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New Approaches to the Concept of Energy Transition in the Times of Energy Crisis

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Abstract: The article presents conceptual foundations for solving the problem of global importance that determines the sustainable development of all countries and regions without exception. The energy transition is being implemented amid the unfolding global energy crisis; economic ties and logistics routes are being broken and rebuilt; and political decisions are being taken, shaping the socio-economic and technical architecture of the world. Having summarized scientific publications and analytical reports and the results of expert surveys, the authors were able to substantiate that the energy transition is an interdisciplinary task that requires taking into account numerous factors of different nature and risks arising from the one-sided orientation of energy systems to use a particular type of energy source or type of energy production. As the main conceptual provision of the article, a thesis about the social equivalence of the final results of the energy transition is put forward: reducing greenhouse gas emissions and ensuring the reliability of energy supply and a socially acceptable level of electricity prices. New elements of the energy transition concept include the definition of transformation milestones, a diversified technical policy, and tools for advanced training of personnel to work in complex projects of energy system transformations. It has been proven that the main factor for the successful implementation of the energy transition is the presence of a technical policy, i.e., a set of measures that enable consistent decisions regarding various types of generating capacities, the development of the power grid complex, and the transformation of power-consuming systems. As part of this policy, special attention is paid to recommendations for the development of thermal and nuclear power plants, which are often ignored within long-term energy transition programs.

Keywords: energy transition; concept; technological modernization; energy sector; crisis; technical policy; systems approach; cross-disciplinarity

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1. Introduction

1.1. Clarification of Terminology

The energy transition (ET) is understood as a process of the energy sector's transition to the low-carbon model (including the co-generation of energy and heat). The main objects of the energy transition include IES and various facilities within the decentralized (autonomous) power supply systems located in the vicinity of consumers.

The energy transition is a worldwide challenge which encompasses profound technical and economic transformations in energy production, supply and consumption, aimed at minimizing the environmental impact of the energy industry [1]. These transformations include an increase in the share of renewable energy sources (RES) and nuclear energy, which are zero-emission sources of clean energy, in the structure of the energy sector's generating capacities [2]; finding the optimal proportion of eco-friendly and energy efficient thermal power plants (TPPs) [3]; enhancement of the efficiency of energy use through demand side management programs [4]; and fostering the substitution of fossil fuels with electricity through the mass electrification of energy utilization processes [5].

The ET is crucial due to the need to drastically reduce the massive negative effect of the large-scale burning of fossil fuels on the environment. Another factor is the growing public awareness of the true cost of fossil fuels and the rising demand for clean energy—a trend that has become especially pronounced in the last decades (Figure 1).

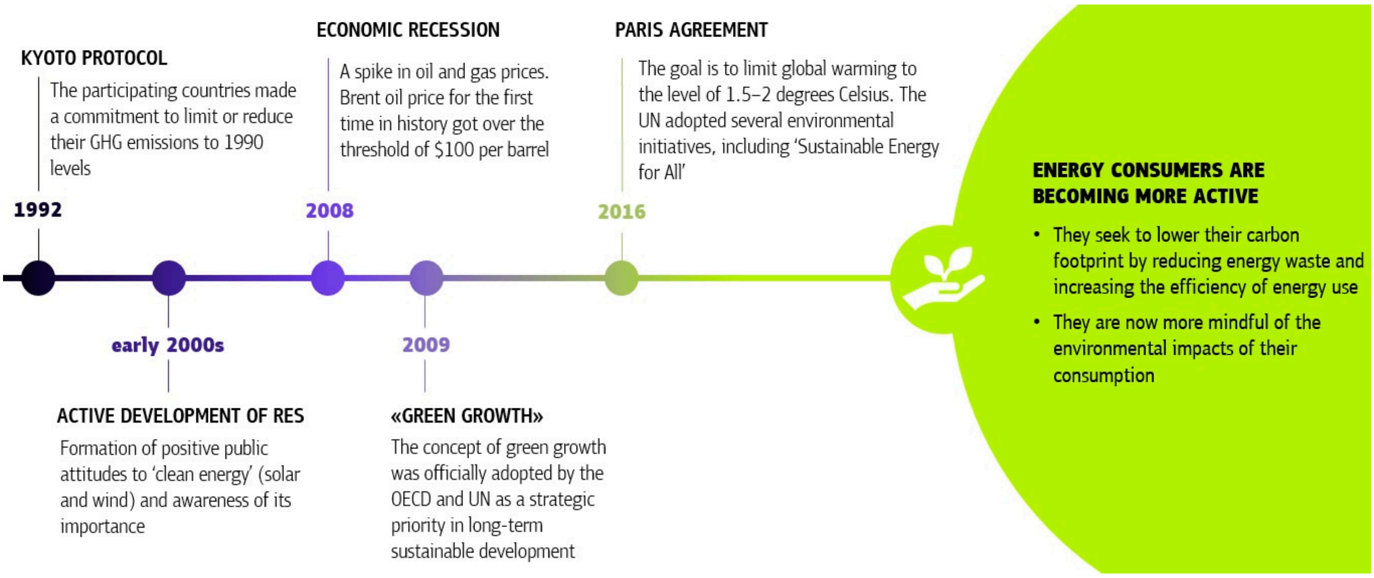

Figure 1. Milestones in the development of the global low-carbon agenda.

The high speed in which many countries are converting their energy industry to renewable energy sources (primarily solar energy, wind power and biomass) and the focus on total decarbonization are the distinctive features of the current energy transition. Earlier energy transitions were characterized by a gradual reduction of the use of "last generation" fuels in favor of other energy carriers with better technical and economic characteristics [6]. Today, the question is about the radical restructuring of energy systems on the basis of a whole mix of green renewable sources that are replacing carbon fuel and nuclear power at a speed that is two or three times faster than during the previous structural shifts in the energy industry [7].

In the short and medium term, hydrocarbons are likely to remain significant energy resources in a number of countries. For example, in the Middle East and the Asia-Pacific region, their share in the energy mix in the coming decades will be up to 60% according to some estimates [8]. However, in general, it is assumed that greater use of renewable energy sources will minimize the risks of volatility in oil and gas prices and contribute to greater stability in the exchange rate of national currencies, which in turn is a significant factor of regional economic security [9,10].

The energy transition is largely associated with cutting-edge technology advances generated as part of Industry 4.0 [11], and calls for major scientific research in the fields of technology [12,13], economics [14–16], IT [17], environmental protection [18,19], management [20] and law sciences [21].

The social focus of the energy transition is one of its distinctive features [22]. Moreover, it is believed that the energy transition was made possible thanks to strong public demand for clean energy. As the low carbon agenda is becoming larger across the world, domestic and industrial consumers no longer want to remain passive consumers of energy. They seek to limit their own carbon footprint by reducing demand for energy through RES technologies, better controllability and, therefore, efficient energy use. Informed consumers demand to be provided with more data on the environmental impact of this or that product, and this influences the choice of energy sources and technologies used by energy companies. During the COVID-19 pandemic, such a demand was particularly urgent because the presence of any environmentally harmful product, asset or production facility in the immediate vicinity of the consumer started to be perceived as a vital threat [23,24].

This context drives research in the field of so-called «energy democracy» [25] and nurtures «a society with a responsible attitude to energy» [26]. Energy democracy is defined as a concept for encouraging innovation at political and institutional levels, the uptake of which would improve the sustainability of the energy sector thanks to controllable diversity of energy solutions and active participation of prosumers in the energy market [27–29]. As part of the problem of responsible attitudes toward energy, the focus of research covers issues such as ways of improving energy consumption behaviors [30], waste-to-energy options [31], circular economy models [32], employment in low-carbon economies and green energy [33].

To sum up, the development of the energy transition concept and programs is a complex cross-disciplinary problem.

