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Diversification as a Method of Ensuring the Sustainability of Energy Supply within the Energy Transition

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Abstract: This article presents a structured approach to the implementation of diversification in the energy sector during the energy transition, accompanied by crisis phenomena in the economy. On the basis of the study of the unique features of the electric power industry, it is proved that diversification is an effective tool ensuring sustainable operation and development in the course of transformation. The specific directions of diversification to achieve technical, environmental and economic results are considered. The authors demonstrate that diversification can manifest itself in different forms: as a way to implement a systematic approach to energy transition management, as a complex set of organizational and technical changes in the electric power industry, and as an institutional mechanism to support innovations. Tools for managing diversification during the energy transition have been identified. In particular, the experience of implementing systems of integrated planning of energy resources is systematized, representing a set of legal and economic procedures that contribute to minimizing public costs for energy services to consumers. The key provisions of the structural maneuver have been formulated. These include specific directions of diversification, consisting of a certain increase in the specific market share of thermal power plants, in the structure of generation capacities of renewable energy sources in order to compensate for their increased production costs, and nuclear power plants under advanced development. The advantages and limitations of the developed principles of diversification in the context of the global energy crisis are discussed.

Keywords: diversification in energy; energy transition; sustainable development and performance; integrated resource planning; technical and organizational transformations; structural maneuver; energy crisis

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1. Introduction

In economics and finance, the term "diversification" has traditionally referred to a corporate strategy involving the distribution of financial assets and investments in favor of promising areas of business development that could ensure competitiveness and sustainable growth. The term was used for the first time in 1952 by the American economist Harry Markowitz in his article, "Portfolio Selection" [1]. Today, diversification scenarios relating to production, products, prices, risks, investment portfolios, and the overall economy are well-known and widely described [2–4].

Diversification is a complex term which is used in various fields of knowledge, science, and technology. At its core, processes are understood from the viewpoint of diversion, which means that risk reduction by means of variable solutions increases—adding flexibility during the implementation of various processes, and resource usage. It is relevant that in the contemporary view, almost any company is more or less diversified: a single-product company is an exceptional phenomenon today [5].

One of the most vivid examples of the term's usage is the diversification of business models in terms of expanding product ranges, forming consumer values, optimizing alternatives of enterprise resource usage, and development of sales schemes. Market players from a wide variety of markets apply diversification to their business models: airlines work with both a full range of services, and with simple or discount carriers; publishers use digital forms of communication with consumers along with traditional subscription-based models; and retailers can work both in regular outlets and through e-commerce [6,7].

A number of studies are dedicated to the peculiarities of diversification in fast-growing industries (digital/IT firms working with big data, and innovative startups). It is emphasized that big data analytics allow firms to continuously monitor the state of markets, scan data from various sources, and better integrate resources to proactively respond to structural changes in demand. The firm armed with the most complete information can use to its best advantage the business opportunities based on cross-industry development [8,9].

Rising competition, the creation of fundamentally new ways of delivering value to the consumer through digital technologies, and the overall uncertainty of the external environment can all cause an increase in interest in the problem of diversification as a way to reduce business risks and improve an enterprise's sustainability. It is significant that this interest is also observed in those markets that, until very recently, did not have a great requirement to compete for consumers.

In the power industry—a complex infrastructure industry that is the object of this study—diversification as a form of development has become increasingly common over the last two decades. An important factor here is the cascade of innovative technologies of a different nature that appeared during the Industrial Revolution 4.0 [10–12], digitalization [13,14], and energy transition [15–17] which, through their synergies, open "windows of opportunity" for different types of energy businesses.

A confirmation of the growing interest in this phenomenon is a comparative analysis of the frequency of using the concepts "diversification", "diversification in energy", and "diversification in business" as keywords in scientific publications indexed in one of the world's largest databases, Science Direct [18], which is shown in Figure 1. It is noteworthy that the number of publications containing the keyword "diversification in energy" is significantly higher than the number of articles with the words "diversification in business". In part, this can be explained by the fact that the problem of diversification at the industry level, and, in the case of the current study, in such a complex entity as the electric power industry, is underexplored. However, as can be seen from Figure 1, its relevance and significance have become much more acute during the economic recession caused by the consequences of the coronavirus pandemic and the energy crisis that is growing today [19].

The main intent of the article, therefore, is to ameliorate the lack of knowledge about diversification in the energy sector: firstly, in terms of systematizing the main theoretical ideas about energy diversification as a complex phenomenon that covers not only business issues (for example, the spectrum and variability of energy services for consumers), but also a large number of technical, environmental and economic changes in the energy production circuit; and, secondly, when substantiating priority directions and recommendations for diversifying during the energy transition, which could form the basis of the energy and resource policy of the regions, as well as plans to ensure their energy security.

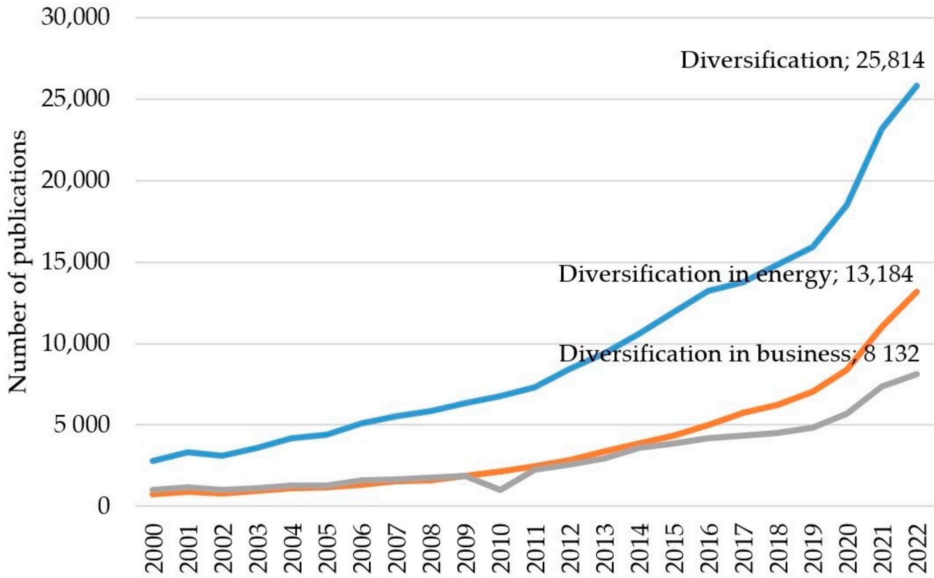

Figure 1. Dynamics in number of publications with key words “diversification”, “diversification in power energy”, “diversification in business”: database Science Direct analysis.

