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Energy Transition Manifesto: A Contribution towards the Discourse on the Specifics Amid Energy Crisis

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Abstract: The article seeks to describe a more realistic approach to the transition to a carbon-neutral energy model in the current period of economic and geopolitical turbulence, with the high volatility of energy prices, and the disruption of geopolitical and logistic ties, and puts forward a set of fundamental principles for the energy transition. The hypothesis tested is that the development of low-carbon energy is based on the structural-technological diversification of production methods and rationalization of energy consumption through expanded electrification and application of energy demand-side management programs. The analysis of the main approaches to the energy transition across the world shows that many countries now prioritize renewable energy sources, even though, despite their obvious environmental benefits, they are less reliable due to their intermittent nature. The proposed principles of the energy transition draw from a more flexible, compromise approach that implies an optimal balance of mutually reinforcing centralized and distributed technologies of energy generation and their characteristics. The key provisions of the manifesto were verified by means of theoretical generalization and graphical interpretation of data from a number of analytical reports of international energy agencies and the results of an expert opinion survey. The survey was conducted among leading Russian experts from energy companies, who had relevant experience of developing innovation projects in this sphere, and university researchers. Most of them subscribe to the view that, despite the economic downturn, it would be unfeasible to curtail energy transition programs at this point, and even more so, it is important to continue local modernization projects. The results of the study could have a practical application when planning structural, organizational, and market transformations aimed at achieving the objectives of energy transition amid growing uncertainty, including the expansion of the structure of generating capacities in regional energy systems and the active use of low-carbon technologies in the energy sector and related industries.

Keywords: energy transition; carbon-neutral economy; economic crisis; renewable energy sources; systems approach; diversification of energy supply; electrification; flexibility of energy systems

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1. Introduction: Energy Transition–The World's Number One Challenge

Emissions of greenhouse gases (GHG) such as carbon dioxide (CO_2), which result primarily from fossil fuel combustion, cause changes across the climate system worldwide. The world's wealthiest nations, responsible for a large share of global warming, undertake to drastically reduce GHG emissions in their territories by implementing a carbon-neutral model of economic development, commonly referred to as energy transition.

Energy transition is usually understood as the global energy sector's shift from fossil-based systems of energy production and consumption to renewable energy sources (RES) and decentralized energy solutions [1,2]. The energy transition was made possible by the achievements of the Fourth Industrial Revolution (Industry 4.0), associated with advances in information and communications technologies and intelligent systems used to enhance energy generation and energy utilization systems, and, by extension, the life of society as a whole [3].

It should be noted that the energy sector plays a pivotal role in this process. First of all, electricity generation today is, to a large extent, concentrated in thermal power plants [4,5]. Second, electricity is a universal energy carrier with general application [6]. Advances in science and technology have already resulted in a whole range of green production technologies that have proven effective and commercially viable [7–9]. Importantly, the energy sector is, to a varying degree, subject to state regulation, which simplifies the task of resource mobilization for a smooth energy transition [10,11].

The currently existing international environmental conventions and state programs are mostly declarative frameworks which establish collective intent to take action on climate change, etc. [12,13]. The principles underlying the energy transition are surrounded by much debate, with some polarized views being expressed, for example, regarding the prospects of nuclear energy and thermal power stations using different fuels [14–16]. Remarkably, experts asked to comment on matters related to the energy transition are usually climatologists, ecologists or politicians, and on rare occasions, economists of various creeds, but not much has been heard from technical specialists or energy engineers. This situation can be explained by the absence of a commonly accepted comprehensive model of energy transition management that would consider all its consequences and contain effective mechanisms to navigate the transition by preventing possible economic losses and energy supply disruptions.

Energy transition encompasses profound organizational and technological transformations of power generation, supply, and use to create a climate-friendly and environmentally safe power industry. These goals are among the top priorities on the political agenda of many national governments. At the same time, energy transition also works as a driver for the radical modernization of the electric power industry, which is particularly urgent in regions with obsolete and worn-out energy infrastructure, a shortage of power generating capacity, grid connectivity constraints, growing fuel prices, and delays in the expansion of the natural gas transportation system.