Earlier, the authors provided arguments substantiating the application of the systems approach methodology to solving such problems [34]. In the case of the electric power industry, it takes the shape of so-called multi-vector structural and technological diversification that constitutes the result of innovative transformations encompassing and combining processes of power supply and power consumption [35]. These include the expansion of the list of energy carriers in the energy mix of the region with a growing share of RES and nuclear power [36,37]; the use of high-efficiency power generation technologies envisaging the installation of emission capture, storage and sequestration systems at heat and power plants [38]; the adoption of advanced instruments of price-based demand side management that boosts energy efficiency and creates the «postponed investment» effect [4]; and the implementation of a new «cybernetic» phase of electrification that implies the widespread use of electricity as the priority energy carrier in manufacturing, transport, household activities and the expansion of the resource base of natural gas [39].

In this study, an emphasis is made not only on a comprehensive conceptual presentation of the energy transition as a complex cross-disciplinary problem, but also on the methodological framework that fulfils the idea of structural and technological diversification and sets the foundation for making essential engineering, economic and investment decisions at the level of regions while taking into account current crisis developments.

1.2. The Purpose and Hypothesis of the Study

The concept of ET provides a generalized framework for driving the transformations in the systems of energy generation, delivery and consumption. The purpose of developing the authors' vision of this concept is to create a management structure that can determine realistic directions for the transformations necessary to achieve the goals of ET.

The basic principle behind the energy transition concept is the social equivalence of its environmental, technical and economic outcomes; in other words, greenhouse gas emissions (CO_2), reliable energy supply and energy prices should be kept on par. The problem resides in the fact that the first parameter—environmental—is commonly considered as the main one and all the rest are deemed secondary. Therefore, improved results in the target parameter usually mean lesser reliability of energy supply and higher costs of energy generation. This renders ineffective methods such as multi-criteria optimization (compromise solution) and single-criterion optimization (reliability and efficiency as constraints) because for both of them, the target indicator will show worse results.

The optimal solution in this case is the compensation method; from this perspective, all the three groups of the energy transition outcomes (environmental, technical and economic) are considered equal in value. The desired value of the main indicator (environment) is achieved while keeping all the other indicators at the specified level (energy supply reliability), or the socially acceptable level (prices). The latter two (reliability and prices) are not seen as constraints, because they have a minimal influence on the target parameter, in particular, the minimization of CO_2 emissions.

From this perspective, it becomes evident that it is necessary to prepare regional integral energy systems (IES) for the energy transition, and to build a mechanism for managing the transition by targeting its functional characteristics corresponding to the key aspects of this process. These aspects are as follows: the energy transition can be seen as a process of innovation, as a regional process and as a process of diversification.

It is important to emphasize that, in our opinion, at the core of the energy transition concept is technical policies aimed at ensuring the reliable, efficient and environmentally safe operation of energy companies' operating assets. The technical policy encompasses key engineering solutions, technical requirements and organizational measures aligned with the energy transition goals. In the time of energy crisis and global economic recession, it is this focus that helps bring together the goals of the energy transition with those of the sector's planned technological modernization.

Thus, there are four central assumptions that form the subject of the article:

1. The energy transition is a complex interdisciplinary task that requires taking into account numerous factors (technical, economic, managerial, etc.) and risks arising from the unilateral orientation of the region (energy system) towards the use of a particular type of energy source or energy production.
2. Transformations in energy systems during ET involve ensuring the social equivalence of environmental, technical and economic results, which in turn determine the need for special compensation mechanisms that maintain energy supply parameters at an optimal level.
3. The main factor and mechanism for the successful implementation of ET is the presence of a technical policy—a set of measures that provide for consistent decisions regarding various types of generating capacities, the development of the power grid complex and the transformation of power-consuming systems.
4. The implementation of ET projects requires special training mechanisms that involve changes in the paradigm of professional education. They are related to the strengthening of the R&D component, the rapid transfer of the latest scientific results into educational content and the project agenda and the acquisition of competencies for working in new types of activities arising in connection with the energy transition; for example, managing structural and technological innovations in the IES, demand-side management for energy and power, energy security management and digitalization of energy systems.

2. Materials and Methods

The study is based on a systematic approach and takes into account interdisciplinary relationships between the technological, environmental, economic and managerial features of the energy transition. The logic of the authors' study suggests a certain sequence of phases (Figure 2).

A number of appropriate scientific methods were used: analysis of scientific publications; logical and structural analyses; and conceptual design, expert assessment, ranking. In particular, 30 experts—top managers of energy companies and university professors—were involved to rank the energy transition scenarios in the context of the growing economic and energy crisis. Among the sources of information that were used, there are reputable scientific papers; analytical reports by global organizations and institutions (International Energy Agency, the United Nations Economic Commission for Europe (UNECE), the International Renewable Energy Agency (IRENA), the European Parliament, the World Energy Council, the OECD); energy research units at Oxford University and the Rocky Mountain Institute; international consulting groups (Deloitte, Accenture, McKinsey & Company); raw data collected by the authors in the course of theoretical generalizations; and interviews with experts. The search for publications was mainly carried out in the ScienceDirect, SCOPUS and MDPI databases. The breakdown of the analyzed literary sources by type is shown in Table 1.

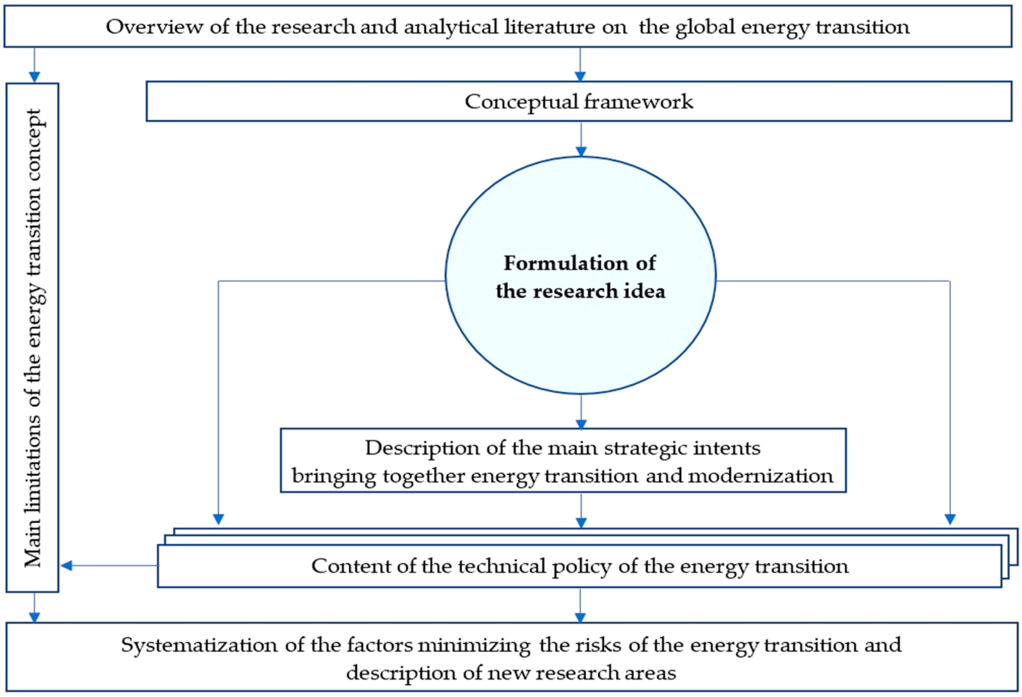

Figure 2. Research logic.

Table 1. Scientific sources analyzed in the course of the research.