2. Theoretical Background: Hypothesis and Logic of the Study

The purpose of this study is to determine the directions and mechanisms for diversification management during the energy transition (ET)—the process of deep organizational and technical transformations in the production, transmission and use of electricity to create a climatologically and environmentally safe power industry. The solution to this task is based on the latest scientific and technical achievements, innovations in energy technologies, methods of organization, and forms of interaction of energy-generating organizations maintain with consumers. It requires significant intellectual, investment, and energy resources.

The authors’ hypothesis lies in the fact that structural and technological diversification, which assumes an optimal combination of different methods of energy production and rationing of energy use based on advanced collaborative tools with consumers, provides comprehensive sustainability of energy supply, which in the context of ET is considered by us from three perspectives: environmental, economic and technical.

The research is based on three logically-interrelated steps. The first step supposes the conceptualization of the “diversification” phenomenon in the industrial dimension. Theoretical methods of analysis, work with the scientific publications’ databases, and statistical materials of consulting companies were utilized. At the second step, the development of methodological provisions and instrumental bases of diversification in the power industry in the context of ET were carried out. Among the methods, the following ones were used: a logical framework approach, conceptual design, and visualization methods. The third step supposes discussion of the provisions developed in terms of their advantages and limitations in the context of the global energy crisis.

As our analysis has shown, in the context of the specifics of energy sector, the process of diversification is understood as: an increase in the range of forms and types of power facilities of primary energy sources [20,21]; an increase in the number of types of energy products and services, ensuring the diversification of the national economy [8,22]; and expanding the range of economic actions of the state, minimizing environmental impacts, and increasing energy independence and national security [23–25]. There are articles devoted to local aspects of the diversification of regional energy in order to improve the efficiency of certain industries such as agriculture [26], transportation [27,28], service industries [29,30], and the construction industry [31].

The term "diversification" is particularly often used when describing diversification of electricity and heat supply methods based on RES as an important task of the ET [32–34]. For example, Giannuzzi [33] stated that, "the growing attention to environmental problems leads to an increasing integration of renewable energy sources into energy systems, contributing to their decarbonization, supporting the diversification of primary energy sources and increasing the safety of energy supply, which is threatened by the uncertain cost of traditional energy sources". Along with the diversification of energy production methods, a separate category of research [35–37] is dedicated to the diversification of the structure of energy consumption—a strategy aimed at strengthening both the economic and political safety of the country, the purpose of which is to reduce the risks in energy resource supply disruption, as well as preventing the creation of monopolies on the supply of certain energy sources.

The above-mentioned direction of diversification of business models has also been very actively analyzed in the energy sector in recent years. The trend to reversing the business models of energy companies in the segment "energy as a service" (Energy-as-a-Service, EaaS) is worth mentioning, which supposes the creation of a diversified portfolio of various science-based services for the ultimate customer (customized microclimate, integrated management of household utility infrastructure, energy storage management, charging station rental, differentiated power and heat rates, and energy consumption automation and programming for household devices) [38,39]. EaaS agreements are becoming more common in the world: by 2026 the market volume is expected to reach $220 billion (Figure 2).

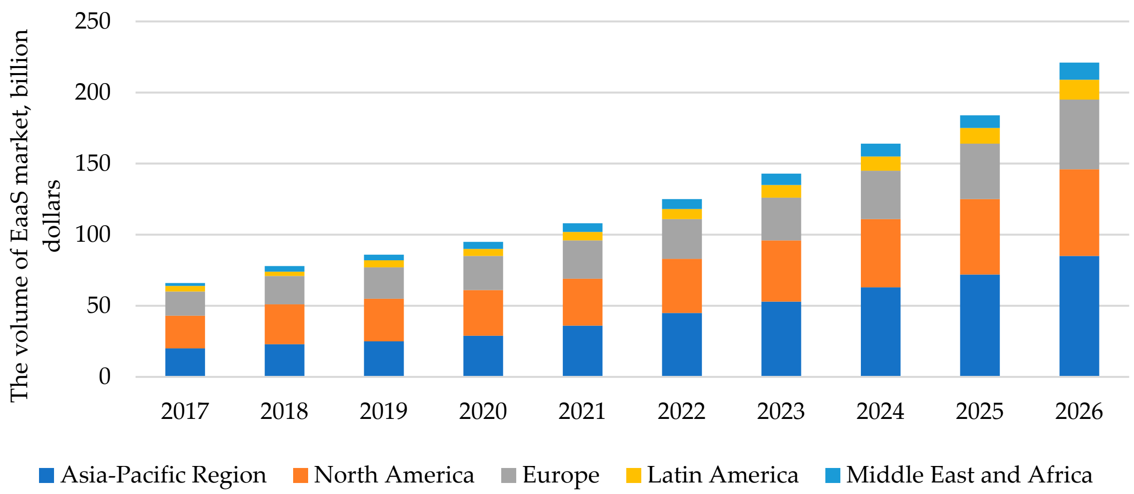

Figure 2. Global market value EaaS for commercial and industrial sectors, in billions of dollars.