To tackle this challenge, it is necessary to advance innovation in energy technology and develop methods of organization and forms of interaction between power companies and consumers. It requires considerable mobilization and concentration of intellectual, financial, technical, and energy resources. The transition is expected to result in a highly diversified energy industry of a new type capable of sustaining high rates of economic growth and the further development of electrification. The environmental factor, therefore, largely acts as a trigger for the takeoff of modernization in the sector. The above-described transformations require measures to enhance environmental security, energy efficiency in production, and the reliability of energy supply at the local level.

This interpretation of energy transition focuses policy-makers' attention on the need to adhere to the principles of noncontradiction, interdetermination, and synergy of environmental, economic, and technological outcomes.

The concept of energy transition is, in fact, an answer to the two main questions: what price the global community will have to pay for the transition to carbon-neutral energy and how this price can be minimized amid surging economic and geopolitical uncertainty, disruption of the established logistics chains, volatile energy prices, and considerable cleavages in public opinion concerning the prospects of the 'green' agenda.

The purpose of this research is to propose a coherent and comprehensive concept of an energy transition based on the systems approach and comprising technological and organizational transformations in the energy sector. This concept can be taken as a point of departure by policy-makers to set the priorities of national energy policy and develop corresponding regional programs. The central premise of this article is that it is necessary to apply a compromise approach to energy transition that is based on the multi-vector diversification of the structure of power generating capacity (RES, thermal power plants, nuclear power plants) and on the maximum possible use of low-carbon technologies for energy production and consumption. This approach would be a fundamental factor of stable energy supply in all aspects: economy, environment, technology, and resources.

2. Materials and Methods

2.1. Hypothesis

Proceeding from the objectives and the central premise of the article, a research hypothesis (Figure 1) can be put forward that is expanded into the following assumptions.