Type of the Source	Number of Works Analyzed
Scientific publications	55
Monographs	4
Analytical reports of world institutional organizations	16
Consulting companies' reports	4
Internet resources containing expert opinions on energy transition issues	16
Total	95

3. Results

3.1. The Authors' Idea of the Energy Transition Concept

The energy transition as the process of creating an environmentally and climate safe energy sector is considered to be a critical task for the state. Its implementation will take place amid major geopolitical and socio-economic developments accompanied by crises [40]. Apparently, many of the projects that were initiated by global institutions will have to be reconsidered, in terms of their cost and deadlines in the first place [41]. Nevertheless, despite the strong uncertainty of the context, the current pace of the energy transition needs to be maintained because it serves as one of the drivers of economic growth, while the electric power sector is the infrastructure industry that is key to the success of crisis management [27–29].

At the same time, the energy transition simultaneously acts as a driver for the modernization of the electric power industry. The latter is particularly important for regions and countries whose energy infrastructure is becoming increasingly technically, functionally and physically obsolete and which are, therefore, facing capacity shortages and grid constraints, rising fuel and energy prices, and problems caused by the inadequate and outdated gas pipeline system [42,43]. According to the energy transition index developed by the World Economic Forum [44,45]; the UNECE Renewable Energy Status Report [46];

and the information provided by the data aggregator on the IRENA website [47], the above-described problems are mostly faced by the following countries:

- The vast majority of African countries (for example, Zimbabwe, South Africa, Senegal, Ethiopia, Nigeria, Cameroon and Zambia);
- Asian countries, especially those located in the central and south-eastern parts of this region (Nepal, Bangladesh, Mongolia, Pakistan, Indonesia, the Philippines, Sri Lanka, China, India and Vietnam);
- CIS countries (Kyrgyzstan, Tajikistan, Kazakhstan, Russia and Armenia);
- Countries of North Africa and the Middle East (Iran, Saudi Arabia, Algeria, Jordan, the UAE and Egypt);
- European countries, especially those located in south-western and eastern parts of the region (Moldova, Serbia, Poland, Turkey and Bosnia and Herzegovina);
- Countries of Latin America (Venezuela, Bolivia, Haiti, Jamaica and Guatemala).

This interpretation of the task implies that its solution is based on the latest achievements in energy science and technology, organization methods, forms of interaction between energy companies and consumers, and requires considerable resources in terms of intellectual contribution, investment and innovation. As a result, the energy transition generates a highly diversified energy sector of a new type that is capable of supporting high rates of economic growth and the further expansion of electrification [48]. The environmental factor determines the key parameters of relevant projects, acting as the driver of industry modernization [49].

The basic principle underlying the energy transition is to ensure that the environmental, technical and economic results of the low-carbon transition should be carefully balanced and considered equal in value. This means maintaining the performance standards of power systems, keeping energy prices affordable and ensuring the rational use of clean energy sources, especially scarce natural gas.

As the object of transformation, the authors choose the integral energy system that has a balanced capacity and load configuration and a complete reserve in terms of size and structure. The IES contains three technological complexes: power generation (PGC), power distribution (PDC) and power utilization (PUC). Each of them is in the process of implementing technological and organizational innovations that have certain compensatory functions and complying with the core principle of energy transition as described above. The detailed descriptions of the complexes are given in Table 2. The resulting diversification of energy technologies and ways of power supply leads to lower capital costs of the IES overhaul, which, in turn, solves the problem of investment that comes along with capital-intensive structural shifts in energy [50,51].

Table 2. Targets and results of transformations amid energy transition.

Technological Complex	PGC	PDC	PUC
Key objective of transformation	Maintaining system reliability and saving natural gas at power plants	Stabilization of retail prices for electricity and capacity, higher power supply reliability	Stabilization of prices, higher reliability of power supply and natural gas savings in the consumer sector of IES
Key implementation outcomes	Wider diversity of primary energy forms utilized, working cycles and schemes of power installations, wider scale of utility capacities	Development of small-scale generation and smart grids with real-time power balancing	Expansion of natural gas resource base through its replacement with electricity in the course of electrification, e.g., in manufacturing
Contribution to investment availability problem solving	Lower per-unit investment thanks to technical upgrade of thermal power plants by increasing their installed capacity	Lower investment in construction of power transmission lines, shorter distribution networks, reduction of losses	Additional electrical resources thanks to energy conservation

3.2. Rational Sequence of Energy Systems Transformation Stages in the Context of the Energy Crisis

The main phase of the energy transition will have to be implemented during the energy crisis. Based on the analysis of scientific literature, it seems possible to identify factors that, on the one hand, express individual crisis manifestations in the energy sector and the economy of various countries, and on the other hand, determine the course of their actions in relation to the ET. These factors include:

- A decline in industrial production;
- Rising natural gas prices;
- Rising electricity prices;
- Reduced investment opportunities of energy companies.

Decline in industrial production. The overall decline in industrial production leads to a decrease in energy consumption and, therefore, reduced energy generation. Since recession usually has a structural nature, the environmental effects usually depend on the share of industrial manufacturing in the economy of the given region and the scale of decline in the industries whose energy intensity is above average. These enterprises are objects of prime importance for demand management in the transition to economic growth and as such, they deserve special attention.

The structural shifts resulting from the recession have a direct impact on the configurations of the daily load curves of the energy systems. For instance, the shrinking proportion of industrial manufacturing in a region's economy together with the smaller share of energy-intensive industries cause the decompression of the load curve. This results in a relative increase in energy generation at highly maneuverable stations with predictable environmental consequences. In some regions, these will be gas-fired TPPs and in others, depending on the natural conditions—hydroelectric and pumped storage power stations.

Rising natural gas prices. This trend gives a competitive advantage to renewable power stations, nuclear power stations and coal-based thermal power stations. At gas/oil TPPs, energy generation is reduced as a result of the shift to the maneuverable regime of the energy system and the replacement of gas by cheaper solid fuels at some power stations. In the latter case, reduced energy demand will compensate for the growing environmental pressure from coal-based TPPs.

Rising electricity prices. The government should respond to the rising energy prices by stimulating energy conservation, which should be made an absolute priority for operating enterprises, organizations and the utilities sector. This concerns primarily no-cost or low-cost measures. The minimum level of electricity consumption is determined by the safety requirements, working conditions and consumer comfort requirements. The energy conservation policy provides a valuable contribution to the general reduction in energy generation in the given region.

Reduced investment opportunities of energy companies. In this situation, the government should stimulate capital investment in the restructuring of the energy sector with the help of tax cuts and investment incentives as well as direct government spending (subsidized loans and grants). It is also necessary to put some effort into reducing the pressure on energy consumers, primarily individual households and those enterprises that are critical to national security.

Table 3 shows the sequence of transformations presented as separate stages with the corresponding sets of measures (projects), interdependent and complementary. These measures are intended to partially eliminate the above-described impediments. This division is of course rather tentative, but it reflects the order of priority for different projects. This order should be determined by expert assessments; the energy efficiency, environmental effectiveness and costs of these projects, and their alignment with the objective of ensuring the general balance of the power system in terms of its output and capacity.

Table 3. Energy transition stages.

Stage	Energy Generation	Energy Consumption
I	Building renewable power stations of different types and with different schemes of connections with the power system. Construction of the next generation NPPs on new sites. Technical modernization of TPPs operating on solid fossil fuels with condensing steam turbines and heat recovery turbines. Technical modernization of local and industrial gas-based CHPs.	Intensification of demand side management in energy-consuming processes and systems and in energy companies; engagement of both energy consumers and suppliers into demand management programs to achieve the reduction in the daily loads of consumers as well as in the peak loads.
II	Technical modernization of the gas-based TPPs with condensing steam turbines. Building PSPPs on new sites to replace some of the peak gas turbine sets. Construction of gas turbine peak plants due to the restrictions on the construction of PSPPs (siting and economic restrictions—PSPPs require much larger capital investment).	Electrification of high- and medium-temperature processes to replace fossil fuels in industrial manufacturing. Electrification of railroad and urban transport.
III	Completion of the planned modernization of steam turbine TPPs. Ensuring the balanced state of the IES in terms of its capacity and load.	Electrification of low-temperature processes in the utilities sector.