The EaaS business model has become especially widespread in the last few years at the level of energy transition activation in the advanced world [40,41]. It is implemented through partnership with suppliers of services and products from other industries—power plant engineering, electronic and automotive industries, and the IT industry. Among the active participants of the EaaS agreements are companies such as ABB, Siemens, GE, Tesla, Solar City, and Google. Thus, during the energy transition, diversification often takes on intersectoral forms.

Another example is oil and gas companies engaged in diversification projects, who may consider alternative energy the most advanced option. For example, in 2020, the Total corporate group (fourth in the world in terms of production) announced a new strategic goal: to become a world leader in renewable energy sources (RES). The company relies on liquefied natural gas (LNG) and electric power. British Petroleum has also been engaged for quite a while in the development of RES, on the basis of their Alternative Energy division, created in 2005. The company aims, by 2025, to increase its generation capacity (wind power plants and solar power plants) up to 20 GW, and up to 50 GW by 2030.

The generalization of scientific papers and analytical studies allows us to draw conclusions about a very wide range of options for diversification in the industry (Figure 3).

In general, it can be concluded that in the energy business, diversification pursues two goals. First, it relates to risk reduction around energy supply reliability by means of employing a variety of technological methods and forms of energy production management. Second, there is a search for new, profitable scopes of activities. This is the result of an integrated recording of the natural and climatic, fuel-energy conditions of electricity production, the features of the spatiotemporal distribution of electric energy demand, and the power consumption characteristics of individual consumer groups in different regions of the country.

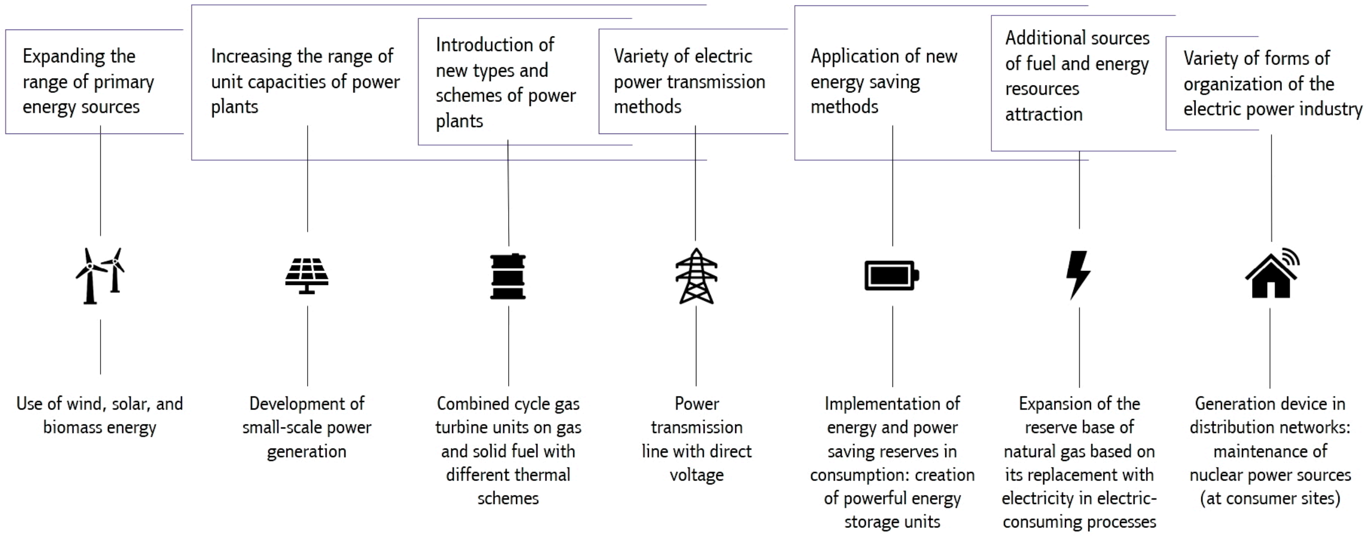

Figure 3. Current directions of diversification in the power industry.

The critical factors for diversification are progress in the field of technical equipment, organization of energy production, and applied market mechanisms [42]. Thus, the semantic charge of "diversification" in the energy sector, in contrast to "diversification" as a general business term, has a significant multidimensional specificity that imposes special requirements on the choice of directions and forms of diversification as a tool for solving a multi-criteria task—ensuring a balanced increase in the reliability, environmental friendliness, and efficiency of the energy supply.

3. Results

3.1. Forms and Methods of Diversification in the Electric Power Industry

In relation to an abstract technical object, the understanding of diversification can be expressed in the following way: the object is saturated with structural, active elements endowed with different properties that form the final results of its functioning. Such an element taken separately has a contradictory effect on the final result: it simultaneously improves some and worsens others.

Working as part of a single mechanism, these elements interact, both complementing and limiting each other. Under some optimal combination, they neutralize the mutual influence of the final results of the object's functioning. It ensures the stabilization of these results at an optimal (normative) level.

It is obvious that the number of elements forming a diversified structure should be proportional to the number of final results characterizing different aspects of the object being examined.

Example: creation of a diversified structure of a large-scale energy system, including power plants with RES, nuclear power plants (NPP), and thermal power plants (TPP) of various types using natural gas. Examined separately, these power plants have both known advantages and disadvantages. However, combined into an energy system for operation in parallel on the supergrid system, they form a certain structure that allows balancing of the integrated environmental, technical, and economic characteristics of energy production at the optimum level.

In this regard, we will highlight the characteristics of the structure-forming power facilities (Table 1).

Table 1. Advantages and disadvantages of various types of power facilities.