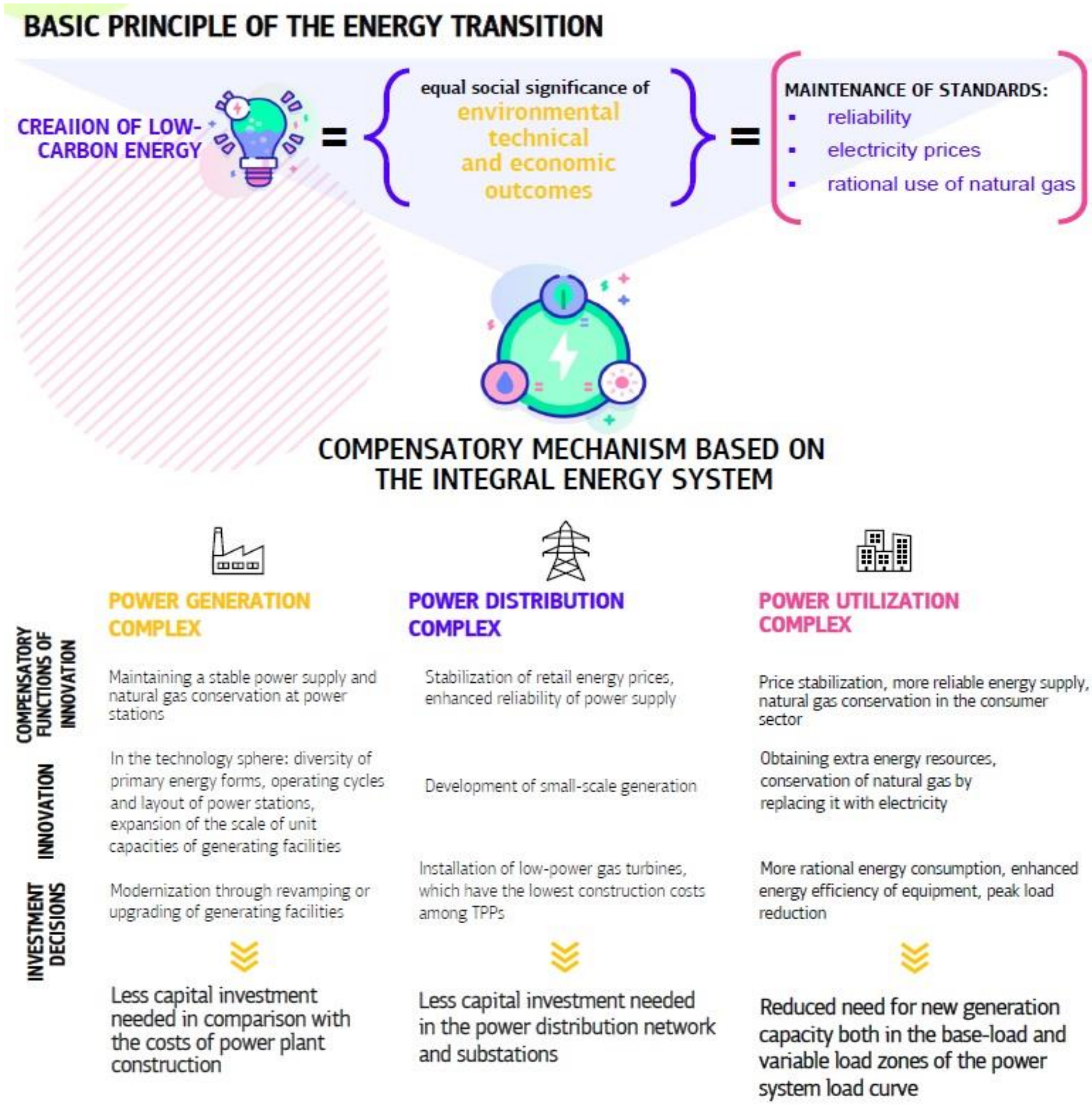

Figure 1. Hypothesis visualization.

1. *The environmental, technical, and economic results of the low-carbon transition should be carefully balanced*, which means maintaining the performance standards of power systems (e.g., reliability of energy supply), ensuring affordable electricity prices, and promoting the rational use of clean energy sources.

In this context, the notion of reliability can be interpreted rather broadly. First, it implies stable and uninterrupted power supply in line with power quality standards. Second, it means the absence of capacity and grid constraints for greater user participation. Third, it is important to ensure the reliable operation of all power stations within the selected load regime parameters and according to the daily load curve of the energy system;

2. *To address this problem, a special compensatory mechanism is created in the energy industry that applies to the entire industry value chain.* The compensatory mechanism is defined as the entirety of the organizational, technical, technological, and financial methods that provide for the necessary level of energy security, which means, first and foremost,

the cost and reliability of the power supply, amid the transition to carbon-free energy. The compensatory mechanism includes the rationalization of the structure of electricity generation capacity, the adoption of energy-saving technologies of electricity transmission and use, and direct compensation of losses incurred by energy market participants.

The main object of the energy transition and the corresponding innovation-driven transformation is the integral energy system (IES). This system should be balanced in terms of aggregate generation capacity and load, and provided with a robust reserve (both in size and structure). The IES comprises three complexes: power generation complex (PGC), power distribution complex (PDC), and power utilization complex (PUC). In each of them, structural-technological and organizational-technical innovations performing specific compensatory functions are realized.

Transformations in the PGC are targeted at maintaining system reliability and natural gas conservation at power stations; in the PDC, the main goal is the stabilization of energy retail prices and enhanced reliability of the energy supply; in the PUC, the focus is on price stabilization, the enhanced reliability of the energy supply and natural gas conservation in the consumer sector. It should be noted that innovation in the PGC contributes to a great extent to the environmental security of the IES zone.

Innovation in the PGC, PDC and PUC results in the diversification of energy-generation technologies and ways of delivering energy to customers. In the sphere of technologies (within the PGC), this means the diversity of primary energy forms, operating cycles and layout of power stations, and expansion of the scale of unit capacities of generating facilities. Regarding the types of power supply, this means primarily the development of small-scale electricity generation (PDC), extra energy resources obtained through energy conservation, and expansion of the natural gas reserves by replacing gas with electricity in the process of electrification, including the electrification of industrial production (PUC).

3. *Investment has a special significance for the energy transition since such structural shifts are usually highly capital-intensive*. Diversification of energy technologies and methods of power delivery can reduce the costs of comprehensive modernization in the IES.

In the PGC, modernization means the revamping or upgrading of TPPs: increasing their installed capacity will require less capital investment than the construction of new facilities. A decrease in the average capacity of power stations of all types will not bring a decrease in the accompanying one-off expenditures and capital investment necessary to create reserve capacity. The use of natural gas in TPPs significantly reduces the costs of building such facilities.