3.3. Technical Policy to Combine the Energy Transition with Planned Modernization

3.3.1. Integral Energy System as a Foundation for Organizational and Technical Innovation

The IES comprises clusters of local power systems located within the boundaries of a large economic region of a country. Regarding the purpose of the energy transition, the 'scale effect' from the creation of an IES will bring the following results.

- The structure of the energy system becomes more diversified in terms of unit capacity, types of power stations, maneuverability of power installations and primary energy sources. To ensure diversification, it is necessary to consider a variety of factors: natural and climatic conditions, access to fuel and energy, economic factors of energy generation, characteristics of consumer demand in regional and local energy systems. Diversification contributes to the energy system's flexibility and adaptability to changing external conditions and electricity demand. Energy generation thus becomes less sensitive to the prices of fuel and various energy products and constraints to their use at TPPs (for example, natural gas).
- A carefully thought-out combination of renewable power stations, NPPs and TPPs will bring a significant economic effect and help save fuel while maintaining the necessary level of power supply in the region. The use of various types of power plants in the context of individual parts of the load of the energy system is shown in Figure 3.
- Search for the opportunities to optimize the technological structure of power stations and modes of their use to enhance their economic and environmental performance (under the conditions of changing fuel prices, energy demand and environmental restrictions).
- Favorable conditions for high-capacity wind and solar power stations (up to hundreds of megawatts); these primarily include finding a suitable location and maximizing their efficiency as part of the power system.
- The transition to energy systems that are entirely balanced in terms of their capability and load (at any given time). This increases the resilience of the power system in the face of changing economic conditions and fluctuations of demand within a broad load range.

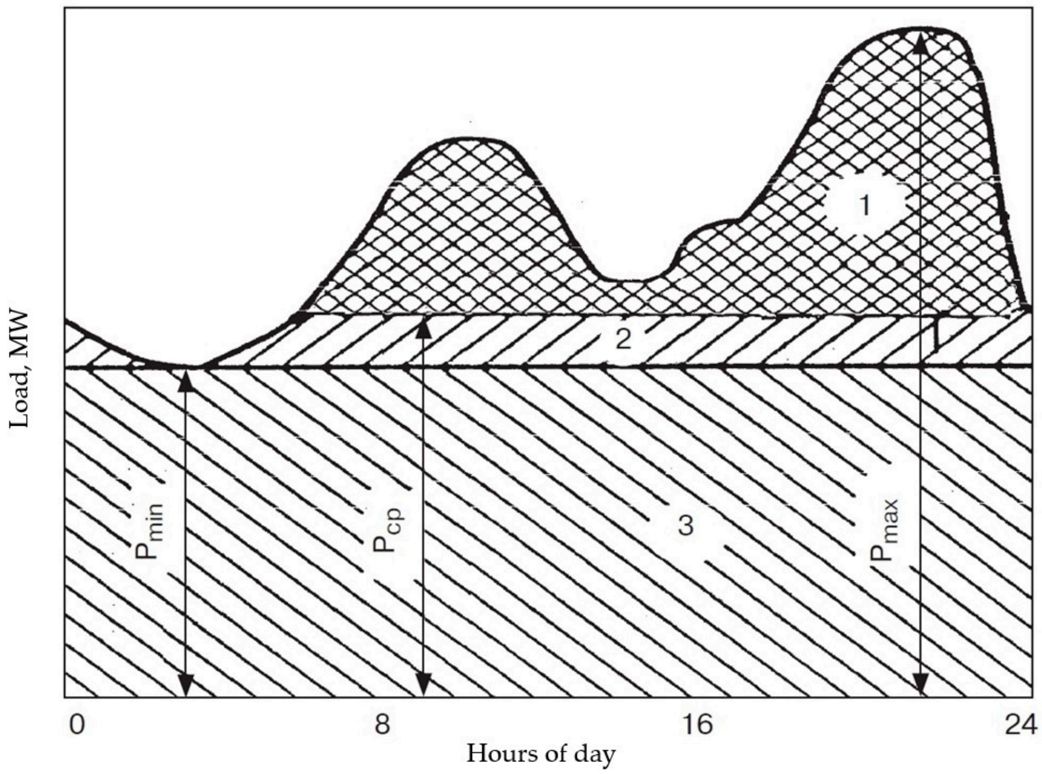

Figure 3. The structure of the daily graph of the energy system electrical load: 1—peak part (gas turbine TPPs and pumped-storage power plants); 2—semi-peak part (TPP with steam-gas units, steam turbine TPPs with capacity of 100–300 MW and parameters of steam below supercritical); 3—basic part (nuclear power plants, large hydroelectric power stations and steam turbine TPPs with supercritical parameters on coal or gas, as well as renewables operating on free graphics with the highest possible load depending on natural conditions).

Provided that there is projected excess capacity in the power system combined with a decrease in energy demand, it is possible to ensure the optimal load distribution among power stations with different environmental and economic characteristics within the IES in a given region. Since available capacities are used within the boundaries of individual zones of the energy system's load curve, they tend to be distributed 'horizontally'. The least efficient facilities are used to form (refill) certain types of capacity reserve in the IES.

In the case of significant changes in the ratios of fuel and energy prices, it may be reasonable to distribute the load 'vertically', that is, power plants can be redirected to cover other parts of the load curve. For example, steam turbine plants and even energy-efficient steam/gas installations using expensive natural gas are pushed out of the base-load zone to the semi-peak zone with the lower unit capability factor by nuclear power units with combined cycle plants on cheap solid fuels. As a result of horizontal load optimization, these units can be used to push the least efficient power plants out into the peak zone or into the power system's reserve.

The horizontal and vertical load distributions are shown schematically in Figure 4.

3.3.2. Power Grids in the Energy Transition

The average unit capacity of power installations (power units) and the total installed capacity of power plants can be reduced to bring generating facilities closer to the load centers, minimize the length of transmission lines, increase the transfer capability of certain parts of the bulk power system and reduce transmission energy losses and the costs of building new lines and substations.

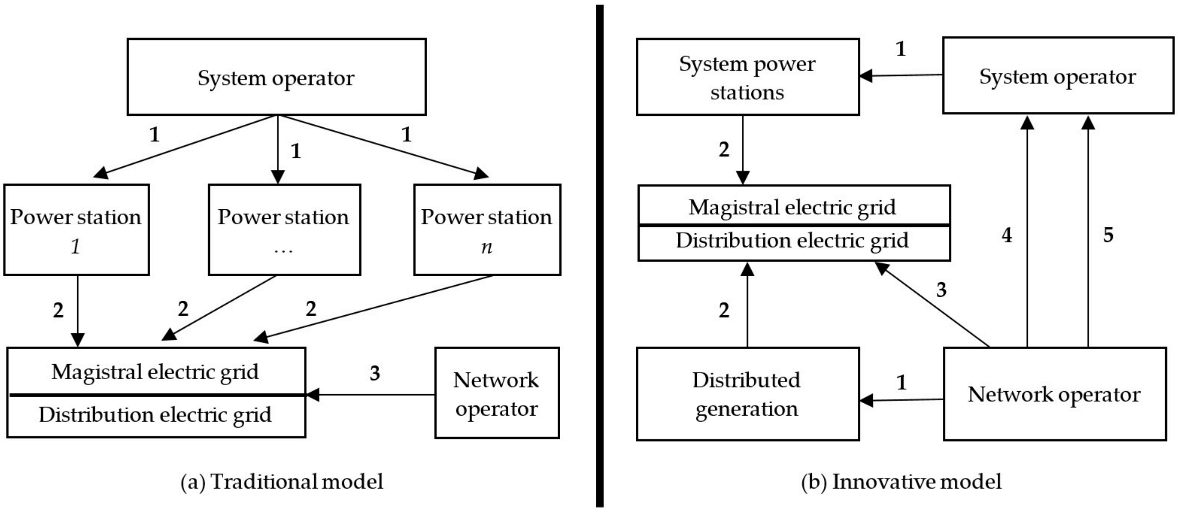

Figure 4. Horizontal (**a**) and vertical (**b**) distributions of electrical loads in the regional electric grid complex: 1—control of the generating objects modes, 2—output of power by generating facilities, 3—control of the distribution network modes, 4—information about loads in distributed generation, 5—a request for peak and reserve capacity.