<table>
<tr><th>Type of Power Facility</th><th colspan="2">Advantages</th><th colspan="2">Disadvantages</th></tr>
<tr><td>Power plants on RES</td><td colspan="2">• Absolute environmental friendliness towards the impact on air
• Lack of demand for high-quality organic fuel (natural gas saving)
• Short construction time</td><td colspan="2">• Restrictions on ability to exceed installed capacity
• Lack of stability in electrical generation
• Enhanced cost of construction
• Large area required to set high-capacity power plants</td></tr>
<tr><td>NPP</td><td colspan="2">• High environmental efficiency in air environment (in a normal operating environment)
• Significant saving of organic fuel when operating in a constant load mode with a maximum installed capacity utilization factor (ICUF)
• The possibility to bring NPP to the load concentration centers (due to the independence of their location from the fuel base)</td><td colspan="2">• Difficulties in choosing construction sites
• Technical and economical limitations for operation in variable duty (low maneuvering qualities of nuclear power units)
• High cost and long construction time
• Significant repair and operating costs</td></tr>
<tr><td rowspan="2">TPP with CCGT</td><td>By comparison with NPP</td><td>• The lowest cost of construction
• More freedom in the choice of locations
• Maneuvering capabilities</td><td rowspan="2">By comparison with NPP</td><td rowspan="2">• Emission of hydrocarbon fuel combustion products
• Significant absolute volumes of natural gas consumption (with increased COP of energy units)</td></tr>
<tr><td>By comparison with steam-turbine TPP</td><td>• High energy coefficient of performance (COP)
• Low specific indicators of combustion products air emissions (for all components)</td></tr>
</table>

Directional diversification of organizational and technical transformations in the electric power industry includes:

- introduction of new technological elements into the structure of generating capacities of power systems (for example, combined cycle gas turbines [CCGT] on various circuits during work on gas and solid fuel);
- introduction of additional methods of energy supply based on demand-side management for energy and power;
- range extension of unit capacities of power plants based on the development of small-scale power generation;
- obtaining of additional natural gas resources through replacement with electricity in technical processes (fuel-saving direction of electrification). Diversification of the mechanisms of management methods involves:
- methods of direct public administration: strategy, programs, organization, and investments;
- administrative and legal measures to attract energy companies;

- methods of economic stimulation of the energy business (guaranteed investment mechanisms, tax incentives, etc.);
- market mechanisms.

3.2. Ensuring the Sustainability of Electricity Supply by Means of Diversification

A number of special studies devoted to the problem of sustainability in the electric power industry conducted by the authors of the article [43–45] made it clear that the concept of sustainability can be used in two ways.

1. Sustainable functioning of the electric power industry. In this context, it means the ability of the industry to meet, at any given time, the electricity and capacity needs of the national economy of a country (or region) with the necessary level of power supply reliability, maintenance of quality indicators of electricity (frequency, voltage, etc.), minimal impact on the environment, and for this to be achieved as a socially acceptable cost (both for consumers and producers). The mode of sustainable operation supposes limited commissioning of new facilities to ensure the reserve and fixed capital renovation (replacement coverage and modernization), increasing electrical network transmission capacity, and the improvement of technological systems of operational dispatch management.
2. Sustainable development of the electric power industry. In this context, it assumes the expansion of its scale (introduction of new capacity) to ensure economic growth and increase the level of electrification of the national economy by means of advanced electric-intensive processes introduction. At the same time, qualitative transformations of the industry are taking place (optimization of the generation structure, fuel-energy balance, and introduction of environmentally-friendly units). Sustainable development of the electric power industry is a condition and consequence of economic growth.

It is significant that sustainable development is impossible without ensuring the sustainable functioning of the electric power industry, which can be regarded as a necessary but insufficient condition. It should also be noted that sustainable development is based on effective management of all risk types generated by the uncertainty of the external environment.

The problem of sustainability in the context of this study has technical, environmental and economic aspects.

Technical sustainability is the ability of the power system (including distribution power grids) to maintain electric power supply and its parameters to a normative value under the conditions of various disturbances. At the same time, sustainability of the power supply can be accomplished in two ways.

The first (traditional) way is aimed at restoring the volume and quality of the power supply in case of its interruption. For this purpose, an operational reserve of power is created in power systems and automatic control devices are installed. The main drawback of this method is the management of "deviations", that is, a reaction to an event that has already happened. The effectiveness of this method depends on the rapidity and reliability of automatic protective devices and other means of regime control.

The other method can be called "preventive", which is proactive sustainability management. Its essence consists of the following provisions.

- At the first stage of the power system technical development design, the criterion of sustainability is put forward as a guiding imperative; it relates to the choice of standard sizes of power plants and power grid equipment, the formation of the structures of generation and transport capacities, and the determination of the optimal configuration of intra-system connections.
- Electricity consumers with a certain potential for demand regulation are involved in sustainability management in a proactive mode, especially in terms of rationalization of load schedules, as well as general energy saving.

- The power system is equipped with an automated control system based on the Smart Grid concept, which enables multi-criteria optimization of all processes.
- Monitoring the production, transmission, and consumption of electricity in real-time mode to provide self-monitoring, self-regulation and self-repair of equipment parameters.

Environmental sustainability is characterized by the capability to maintain environmental indicators within the specified standards when production conditions change (fuel balance, generating capacity, load demand, and demand behavior).

Economic sustainability is considered in two forms. The first form is the ability to keep a balance between the available capacity of power plants and the maximum load of consumers at any time and without limiting demand. At the same time, a certain excess of available capacity without reference to the operating reserve over the maximum load creates a so-called strategic reserve in the power system. It is necessary to compensate for an unplanned demand increase or gap to the scheduled date for the commissioning of new power plants. Its value depends on post-evaluation of the reliability and accuracy of long-term demand forecasting and the coordination of plans for the development of the energy system and consumers. It is clear that the generating reserve margin should be supplemented by an adequate reserve of the transmission capacity of electric networks.