The PGC is supplied with low-power gas turbines, which are the cheapest thermal power plants to build. They are connected to the distribution system and are located in close proximity to the users, which reduces the amount of capital investment in the power distribution network and substations.

In the PUC, rational energy use, improved energy efficiency of machines, and peak load reduction help minimize the need for new generation capacity, both in the base-load and in the variable load zones of the power system load curve. Energy efficiency and energy conservation will save on the cost of building more power grids and substations of all voltages.

2.2. Research Procedure

The research procedure comprised three consecutive stages.

At stage one, theoretical aspects and international cases of energy transition were examined, making it possible to utilize logical structure analysis and graphical methods of data structuring in order to systematize the views of various countries, international organizations, and academic and practitioner communities on the key challenges and problems that come up on the road to low-carbon energy in various sectors, such as power generation, power grids, and energy consuming systems. The study relied on the data from academic publications; reports from the International Energy Agency, UN Energy Commission for Europe, International Renewable Energy Agency (IRENA), and energy research groups from Oxford University, the Rocky Mountain Institute, and Bloomberg; and statistical data from online databases Lazard and Enerdata.

The authors consistently analyzed about 70 documents, which can be conditionally divided into three types:

(1) At least 10 reports that form the framework requirements and targets of the ET, made by global institutional structures, such as the UN, IEA, and IRENA (for example, [1,5,12]). The analysis of these documents allowed the authors to formulate the general principles of a low-carbon energy model shared by the international community and to identify the distinctive characteristics of modern ET;

(2) Reports, scientific publications, and statistical resources dedicated to the specifics of the ET in separate countries (regions) and sectors of the economy. In addition, a study of the activities of 41 ET international initiatives was made (the list is given in Appendix A). The main result of the analysis of materials of this type is the identification of the key tasks and problems of the energy transition;

(3) Publications discussing various local technical, economic, organizational, and environmental aspects of ET, on the basis of which the possibilities and limitations of different approaches to the implementation of individual programs and projects were identified, and, ultimately, the idea of an author's manifesto was formulated.

At the second stage, the key principles of the proposed manifesto were conceptualized. These principles reflect a down-to-earth, realistic perspective on the energy transition and contain specific technical, environmental, and economic recommendations.

At the third stage, our ideas were tested by comparing them with expert opinions. We surveyed specialists from large Russian energy companies in various domains, and researchers from the Ural Federal University (Ekaterinburg, Russia) to gather their opinions about the feasibility of expensive energy transition projects in a time of global economic downturn. The profile of respondents is shown in Figure 2. Additionally, a large number of expert conclusions were summarized and a series of interviews were conducted on similar issues with energy sector professionals from a number of European countries (Italy, Norway), all for the sake of greater plausibility.

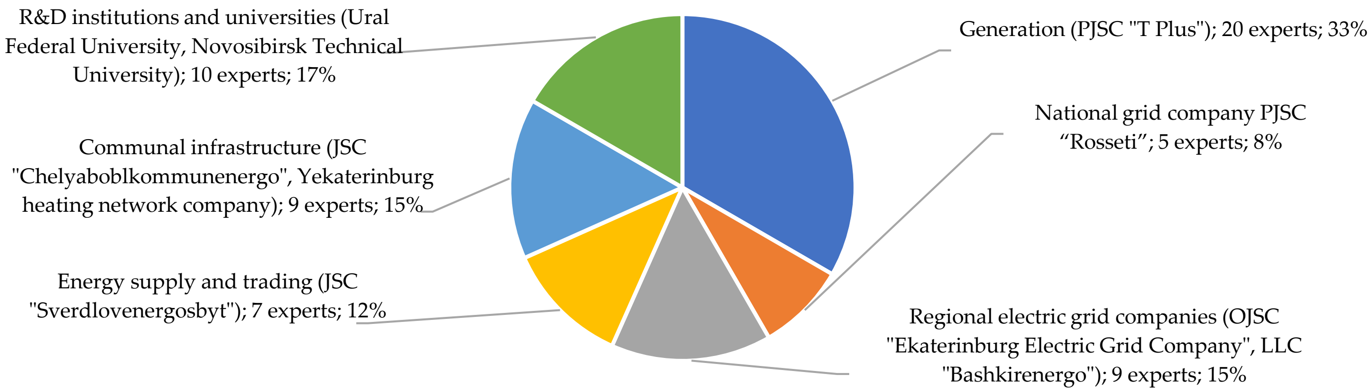

Figure 2. Russian respondents' breakdown by energy sectors.