NPPs, especially medium-power NPPs, do not need to be situated in close proximity to the sources of nuclear fuel and therefore, have greater flexibility in terms of location. For instance, they can be positioned closer to where electricity is needed. The question of safety is obviously of prime importance. One of the crucial siting requirements that also needs to be taken into account is the availability of the sufficient supply of freshwater. In light of the accelerated development of NPPs, such siting will significantly reduce the costs of the power grid and the costs of energy transmission.

CCUs built to modernize steam turbine TPPs increase the capacity of power plants, which will require an increase in the transfer capability of some parts of the main power grid. In large modernized gas-based TPPs, some of the units may be decommissioned (to be later transferred to the reserve and mothballed).

The use of small generation units increases the reliability of power supply and reduces the load on power grids of various voltage levels and the amount of energy lost in transmission and distribution, which is particularly important for low-voltage networks. However, it should be taken into account that when a large number of power installations are connected to the system of energy distribution, it is necessary to conduct a comprehensive technical reconstruction of this system and to implement an automated system for the real-time control of the multi-directional power flows.

A universal, and the most effective, way to reduce spending on the power grid, increase the transfer capability of the PTL and minimize the amount of energy lost in transmission and distribution is the large-scale implementation of energy and capacity demand management programs.

3.3.3. Role of TPPs in Energy Transition

In the context of the energy transition, the development of a large energy system will hinge upon building new capacities as part of advanced power projects: combined cycle power plants, nuclear power stations, renewable power stations and solar power plants. As economic growth becomes faster and energy demand rises, there will be more and more obsolete and inefficient plants. Therefore, while new power stations are being built, installations whose performance becomes inadequate environmentally or economically should be shut down. To this end, it is necessary, first, to make use of lower demand periods; second, enable external demand management; and third, redirect some of the load to smaller generation units, which have higher investment flexibility.

Coal- and gas-based combined cycle plants will be used in the IES as ‘closing’ (least efficient) elements that will cover the capacity needs of the system with a large share of RES when RES output fluctuates (as long as high environmental effectiveness is provided).

The choice between coal versus gas options mostly depends on the conditions of fuel supply in a given region but both of these options are rather universal. In this case, by using low-grade fuel, coal-based combined cycle plants will provide a reduction in the average cost of energy generation in the IES. The following advantages of gas-based combined cycle units come to the fore: low initial costs and a short commissioning period, increased maneuverability and a relatively small impact of the unit capability factor on the operating costs; high CoP; high power supply reliability and low-cost logistics. All of the above are also true for gas/oil and coal-based local CHPs.

As the load is becoming more variable, more emphasis should be placed on developing highly maneuverable capacities, the latter being only possible by using TPPs with combined cycle units. Therefore, the proportion of these TPPs will be growing while the proportion of base-load NPPs will be falling. This situation also depends on the efficiency of demand management in those spheres of energy consumption that cause the decompression of the load curve schedule. In the IES with decompressed load curve schedules, combined cycle plants of various types are supplemented with peak gas turbine sets (with the CoP of up to 45% and deep flue gas cleaning systems). These installations may also serve as the operating reserve. For high peak loads in some power systems, a viable solution would be to use pumped-storage power plants (PSPP) to supplement or replace the capacity of gas turbine sets.

It should be noted that there are limits to the expansion of the capacity of large WPPs and SPPs in some regions because the flows of natural energy may be scattered across the area and thus, it is necessary to allocate large amounts of land for the construction of these plants. Therefore, together with the energy system’s development, the share of these power stations will also grow at first and then at a certain point, they will start falling. The same situation is characteristic of NPPs (in this case, site selection restrictions are determined by other technical reasons). Therefore, it is quite likely that in the future, TPPs’ fast-paced development will have adverse effects on the environment in some regions.

A solution to this problem could be to maximize energy saving and to improve the energy efficiency of consumption. This solution—to save rather than generate power—is universal and the most cost-effective.

The development of renewable power stations is impossible without special maneuverable TPPs that would perform the role of ‘closing’ (least efficient) generators. This means that they will be following all the fluctuations in the electricity supply from renewable power plants; for example, they can be unloaded during night-time off-peak hours, when energy is supplied by wind farms or, on the contrary, they can be used to increase generating capacity in the periods of reduced generation from wind farms (acting as an operating reserve).

To sum up, the trend towards clean energy should be accompanied by the accelerated development of gas-based TPPs. In this light, there is a strong probability that gas steam solid fuel–fired plants, especially those that use coal gasification and are equipped with flue gas cleaning and CO_2 removal systems, will be gaining popularity.

3.3.4. Nuclear Power Plants in the Energy Transition

The share of NPPs’ capacities in the structure of a large power system is determined by the rationally planned participation of nuclear power facilities in covering the daily load curve of the IES. In this case, the best option is as follows:

- NPPs are used to cover the constant or base-load share of energy production (with the deduction of the rated load of RES);
- alternating (semi-peak) zone of the load curve is covered by NPPs and TPPs equipped with CCUs on gas or solid fuel;

- the degree of the NPPs' participation in covering the semi-peak zone depends on their competitiveness in comparison with combined cycle plants (provided that TPPs' environmental performance values remain within the acceptable range).

It should be noted that the competitiveness of NPPs depends on the following factors: site-specific requirements for new NPPs [52]; maneuverability of NPPs and the average costs of energy generation if NPPs are operating in the variable zone of the load curve [37]; the costs of NPPs (construction time, capital investment, payback period) [53]; natural gas prices; restrictions on gas supply to TPPs; and the availability of cheap fuel (low-grade coal) in this or that region [54].

It goes without saying that advanced NPPs should meet all the modern radiation security requirements. In different regions (that is, the IES), the ratio of NPPs to TPPs may vary significantly.

3.3.5. Optimal Capacity of TPPs and NPPs Integrated in Power Systems

The optimal capacity of a power plant is the minimum capacity for which an increase in the capital investment caused by the scale effect reduction can be compensated through advanced organizational and technological solutions in the process of the plant's construction. This can also be achieved by improving the methodology of calculating the direct and indirect costs of putting the plant into operation.

Since there is a diversity of power station types as well as regional conditions of their construction, the average optimal unit capacities fall within a certain interval of values (for example, 200–500 MW). Having said that, it is recommended to follow the standards accepted in power machinery engineering and the technical policy of this or that energy company. Among other things, it is necessary to provide guidelines regarding the number of power units for a TPP and NPP, for instance, not more than 2–5 power units of the same capacity. It should be noted that single unit power stations are now gaining popularity [55].

By reducing a TPP's unit capacity and installed capacity, it is possible to reduce the time it takes to build a power station on a new site; to use highly automated power installations and to apply systems of automated control for the station's power units; to increase the maneuverability and quality of the power system; to maintain the stable operation of power installations in different operating regimes; to increase the reliability of energy supply by reducing the length of the distribution lines and promote the rational use of their transfer capability; to cut electric power transmission and distribution losses and the total costs of energy transmission; and to reduce the capacity reserve margins in the IES and minimize the costs of building the capacity reserve.