The second form of economic sustainability is considered as an opportunity to set a price for a given electricity capacity at a mutually acceptable level, given any changes in the demand and structure of generation capacities. It allows, on the one hand, ensuring the desired level of production profitability for energy companies, and on the other hand, keeping consumers from switching to self-generated power supply. It is referred to as the franco-consumer price for high-voltage enterprises that have an increased energy intensity, and who might have their own energy utilities and the ability to consider alternative forms of energy supply.

Determining the lower price limit, the profitability of production in generation and grid companies is assumed at the level of the average bank rate on long-term loans, increased by 2–3 percentage points.

The upper price limit is determined from the condition of equal efficiency of external and self-generated power supply. It requires a model of a virtual TPP equipped with advanced energy units and providing parameters of electrical and thermal loads averaged over a selected representative group of industrial enterprises in a given region or power consumption system. The cost of production at a virtual TPP is calculated by summing up standard costs with a nominal standard profit, also determined on the basis of interest rates. This is the maximum price of electricity—the upper limit of the price range established under the terms of economic sustainability of the price range.

To organize sustainability monitoring, it is necessary to create an appropriate regulatory framework. With regard to economic sustainability, this applies, in particular, to determining the minimum required excess of available capacity over the maximum load in balance, as well as the boundaries of the price range (upper and lower price limits). The price of electricity should be within these limits, according to the conditions of sustainability. Below, in the context of the proactive method of ensuring the sustainability of power supply, the issues of forming the structure of generation capacities of power systems are considered.

Diversification of generation capacities means a variety of production and technical characteristics of power units that determine their functional purpose and area of application. These characteristics include:

- the type and thermal scheme of the power unit (for example, a CCGT-TPP with heat recovery steam generator);
- the type of primary energy resource (organic fuel, nuclear fuel, or natural power);
- the unit power of the power plant in the selected range (small, medium, large).

The demand for a particular power plant in the generation market and its prevalence in the power system depends primarily on economic indicators, as well as on technical and economic efficiency: COP, maneuverability, durability, reliability, and service life (technological lifespan).

Among the factors of diversification, we will first highlight the introduction of new advanced power plants for certain areas and conditions of application.

Examples: highly economical low-power heating plants, small nuclear power plants of advanced safety, environmentally-friendly pulverized powder-coal steam-turbine plants (STPs) with increased COP at supercritical steam parameters.

It is also contingent on the spread of limited-use power plants, due to the improvement of economic indicators and technical improvements that increase the efficiency of their use.

Examples: reducing the construction cost and operating cost of the wind power plants by equipping them with energy storage units, increasing the COP of gas-turbine plants (GTPs) operating either as a part of an STP, or as peak energy sources.

3.3. Diversification Supervision in the Time of Energy Transition

Engineering policy in the field of diversification should become the basis for the development of long-term programs for the development of energy systems of all levels, including elements of optimal planning.

Next, it is necessary to form special-purpose generation companies having only the single-type power plants in operation—for example, units of RES or GTP and CCGT, nuclear power units, etc. It is worth pointing out that in this case, competition shifts from the field of generation to that of equipment suppliers, and of construction and installation contractors.

Energy generation companies carry out the new capacity addition as directed by a special authority of energy systems development management (for example, a transmission system operator with extended functions) on the basis of a project issued to them.

Energy generation companies choose equipment suppliers, and construction and installation services, on a competitive basis. Energy companies attract investments and make a profit on the invested capital during the operational process of the commissioned facility. The relevant divisions of power engineering firms are contracted to carry out the turnaround maintenance. The latter should ideally provide service support for equipment throughout the entire life cycle of the facility. They can also carry out work on the modernization of power equipment according to projects agreed with the generating company—the owner of the power facility. Maintenance of energy enterprises is carried out in the same manner as new construction.

The operating and repair expenses of generating companies are covered by the payment of the transmission system operator to bear the load at a fixed price calculated using the standards of variable and fixed costs. This price also takes into account the regulatory level of profitability for the energy company's profit generation. Repeatedly, the price is indexed with respect to cost variations in fuel, staff wage rates and interest on bank credit. If expenses are reduced compared to the predetermined and standard costs, this price is not subject to revision downwards in a given period. If the generating company has made capital investments, then a contracting price is applied for the payback period, in particular, exceeding the standard one.

Thus, government programs of diversified energy development will be implemented on the basis of attracting private investments and with respect to the economic interests of the relevant business structures.

Integrated Resource Planning (IRP) is considered a highly effective management tool for the regional electric power industry, in essence optimizing all directions and forms of diversification in power generation, distribution, and utilization.

The Integrated Energy Resources Planning System is a set of legal and economic mechanisms, as well as procedures that ensure the minimization of social costs, for energy consumer services [46]. Minimization can be achieved both by increasing the efficiency of energy production, transmission and distribution, and by increasing energy efficiency in the consumer sector. In this regard, the term "integrated" reflects the requirement for a comprehensive analysis and comparison on equal footing of all available options for solving the problem of energy supply to the region served by the power generation company, with respect to all types of resources and the effects of their use.

In particular, the IRP system is based on an integrated approach to realizing the possibility of energy saving in both sectors of the national economy—in the electric power industry and in the areas of end-use energy demand, where the energy saving potential is significant. At the same time, the energy company's expenses on energy saving for consumers replace significantly high costs for its development (including the process of renewal of generating capacities). It should be noted that this difference in costs is the economic basis of the IRP and the balancing of interests for the main subjects of the energy market.

As a result of the application of the IRP method, all interested parties benefit: energy companies, electricity and heat consumers, and the region as a whole.

Energy companies reduce the risk of investing in new and expensive generation capacity in conditions of high uncertainty around the dynamics of energy demand. Due to the involvement of additional resources, primarily energy conservation but also renewable energy sources, the flexibility and adaptability of energy systems are increased.

Consumers receive a more reliable energy supply at a relatively lower cost. They are also granted additional technical and financial opportunities to access advanced energy-efficient technologies.