A comparison of theoretical and empirical results obtained at the different stages of the study made it possible to substantiate the most realistic approach to carrying out the energy transition that could be implemented in its general form in various countries and regions of the world, and to formulate the most controversial points that require special attention when planning specific projects.

3. Results

3.1. Characteristics of the Contemporary Energy Transition

The development of the main energy-transition principles and programs requires a cross-disciplinary effort, bringing together expertise from diverse fields.

The ongoing energy transition is characterized by the following:

- Unprecedented speed. Previous energy transitions were more gradual and unfolded over lengthy periods of time [17]. The speed of the current energy transition is 1.5–2 times higher: for example, it took 50 years for oil to reach the level of 16% in global energy generation and consumption, while for RES (primarily wind, sun, and biofuel), it could take about 30 years (Figure 3);

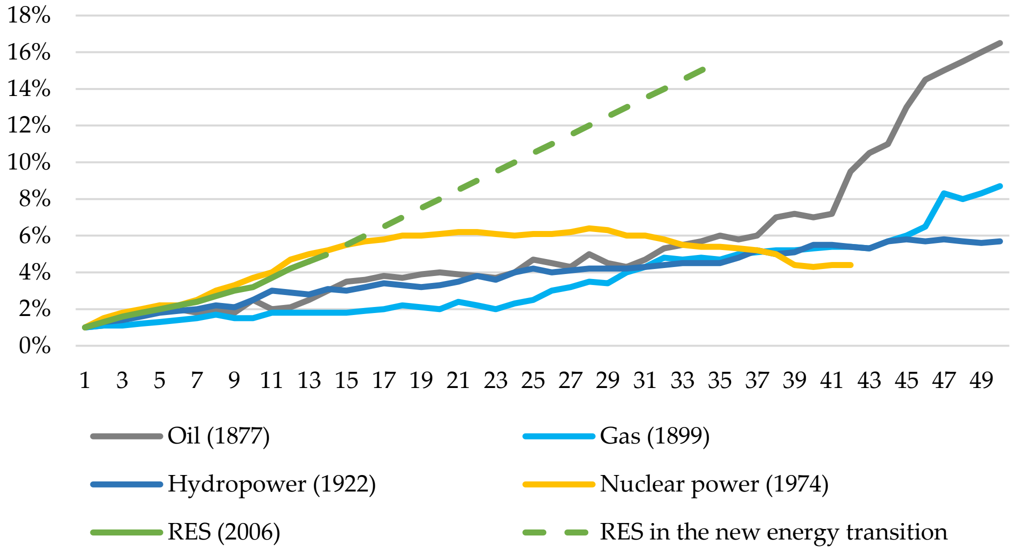

Figure 3. The speed of the shift to specific primary energy sources in different energy transitions (the first year is the year when a certain type of energy source reached 1% of the global energy mix) (based on [18]).

- Focus on carbon emissions. Previous energy transitions aimed at introducing more cost- and technically effective energy sources to the structure of energy generation and consumption. The key goal of the current energy transition is total decarbonization. New energy technologies will undoubtedly play a crucial role in this process, yet they will not be the sole means of achieving this goal;
- The grandiose scale of new technological solutions and R&D. The research literature on this topic covers six major areas: technical (efficiency enhancement technologies, solar, wind, biogas and geothermal energy technologies, technologies of energy storage and accumulation, EVs, smart cities, smart manufacturing, smart homes); economic (economy of integrated systems of power, heat and gas supply, markets of knowledge-intensive services, variable energy tariffs, demand management programs, impact of the energy transition on the prosperity of regions); information (cybersecurity, intelligent metering infrastructure, digital platforms); environmental (development of environmental standards, realization of the principles of the circular economy, deployment of carbon capture and utilization systems); management (new business models and systems of management); legal (international and regional energy laws, institutionalization of support for clean energy producers and consumers) [18–23]. Another strand of the literature deals with the ways to enhance consumers' energy culture, green economy employment, the concepts of energy democracy and energy citizenship. The term 'energy democracy' stands for the efforts on political and institutional levels to promote innovation that would contribute to the growing sustainability of the energy sector through the manageable diversity of energy solutions and the

active engagement of prosumers in the energy markets. Energy citizenship, in turn, is the view of the public that emphasizes people's awareness of their responsibility for climate change and the need for energy efficiency, as well as their active involvement in the energy transition [24–26].