Moreover, a reduction in the available capacity of TPPs will reduce emissions of toxic air pollutants.

To identify the optimal capacity levels of power installations and power plants, it is necessary to take into account the fact that a reduction in their power capacity usually means an increase in the capital spending on their construction. Additionally, importantly, capital spending grows exponentially, which means that there is a level of unit capacity for this type of power installation below which further reduction is economically infeasible. Therefore, in our view, it would be reasonable to settle on average values within the range of 200–500 MW for individual energy units. In this case, power stations would house two to five units, depending on the type of fuel used. In this case, a certain growth in the cost of energy generation will be compensated for by the systemic effect produced by automation, maneuverability and reduced energy transmission and distribution costs. It should be emphasized that this refers primarily to those power plants that are integrated in large energy systems. All the above are also mostly true of NPUs and NPPs.

In addition, it is important to achieve greater freedom in the siting of nuclear power stations (in terms of water supply requirements) and to reduce the costs of ensuring extra radiation protection and nuclear security.

3.3.6. Priorities in the Development of System TPPs

Gas-based TPPs. An absolute priority for TPPs with condensing steam turbines is their technical modernization. This can be done with the help of gas/steam sets of various schemes; these efforts should be focused primarily on those power units that have reached the end of their useful life. This way, the capacity of power stations is increased and their CoP reaches 60%. Some TPP units can be transferred to the operating reserve of the energy system.

In relation to combined cycle plants with condensing steam turbines, the prospects that new generation capacities will be commissioned still remain rather hazy. This situation is influenced by such nondeterministic factors as the accelerated development of NPPs with reactors that have increased safety performance, construction of small generation facilities in regions and energy systems' growing need for highly maneuverable power installations. Importantly, there is much uncertainty surrounding the natural gas supply to TPPs and the price expectations in the foreseeable future. At the same time, it is obvious that the construction of the new gas turbine sets and combined cycle plants for the peak and semi-peak parts of the load curve of power systems cannot be avoided.

It is no longer necessary to build large steam turbine TPPs integrated in the energy system and connected to a centralized heat supply with a long-distance heat transmission. Instead, the focus should be shifted to medium- and small-capacity combined cycle plants and GTS-TPPs generating electricity from heat energy. In this respect, a viable alternative would be to install cogeneration systems based on gas turbine generators and reciprocating engine generators at local boiler stations. The currently operating large-capacity TPPs should be upgraded and converted into condensing power plants, or they should be decommissioned in proportion to their remaining life and replaced by smaller TPPs.

In relation to those medium-capacity steam turbine TPPs that have all but completed their economic life, it would make sense to replace their equipment according to the schemes 'combined-cycle unit—thermal power station' and 'gas turbine set + waste heat recovery boiler' depending on the ratio of the rated heat and electricity load.

Coal-based TPPs. In the long run, the future of coal-based TPPs (using condensing steam turbines and heat recovery turbines) is determined by the factor of gas availability. Taking into account the uncertainty of the situation, three possible scenarios for the future of these power facilities could be identified: first, technical modernization; second, decommissioning and the transfer to the reserve of power systems; and third, layup. Those coal-based condensation power plants that are too technically difficult and costly to renovate should be decommissioned.

Steam turbine TPPs serving as a heat source should be upgraded. This can be done by using steam turbine technologies of the following two types: combined cycle plants with a pressurized fluidized bed and combined cycle plants based on solid fuel gasification. Our analysis of the research literature on this topic shows that with the help of gas/steam sets with a pressurized fluidized bed installed at coal-based TPPs, it is possible to save 10–15% of fuel and achieve a significant reduction in the amount of sulfur oxide and nitrogen oxide emissions. For coal gasification plants, the CoP of the cycle reaches 50%, which significantly reduces GHG emissions. The construction of these power plants at new sites will require capital investment which will more than twice exceed the corresponding indicator values of gas-based combined cycle plants.

3.4. Staffing for the Energy Transition

Challenges associated with the energy transition are of a cross-disciplinary nature and include engineering and technical, geopolitical, economic, investment, managerial and social issues. In this regard, it is worth noting that one of the key priorities for a successful energy transition is the availability of specialized educational programs for the general audience: from home-owners to politicians and journalists. Unfortunately, this aspect remains largely underexplored in the research literature and analytical reports of international organizations.

This section describes a case reflecting our own experience of creating educational programs for managers in the energy sector.

Such educational programs are aimed at raising managers' awareness of the conceptual foundations and principles of energy transition management. To address this goal, Ural Federal University (Ekaterinburg, Russia) has started a project called 'Proactive Management in the Vigorously Developing Industries and Sectors of Economy'. There was also a set of disciplines ('Proactive Management', 'Innovation leadership', 'Cross-Disciplinary Teams', 'Cross-Disciplinary Sectoral Relationships') introduced to provide more fundamental training for future professionals. These courses will help them obtain a more comprehensive vision of the transformations in the energy sector, gain a better understanding of the forthcoming changes and develop more flexible managerial thinking.

An important element of advanced learning is an online education platform that makes it possible to organize a high-tech process of proactive training and create next-generation educational products to meet the goals of the energy transition (digital knowledge base, a conveyor technology for continuing competence development, a network of communication platforms for connecting the university with energy business: online learning environment and flexible modular architecture) (see Figure 5).

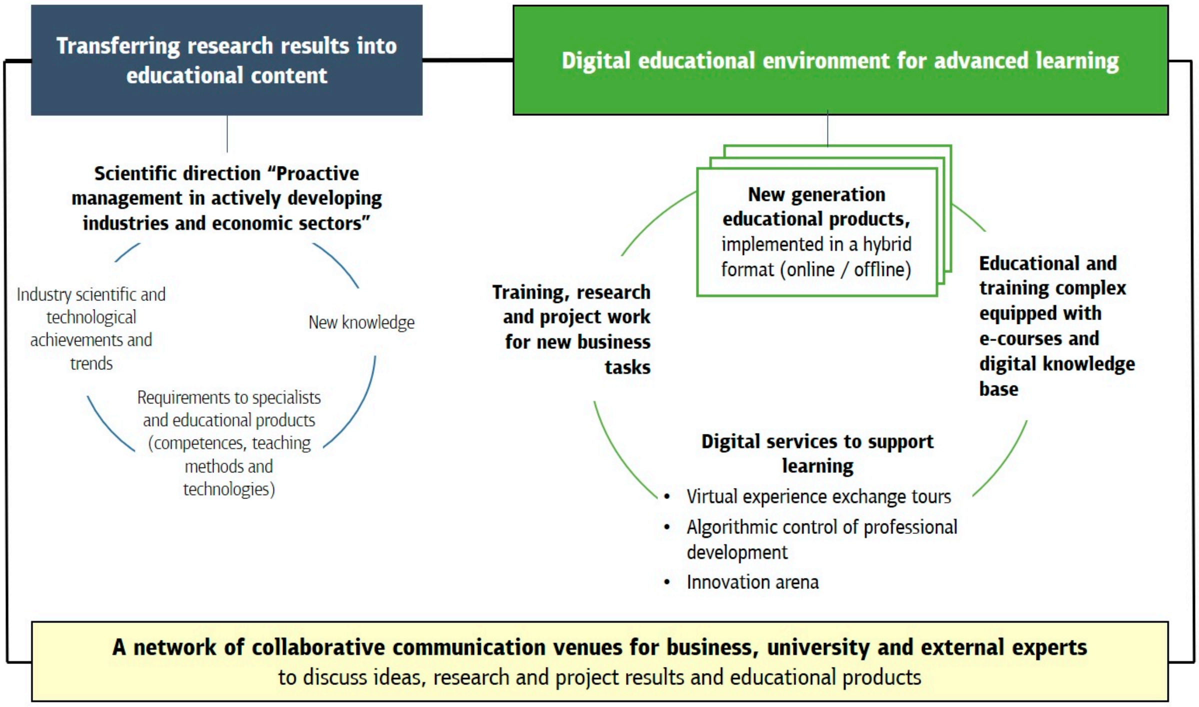

Figure 5. Visualization of the digital platform of advanced learning.