The region increases its level of energy independence and security, and improves its economic situation. Social and environmental situations become more stable.

At the level of an energy company within the framework of the IRP, the planning process includes the following stages:

1. Definition and planning of goals (based on the company's mission);
2. Forecasting of consumers' electrical and thermal loads;
3. Analysis of the available generation capacities and capabilities of the power system, balanced within the planning timeframe;
4. Assessment of developed resources in energy demand, i.e., the potential to increase efficiency in energy consumption;
5. Assessment of developed resources in production, i.e., the potential for efficiency improvement in energy generation;
6. Analysis of environmental consequences for each element of the development of the energy system;
7. Uncertainty and risk analysis;
8. Plan selection for resource management;
9. Public evaluation of the energy system development plan.

In order for efficiency improvements in energy consumption to become equivalent to an energy supply resource, the company should develop and implement demand management programs. Electricity and heat can also be bought from independent producers in a region if the costs are less than the marginal long-term costs of the energy company. At the same time, the activities of regulatory bodies become more complicated, since the structure of the company's costs changes significantly due to the introduction of new types of activities, directions and forms of investment and profit.

Since the future is full of surprises, when making planned decisions, it is necessary to try to minimize possible risk in order to prepare for unforeseen changes. The analysis of uncertainty and its associated risk is a prerequisite for successful planning and an important element of the concept of IRP. The advantages of IRP in comparison with the traditional planning method can be seen from Table 2.

Table 2. Difference between traditional planning method and IRP method in energy company.

Unique Feature	Traditional Method	IRP Method
Type of product	Electricity and heat energy	Power services
Influence of energy company on demand (customer communication)	Power consumption—external uncontrolled characteristic	Power consumption—subject to control by the energy company
Power supply source (resources)	Own generation capacity	Additionally: end-use energy saving; independent energy producers in the region
Engineering policy	Mainly large-scale units on nuclear and organic fuel	Wide range of power plants and power layouts
Environmental factors	Taken into account indirectly through the corresponding costs	Taken into account directly through environmental criteria
Public influence	Involved in decision-making in a limited and non-systematic way	Gets access to the plans of the energy company and actively participates in their discussion and approval
Uncertainty and risk management	Not taken into account or taken into account indirectly	Special measures are being developed to reduce uncertainty and associated risk
Planning models	Optimization (deterministic)	Simulation (probabilistic, multivariative)

Governments apply different approaches to IRP. For example, in the USA, in California and Hawaii there are processes that integrate government transmission and distribution planning into broader distribution system planning processes. California includes integrated distribution planning in an interagency integrated planning process approved by SB 100 and led by a California Joint Agency, comprising the California Energy Commission, the California Public Utilities Commission and the California Air Resources Board. Joint agencies lead processes that seek cost-effective outcomes with integrated environmental goals of the future energy system.

At the level of large regions in the USA, rich experience has been accumulated in IRP application. There is a practice of developing indicative plans covering several states with numerous energy companies. Thus, the Planning Board of the Northwest of the USA has developed a regional model that simulates the effectiveness of decision-making in the field of power plant construction and supposing alternative resources usage when future loads are unknown, and they are expected to cover a wide range. This has been dubbed the "integrated analysis of the energy system developing" model. It allows planning of energy sources based on the analysis of multiple options of energy system development. Iterative procedures are carried out until the structure of energy sources is determined, which most accurately allows the combining of low costs with an acceptable level of risk.

The procedures required to develop a regional plan include:

- electrical load forecast;
- analysis of the existing power system with all its sources and load diagrams;
- technical and economic assessment of all available resources, including energy conservation;
- simulation modeling of the power system's operation.

Alongside with the development of forecasts, the availability, reliability, and cost of possible options for energy production and energy conservation are analyzed. Moreover, energy efficiency growth reserves are considered for all elements of the energy supply process: end use, transmission, distribution, and generation. The simulation technique results contain massive information, such as "What ifs?", about a large number of forecast options. Each of them has its own cost allocation.

In its final form, the plan contains:

- the final set of resources, which are ranked based on costs and risks associated with their use;
- regulations that should be followed when making decisions on the development of the energy system;
- a package of measures that, on the recommendation of the regional Council, should be taken over the next few years.

3.4. Structural Maneuver

The idea of structural maneuvering consists of a certain increase in the share of TPPs in the structure of the generation capacities of energy systems, in order to compensate for the growth in production costs with the outsized development of renewable energy and nuclear power plants. Along with neutralizing price changes, due to the structural maneuver, the cost of maintaining capacity reserves is reduced and operation is ensured in different zones of the load schedule.

It requires TPPs running on natural gas, equipped with a CCGT and operating in a constant load mode. These power plants temporarily replace the corresponding capacities of future nuclear power plants.

The structural maneuver is estimated for the period during which measures will be taken to compensate for the growth in electricity prices for consumers. They are enacted in all elements of energy systems: generation, transmission, distribution, and consumption of electricity. In the foreseeable future, such measures will primarily include managing the demand for energy and capacity, developing small-scale distributed energy generation, and reducing losses in electrical networks, the reduction of production costs at nuclear power plants by increasing the capacity factor based on the optimization of the repair cycle.

The appearance of persistent signs of lower prices in the wholesale and retail markets means the end of the strategic maneuver; the corresponding TPPs are transferred from the base to the variable mode of operation or the operational reserve. NPPs take their place in the constant part of the load schedule of the power system. It should be taken into consideration, however, that this process is carried out gradually, with the preservation of part of the capacities of these TPPs in the load base.

The power of the structural maneuver is limited by the possibility of increasing the supply of natural gas to TPPs, as well as the deterioration of the electricity generation's environmental performance. Therefore, with a significant increase in electricity prices, it will be necessary to also apply direct regulation of tariffs, in the form of reimbursement of costs to consumers or payment of a difference in prices to suppliers.