3.2. Analysis of the Energy Transition Practices across the World

Analysis of various energy transition programs and initiatives across the world shows that the shift to low-carbon energy comprises three tasks: to increase the share of RES in the energy mix (combination of various primary energy sources in energy generation and consumption [27]); to accelerate electrification (especially in energy-intensive industries); and to increase the flexibility of energy systems.

The steady growth in electricity generation from renewable energy sources in the last twenty years (see Figure 4) is expected to continue across the given timeframe, that is, until 2050.

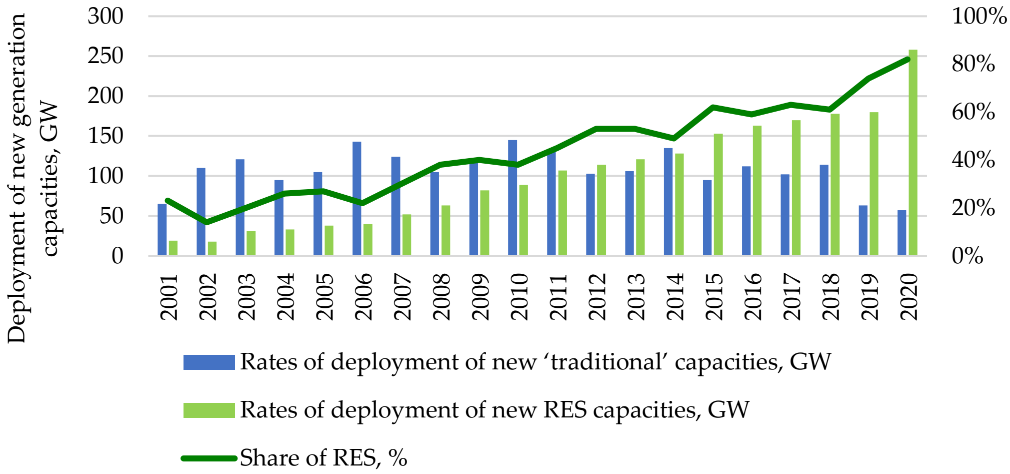

Figure 4. Comparison of the rates of deployment of new generation capacities (traditional and RES) (based on [28]).

It should be noted that there are significant regional variations in the growth rate of the share of renewable energy. Not all countries are planning to accomplish a 100% transition to RES in the foreseeable future. For example, while in North America and Europe RES are likely to replace coal and, partially, other hydrocarbons, in Asia hydrocarbons will still account for almost 50% of primary energy sources within the timeframe of 2040–2050. It is also expected that Asian countries will experience a dramatic increase in the consumption of natural gas. In the Middle East, hydrocarbons are predicted to account for over 75% of the energy mix by 2040 (Figure 5). For these countries, such an arrangement is quite natural, considering their large hydrocarbon reserves or their relative proximity to such reserves in neighboring regions and, therefore, minimal logistics costs. It is worth saying that for the Asia-Pacific and the Middle East, the active adoption of carbon capture, utilization, and storage technologies at fossil fuel power plants will be one of the key trends in the energy transition [29,30].