In addition, procedures to make prompt adjustments to the content of educational programs have been devised. This way, the programs can be kept up to date with the emerging knowledge and practices associated with the global energy transformation.

To stay on the cutting edge of the energy transition, it is important to bring together R&D and education. In other words, theoretical problems should be turned into hands-on tasks and projects for students and trainees. In this regard, monographs titled 'Energy Transition. A Guide for Realists' and 'Systems engineering for managers' have been prepared by the authors as well as online courses of the same names in different languages. The specialized Master's program 'Energy Business' and a set of continuing education programs were revised and expanded to include relevant courses on demand management, electrification and advanced business models. This made it possible to significantly expand the range of strategic work with personnel and breakthrough teams in some of the largest energy companies of the Russian Federation—PJSC T Plus, PJSC Rosseti and Bashkirenergo

LLC. Moreover, a series of seminars were launched, involving university researchers, state officials and top executives from energy companies and industrial enterprises into the discussion about the energy transition—the problem that can be tackled only through the synergy of intellectual resources, expertise and experience of specialists from different disciplinary areas.

It should be noted that this approach is consistent with the principles of energy transition engineering, a relatively recent subject area that is gaining popularity among organizations involved in the development of the ideology of low-carbon energy systems, practitioners implementing specific measures as well as in the educational environment. Energy transition engineering seeks to consider the issue of carbon neutrality in the most holistic way and places special emphasis on the study of cause-and-effect relationships that arise when making certain technological or organizational decisions. In this regard, energy transition engineering studies the changes that occur in the entire fuel and energy complex as a result of the introduction of specific technologies, starting from the mining industry and ending with the electricity and heat consumption sector [56,57]. Specialized associations are currently appearing in the world that unite specialists in the field of energy transition engineering; educational programs are also gradually emerging (mainly at universities in the USA and European countries) [58,59].

The idea about the critical importance of specialist training for the energy industry of the future and for the energy transition in particular is supported by the results of our survey. Thirty university researchers and top executives from energy companies were asked to rank four energy transition scenarios. The scenarios had to be ranked from one to four, where one is the least feasible scenario and four, the most feasible. Our survey shows that the optimal option, in our experts' opinion, is to develop talent for future energy transition projects. This process should be combined with modernization. In the current situation, the pursuit of the most ambitious goals of the energy transition should be put on hold (Table 4).

Table 4. Experts' opinions about the feasibility of various energy transition scenarios in the period of recession.

Scenario Description	Mean Score	Ranking Position
It is necessary, despite all the odds, to move forward with the energy transition, develop investment projects and realize all the necessary measures in energy generation, distribution and consumption.	2.25	2
The most capital-intensive measures should be put on pause and instead the priority should be given to local projects aimed at the modernization of energy facilities.	2.88	3
The energy transition should be put on hold while the following high-priority tasks should be pursued: talent development and accumulation of the expertise for the future cross-disciplinary projects.	3.50	4
The energy transition should be brought to a complete stop.	1.25	1

4. Discussion

The proposed concept and measures that should be implemented as part of the above-described technical policy can be used to align the energy transition goals with modernization in the energy sector. This solution will be especially relevant to the countries that are going through a severe economic crisis accompanied by the extreme shortage of investment capital and other resources.

In the process of modernization, what comes to the fore is characteristics of power stations and grids such as their CoP, generating capacity use and reliability of power supply, all of which are technical effectiveness indicators. This, however, holds true only until the point when the power facility is put into service, starts to participate in energy markets and begins to function as a supplier of energy and corresponding services. Afterwards, the focus is shifted to its economic performance and these parameters are used to evaluate the economic (financial) and environmental effectiveness of the energy sector in general.

The issues of the comparative assessment of the energy and environmental efficiency of different types of energy production are highly debatable in science and are subject to a special assessment in the context of specific regions and cases [60].

It should be noted that energy efficiency indicators are closely connected to the indicators of resource use and that the values of the latter are largely determined by the former. Quite illustrative in this respect is the case of TPPs, whose CoP directly depends on specific fuel consumption, the latter being used to calculate an economic indicator—the costs of energy generation. Therefore, differentiated norms should be set for specific fuel consumption at TPPs depending on different operating regimes. The CoP refers to primary energy losses within the TPP's fuel and energy cycle. Cutting losses is key to the reduction of actual specific fuel consumption and, as a result, to improved environmental performance.

Any concept implies a certain degree of abstraction and should be carefully adjusted to regional specifics. It may also have some limitations and should leave room for debate. One of the major impediments to the manageable low-carbon transition is the lack of a full and accurate understanding of what the resulting model of the energy sector and related systems should look like [61,62]. Another problem is that some of the actors in the energy market may be lacking the necessary motivation for investing in the energy transition [63,64]. Moreover, some energy systems may be technically unprepared for the massive growth in the number of active users connected to the power grid, bidirectional and multilateral flows of power and capacity [1,65]. Innovation infrastructure, especially knowledge-intensive services and education institutions, including universities, may also be unprepared to embrace the change [66,67]. Equally unprepared may be the markets of distributed power generation where the exchange of goods and services with traditional market participants and new players takes place [14,68].

When implementing the energy transition, a huge layer of technological problems arises, which are inextricably linked with economic and market effects. For example, for a speedy uptake of hydrogen energy technology that is viewed in the US and Europe as an important carrier of green energy, an appropriate scientific and technological framework needs to be established, requirements need to be spelt out for logistics systems and energy markets need to be reconfigured [69,70]. Despite the improved economic effects from the use of hydrogen as a primary energy carrier, the hydrogen infrastructure for everyday mobility is still in its early stages from a global perspective [71].

The utilization of solar energy and wind power—the key technologies that define the pace of the transition to carbon neutrality—is accompanied with climate risks that lead to price volatility and induce investment problems and lower levels of energy security [72,73]. For example, the destabilization of primary energy flows may result in the capacity factor of wind turbines hitting economically inappropriate levels, which raises the question about further operation of the entire wind farm in the area. For the successful implementation of energy transition programs and projects, it is essential to take into account the regional factor, that is, local climate, resource and investment characteristics [74,75]. This and the political dimension of the problem of carbon dioxide emissions makes it necessary for regional governments to engage in the solution of energy transition tasks, including through the help of instruments of comprehensive territorial development [76].

Quite debatable is the question of motives and forms of implementation of the energy transition. On the surface, there is the motive of decarbonization which rules out the use of fossil fuels. However, there are situations when the decisive role is played by the commercial interests of manufacturers of energy equipment, lobbying the use of certain types of equipment and justifying its need to minimize carbon emissions. That is partly why there is a solar energy boom in Japan [77] and an exponential growth of investments in alternative hydrogen power in a number of European countries, the USA and Australia. This is happening against the background of active diversification being implemented by energy giants such as BP and TotalEnergies [78,79]. By contrast, Poland, despite its plans for the energy transition, has been unable to get away from coal dependence due to their strong dominance of coal-fired power companies [80].

The colossal costs of the energy transition and its sources of funding are a question surrounded by much controversy [81–83]. The new energy cycle will undoubtedly have a positive impact on business activity, and therefore, on the investment background [84], although these effects will not appear overnight. Consequently, certain financial and investment restrictions will exist. However, in the process of the energy transition, the following should be avoided by all means:

- Average electricity prices exceeding the real inflation rate; it is particularly important to prevent a price spike in the public utilities sector.
- A decrease in energy supply reliability (volume of energy supply, continuity, voltage and frequency standards).
- A decrease in the absolute volume of energy consumption (both for gas and electricity), which may result in a decline in production, changes in the structure of production and reduced consumer comfort in the utilities sphere.