The method of direct price control has two serious drawbacks. First, on an industry-wide scale, this represents a very significant level of budgetary expenditure. Secondly, there is a possibility of regulation replacing organizational and technical methods of price stabilization (as above—e.g., demand management, losses in networks, and small-scale energy), since this approach is explained by the simplicity and speed of that method of financial compensation. However, in this case, there is a slowdown in highly-efficient innovations in the electric power industry. Nevertheless, the method of tariff control can be useful as a temporary and additional tool for price stabilization in the ET process.

A conceptual representation of the structural maneuver is shown in Figure 4.

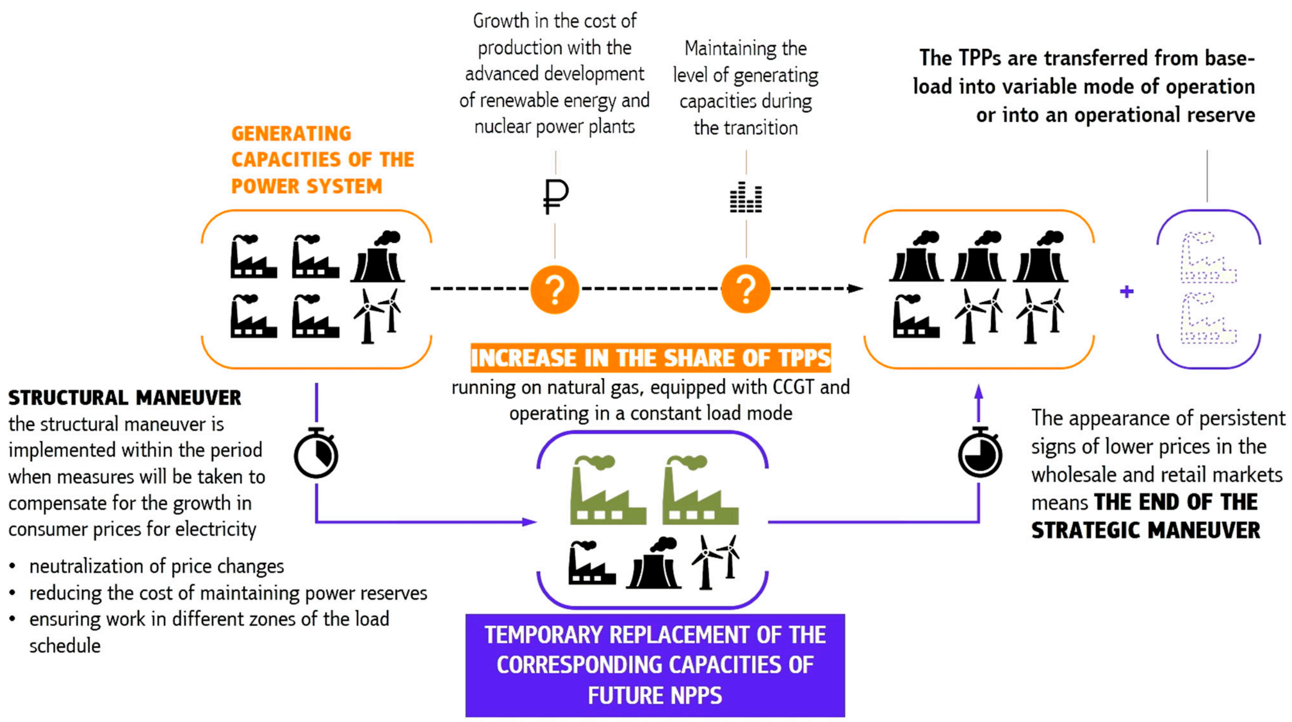

Figure 4. Visualization of the logic of structural maneuver.

4. Discussion

As our findings have shown, diversification in the power industry brings important benefits. In particular, the diversification of energy sources makes it possible to achieve the following:

- Political independence. When one country relies on another country to meet most of its energy needs it exposes itself to the risk of intimidation, coercion, and manipulation by the supplier [47,48]. The distribution of energy requirements among different suppliers allows the importing country to reduce its dependence on one supplier and strengthen its independence in world politics.
- Economic growth. Getting energy from multiple sources and suppliers insulates the importing country from energy disruptions when one source or supplier is unable or unwilling to meet demand [49,50]. Energy diversification ensures permanent energy security, which creates favorable conditions for entrepreneurship, innovation, research, and development.
- Comfortable environment. The use of renewable resources, such as solar and wind energy, reduces the threat of energy shortages with a lower environmental impact compared to hydrocarbon energy sources [51,52].

The possibility of forming diversified structures of generation capacity from installations that perform strictly-defined, specialized functions makes it possible to take into account the regional conditions of power supply to the fullest extent: availability of fuel and energy resources, natural and climatic characteristics, consumer load schedules, and the ecological situation.

For example, CCGT-TPPs are adapted to operate at low electrical and higher thermal loads, while by contrast, combined-heat power plants using CCGT operate at relatively high electrical loads. In addition, such CHPPs have a high efficiency in generating electricity under the condensing regime, which increases their maneuverability when operating in the variable part of the load schedule. At the same time, there may be restrictions on the capacity of these installations associated, for example, with the provision of a region with natural gas.

The creation of an optimal structure of generating capacities in the regions (energy systems) gives the following results:

- The obtaining of a power system balanced in terms of power and load;
- a decrease in the average unit capacity of power plants;
- improved maneuverability of high-performance power plants;
- reduction in the length of electrical networks of all voltage levels;
- reduction of electricity losses in distribution networks;
- increased capacity factor of renewable energy installations (including by equipping them with energy storage devices);
- reduction of the share of natural gas in the balance of TPPs;
- an overall reduction in the consumption of all types of fuel for electricity generation.

