quite complex and unpredictable. In this way, the source of the risk and the reasons for its implementation will not be determined.
- Concentration on minor risks (errors in risk prioritization).
- Inefficient risk management strategy. Use of different standards for risk management, different accountability of management systems.
- Selective risk management. Any type of activity that is subject to risks: market, information, credit, etc.

High-risk business conditions require large companies to focus on economic security issues. The clarity and logic of the sequence of stages of risk identification of energy companies is a guarantee of overcoming risks and the absence of uncertainties that generate them. It is also important to consider human and organizational factors and their deviation from expected indicators in the process of identifying risks. When selecting a risk identification method, one should consider the completeness of the input data, the specificity and the desired expected results.

CONCLUSION

Identification of the level of predictability of indicators of organizational development based on two levels of the hierarchy of the energy system in relation to the distribution infrastructure makes it possible to identify sectoral problems that will influence the activities of energy companies in the future: the inconsistency of regional development programs with the pace of both international and national economic development in the field of energy makes it impossible to form an optimized package of strategic alternatives. Positioning risks on the field of the "probability/impact" matrix allows you to prioritize them by two criteria. The highest probability is characteristic of price and operational risks. Risk positioning in 2–4 quadrants confirms the existence of a potential threat to the energy security of Poland. The structure and content of the energy risk management system were further developed, which includes the possibility of identifying and qualitatively assessing the probability of occurrence of risks, the level of their impact by visualizing the results with the aim of positioning risks on the field of the "probability/impact" matrix, which will contribute to establishing their priority according to these criteria. This system should include the possibility of its gradual implementation in the energy policy. Its use allows you to reduce the level of energy risks for managers of energy companies, civil servants of executive authorities. The energy security risk assessment matrix was created. The development of a strategy for the behavior of the subjects of market relations in the Polish electricity market should be based not only on the results of risk identification and assessment and the developed risk management plan, but also on the risk response plan and the method of their control (monitoring). The method of forecasting the total final energy consumption of the country was improved for forecasting the volume of energy resources with the aim of using it for creation of energy policy, which takes into account such variables as the economic condition and the political situation in the country. The main author's contribution in the study is the development of the structure and content of the energy risk management system, which, unlike the existing ones, includes the possibility of identifying and qualitatively assessing the probability of occurrence of risks, the level of their impact by visualizing the results for the purpose of positioning risks on the field of the "probability/impact" matrix, which will contribute to establishing their priority according to these criteria. The practical significance of the obtained research results lies in the design and development of a methodical and practical basis for ensuring the formation of the economic policy of Poland in the energy sector. At

the same time, the main limitation of this study is the consideration of hybrid energy risks. That is why the perspectives for research in this subject area include the development of a mechanism for leveling hybrid energy risks at all hierarchical levels of the economy.

AUTHOR CONTRIBUTIONS

F. Nazarova performed the literature review, experimental design, analyzed and interpreted the data, prepared the manuscript text, and manuscript edition. T. Voropayeva performed the experiments and literature review, compiled the data and manuscript preparation. N. Andriichenko helped in the literature review and manuscript preparation. O. Sokolova performed some of the remained experiments.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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PUBLISHER'S NOTE

ABBREVIATIONS

b, c. g, k	Desired model parameters
C	Management risk
d_t	Random variable
EU	European Union
Eq.	Formula
F	Financial risk
F(Y)	Mathematical expectation
Fig.	Figure
H	High risk impact
HH	Very high-risk impact
h_{it}	Dummy variables reflecting the action of external and internal factors on the operation of the energy market
I	Types
I	The minimum level of dependence of the EU economy on gas imports
KSV	Relative semivariance value
L	Low risk impact
LL	Very low risk impact
lim	Sequence limit
L(t)	The level of the dynamic series during the time interval t
Leg	Legal risk
IEA	International Energy Agency
n(t)	A deterministic component that describes the main tendency (trend) of changes in an economic indicator over time
M	Medium risk impact
O	Operational risk
P	Price risk
Pol	Political risk
p(y)	Standard deviation (root mean square deviation)

RBS	Risk Breakdown Structure
PSE	Puget Sound Energy
S	Consumption risk
S-shaped	The curve shows the relationship between the costs (efforts) associated with improving the product or production process and the results obtained from it.
SSV	Semi-squared deviation absolute value
SV	Semivariance absolute value
Tr	Partial risk relative coefficient
V	Natural risk
W	Variation coefficient
w	Risk impact assessment
Y	Discrete random variable
Y_1, y_2,y_3	Possible consequences of the event according to optimistic, moderate and pessimistic estimates, and the probability of its occurrence
Z	Interaction risk
%	Percent

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