It should be noted here that the continued active use of TPPs should be accompanied by significant investments in technologies for capturing, utilizing and storing carbon dioxide emissions, which are currently very expensive. In this regard, the proposals of the authors of this article require further research from the financial and economic point of view.

The prospects of natural gas use in TPPs are also worth considering [34]. Due to the rigid barriers for the use of natural gas in power generation, exacerbated by physical constraints and high prices, it is now clear that thermal power stations are here to stay. Thus, the question remains open as to the feasibility of the all-encompassing green energy transition, the way it is understood by its proponents in most countries.

A less critical, but similar question arises regarding the prospects of coal-fired generation. In the context of the ongoing energy crisis in some countries, including those that are leaders in terms of installed RES capacity, such as China and the United States, some experts say the complete abandonment of coal fuel is a premature measure. For example, in China over the past 15 years, coal-fired TPPs with a total capacity of almost 300 GW were decommissioned during the decarbonization process [85]. The closure of TPPs was carried out without taking into account the growing needs of the industry and population in electricity [86]. A rational option would have been to modernize power plants in accordance with modern environmental requirements, but the drop in income due to low electricity tariffs for “dirty” coal generation and the rising cost of coal logistics does not allow energy companies to carry out a comprehensive overhaul of coal-fired TPPs to reduce carbon dioxide emissions.

The Nordic countries (Sweden, Norway, Denmark) have the most optimal policy regarding the energy transition [44], although even in these countries, there are problems associated, for example, with the increasing occurrence of negative electricity prices arising from the absolute priority of RES in the regional energy mix [87,88].

It can be stated that the main mistake made by the advocates of the green transition lies in the fact that they consider different primary energy sources (wind, solar, organic fuel, etc.) separately from the technologies used to convert them into final (useful) energy. This creates the division of energy sources into ‘clean’ and ‘dirty’ (fossil fuels) [89]. It would instead be more reasonable to evaluate the environmental and climatic effects associated with specific methods of energy generation—those linked to the output (steam pressure, temperature, voltage and frequency) rather than to input (type, amount and quality of fuel) parameters of power stations.

With a systematic approach to this problem and within the framework of the equipment life cycle, the corresponding environmental consequences of the production of structural materials for renewal units and their disposal at the end of their life should also be taken into account. This approach sheds a new light on the idealized vision of RES as totally clean energy sources. The negative impacts of RES include noise pollution and jamming of radio frequency signals caused by wind farms, and the use of toxic chemicals in solar panels such as gallium arsenide [83]. In addition, the energy transition requires a radical increase in the extraction of iron, copper, aluminum, nickel, lithium, cobalt, platinum, silver and rare-earth metals [90], which, in turn, can lead to extensive soil damage and destruction of the surface morphology. For instance, lithium—one of the key metals in renewable energy production—in more than half of all cases is extracted in locations suffering from shortages in water supply (Bolivia, Argentina, Australia, Chile) [91]. To date, there are examples of fairly environmentally friendly production of materials and fuels of the future [92,93]; however, these individual innovative developments cannot solve the described problem in its entirety.

On the other hand, the potential of efficient and eco-friendly technologies that burn organic fuel, including coal, that are now being developed and applied at TPPs, cannot be ignored. Fuel preparation, organization of the burning process in the furnaces of steam generators and enhancement of the efficiency of the thermodynamic cycle, implementation of deep flue gas cleaning systems with CO_2 removal all help reduce the amount of toxic and greenhouse gas emissions to acceptable levels according to the climatic and ecological criteria. One such example is the highly efficient gas/steam technologies for coal-fired TPPs based on burning coal within a fluidized bed under pressure and the gasification of solid fuels. The implementation of these technologies will of course incur extra costs. On the other hand, will renewable energy stations, which require energy storage systems, emergency diesel generators and current transducers, cost cheaper? The same can be said about nuclear energy.

Therefore, advanced technologies of energy generation used at TPPs should not be ignored. They should be considered in the light of technological progress on par with alternative sources of energy or at least as complementary. Such diversification of the energy sector's structure provides a comprehensive solution to the problem of ensuring a reliable and high-quality energy supply while minimizing the environmental impact. Thus, all three aspects of the energy transition are addressed: the climate and environment; energy and fuel; and economic feasibility.

In general, it can be stated that the problem of the energy transition is so big and complex that it is impossible to analyze the strengths and weaknesses of certain solutions within the framework of one article, which is its limitation. A more detailed study of the risks of the energy transition requires a bibliographic analysis using special methods, which are described in detail, for example, in [94,95].

5. Conclusions

Within the approach proposed by the authors, the energy transition's main focus should be on reducing the negative environmental effects of the energy sector and related infrastructures and industries, and on the development of the low-carbon economic model in different countries and regions. This approach takes into account the recession that many national economies are currently going through and therefore, advocates the need to combine the movement towards low-carbon power with the modernization of the energy sector in order to minimize the technical, financial and organizational risks.

The proposed concept centers around a technical policy outlining the key areas of the technological and organizational transformations in the energy sector as well as the mechanisms of their implementation. This concept may provide a foundation for sectoral and regional policy-making.

The study showed that the author's hypotheses are confirmed, and the idea of a balanced use of various types of energy carriers, including fossil fuels, and energy production methods, including at thermal and nuclear power plants, does not contradict the goals of decarbonization and contributes to increasing the sustainability of energy supply.

Taking into account the large multitasking of the problems under study, in accordance with the energy transition engineering methodologies, a list of promising issues have been formulated for further research. All the issues can be roughly divided into two groups: those associated with technical progress and those dealing with management solutions necessary to ensure steady progress towards the energy transition.

Technical progress:

1. Creation of powerful renewable power stations integrated into the energy systems.
2. Removal of the siting restrictions for building new medium-capacity NPPs.
3. Equipment of the gas/steam sets with flue gas treatment and CO_2 removal systems (including facilities based on solid fuels).
4. Reconstruction and intellectualization of the power distribution system in regions.

Organization and management:

1. Reliable supply of natural gas to ensure price stability for objects of the systemic and small-scale energy industry.
2. Stabilization of energy prices during structural and technological transformations.
3. Development of management and technological solutions for large coal-based TPPs (using condensing steam turbines and heat recovery turbines).
4. Identification of the optimal level of energy supply decentralization (large—and small-scale power production).
5. Development of the system of small-scale generation management, which includes setting technical priorities, determining forms of organization and identifying possible constraints.
6. Adaptation of the wholesale and retail market models to the highly diversified structure of the energy sector.
7. Determination of the functions that should be performed by regulatory bodies and energy companies in the energy transition as well as the conditions for their performance of these functions.
8. Creation of motivation mechanisms to increase consumer engagement (including demand management programs for specific groups of industrial consumers).
9. Development of regulatory standards (primarily environmental standards) and indicators to monitor the results of the energy transition.

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Abbreviations

NPP	nuclear power plant
RES	renewable energy sources
WPP	wind power plant
PSPP	pumped storage power plant
GTS	gas turbine set
UCF	unit capability factor
CoP	coefficient of performance
FUE	fuel utilization efficiency
PFB	pressurized fluidized bed

CPS	power-generating station based on condensing steam turbine
PTL	power transmission line
IES	integral energy system
CCU	combined cycle unit
SPP	solar power plant
FER	fuel and energy resources
TPP	thermal power plant
CHP	combined heat and power plant
PGC	power generation complex
ET	energy transition
NPU	nuclear power unit
PUC	power utilization complex
PDC	power distribution complex

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