The combination of a diversified structure with demand management on the demand side of electricity can give the maximum effect, reducing the need for peak capacities and facilitating the passage of the night-load drop in the power system [53]. It also makes it possible to constantly balance the power system with some excess installed capacity. The above allows us to conclude that the progressive diversification of the structure of generation capacities provides a significant increase in the stability of the power supply in all aspects: reliability, efficiency, environmental friendliness, and safety.

However, it should be noted that diversification generates a number of technical problems. In particular, connecting a large number of low-power distributed-energy sources to the distribution system complicates the operation of the network and may even cause its destabilization. For the technical integration of these installations into the power distribution system, the introduction of mechanisms for automated control and monitoring of the interaction of RES with the network is proposed [54,55]. A separate problem arises in terms of creating an operating architecture of energy systems that combines centralized and decentralized (distributed) electric and heat power solutions—microgrids, small- and micro-generation, connected through modern information and communication technologies. The issues of optimizing the operating modes of such systems, and the search for options for their most economical and technically stable use, justified in particular on the basis of mathematical tools, are considered in sufficient detail for example in the studies of Zhang [56], Jia [57], Guan [58] and are not the subject of this article. However, they should be taken into account when creating a diversified regional energy system.

Diversification mechanisms acquire special significance during the current energy crisis. Changes in the foreign policy situation in 2022 fundamentally change the vision of the content structure of regional energy markets. According to various experts [59–61], the participants will reduce interdependence from each other by changing the product and the geographic structure of energy supplies. The external challenges of switching to new logistics schemes do not allow this to be achieved for several months and even years into the future, so market entities will have to look for compromise forms of interaction with increased risks of conflicts, and threats of partial termination of relations. An extreme problem appears regarding the use of natural gas. The plans of the European Union to achieve carbon neutrality by 2050 were generally based on moving away from the use of gas supplies, but now, moving towards at least 2030, they will apparently be significantly adjusted. Gas as a transitional fuel was to remain an important pillar of European energy at that time, and possibly beyond, as evidenced by the draft of a new taxonomy of energy sources published in early February 2022 [62]. It assumed that before 2030, new gas generation could be put into operation, if in 2035 it would be transferred to low-carbon gases. The forecasts of the International Energy Agency (IEA) also proceeded from the preservation of the role of gas in the European energy sector. The annual energy forecast of the IEA at the end of 2021 indicated that under the current energy control regime, gas consumption in the EU would decrease slightly, from 401 to 392 billion m^3 per year by 2030, while net imports would remain at about 350 billion m^3 per year, taking into account the reduction in domestic production [63].

As an alternative to gas, it is proposed to ramp up biomethane and hydrogen production, which in total can provide savings of up to 40–70 billion m^3 of natural gas annually [64,65]. However, in combination with the shortage of coal generation and the ongoing shutdown of nuclear power plants, even the IEA does not count on these sources as reliable substitutes for natural gas, and notes an increase in tension in terms of ensuring an adequate level of European energy security.

We proved that in the process of undertaking ET, we could not expect a complete phase-out of fossil fuels [66]. Apart from the crisis, there are other explanations for this. First, energy systems based on RES are subject to sharp changes in the amount of available capacity and price fluctuations, which ultimately translates the problem from a techno-economic one to a social and political one. Most likely, once the geopolitical environment is stabilized, developed countries will seek to create hybrid power systems that combine renewable energy sources and fossil fuel generators. As demand increases, the fossil fuel generators will be used as a backup, in which the marginal cost of electricity generation by a fossil fuel generator will determine the maximum price of electricity on the wholesale market. Second, not all sectors of the economy can be completely decarbonized. These sectors, which account for 40% of the world's total carbon emissions, include heavy freight, shipping, aviation, steelmaking, and the cement and plastics industries, among others [67]. Moreover, the onset of electrification will not be able to solve this problem entirely: according to the IEA, for technical reasons, about 30% of the final energy consumption in the designated sectors will, despite ongoing progress, continue to be provided by carbon-active technologies [68].

All of the above confirms the relevance of diversification principles, as well as the feasibility of diversifying the energy mix, which should combine both decentralized energy solutions (distributed generation), and large power plants that form the contour of system generation.

5. Conclusions

Energy transition is a complex, multi-criteria task that has environmental, technical, and economic aspects to ensuring a sustainable energy supply for the economy of the given country and region during the transition period. The solution to this kind of problem is based on the methodology of a systematic approach and for the electric power industry, a specific form of this is multi-vector, structural (and technological) diversification. It is the result of innovative transformations, covering and combining the processes of energy supply and electricity consumption, which include:

- range expansion of primary energy carriers with an increase in the share of RES and nuclear energy;
- equipping of TPPs with efficient gas turbine and combined-cycle plants that contribute to improving the environmental safety, efficiency, and technical sustainability of power systems;
- scale expansion of energy capacities with an emphasis on medium and small capacities;
- implementation of energy and capacity savings as an alternative to commissioning new generation and grid facilities;
- a new stage of electrification, comprehensively covering industry, transport, commercial, and household sectors, during which the primary hydrocarbon energy carriers are replaced by electricity.

As a result, a highly-diversified electric power industry of a new type is established in the process of ET, capable of providing high rates of economic growth and further development of electrification, and the environmental factor acts as a trigger for industrial modernization.

For the diversification to be undertaken, the following tasks should be performed:

1. A radical increase in the controllability of energy flows based on the latest intelligent technologies;
2. A comprehensive increase in energy efficiency, including through energy demand management programs;
3. Change in energy market organizations, taking into account the shift towards the business model EaaS;
4. Expansion of the generation capacities structure in the electric power industry through a combination of centralized and decentralized solutions;
5. Legal regulation of issues related to the development, implementation, and operation of energy facilities, alongside the establishment of a legislative framework for the development of renewable energy;
6. Effective tax system implementation for dirty energy facilities.

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