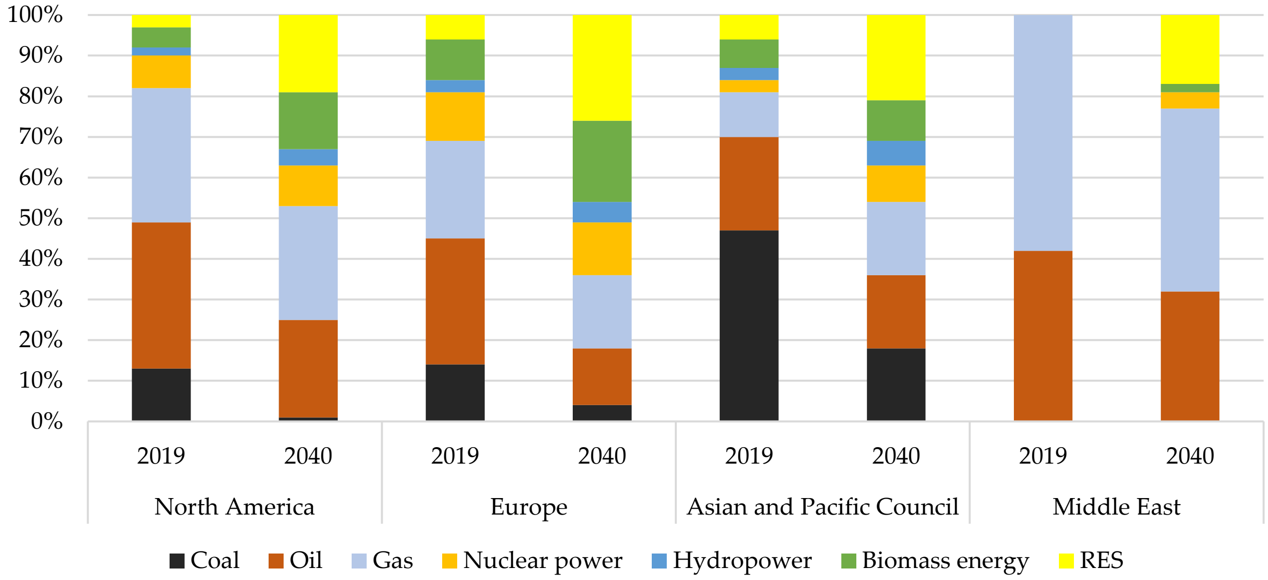

Figure 5. Energy consumption in world regions by energy source (based on [1]).

Nevertheless, the obvious prevalence of RES, first and foremost of wind and solar energy, in the energy transition is an objective fact. To a certain degree, the adoption of RES in various countries is encouraged by economic considerations: over the past 10 years, there has been a decrease in the capital costs of the construction of renewable generation facilities and in the levelized cost of energy (LCOE). At the same time, for most types of RES generation, there is an increase in the installed capacity utilization factor (CUF). The corresponding dynamics of these important technical and economic indicators is shown in Table 1.

Table 1. Dynamics of average technical and economic characteristics of various renewable generation facilities in 2010–2020 [31,32].

Type of Installation	Unit Investment Dynamics, USD/kW, %	CUF Dynamics, %	LCOE Dynamics, %
Bioenergy	−3	−2	0
Conventional solar power plant	−81	17	−85
Concentrating solar power plant	−50	40	−68
Onshore wind farms	−31	31	−56
Offshore wind farms	−32	6	−48

Other sources of energy must not, however, be excluded from the regional structure of energy carriers even if the territory boasts a favorable climate and access to corresponding energy production technologies. There can be two reasons for this. First, the annual median growth rates of energy supply for WPPs and SPPs, in the scenarios for 2020–2050 proposed by the Climate Change Expert Group, are expected to be about 11.5%, which means that the supply of primary energy from wind and solar radiation will increase twelvefold in a 30-year period [33]. According to the International Energy Agency [34], the net installed capacity of an SPP will be 13.5 GW, and for a WPP, this figure will be 7.5 GW, which is not enough and requires the development of other types of renewables, especially biomass energy, as well as highly maneuverable small-scale power-to-gas systems.

Second, excessive reliance on renewable energy creates high risks of energy price volatility due to their intermittency. When the available RES capacity is low, i.e., the energy demand significantly exceeds the output of RES-based generators, the energy price is determined by the marginal cost of energy generation at fossil fuel power stations. Unsurprisingly, as wind power production increases, the electricity price decreases [35].

S. Clò et al. showed that a 10% increase in electricity production through the use of WPPs and SPPs results in a 0.4% drop in retail energy prices [36]. In exceptional cases, when the supply of renewable energy far exceeds the demand, the price either tends to zero or can take negative values. A detailed analysis of the reasons behind the occurrence of negative prices of energy from renewable sources is provided by M. Dillig and M. Yung [37], P. Deane [38], W. Antweiler [39], and other authors.

Between 2017 and 2022, negative electricity prices were repeatedly observed in Germany, Finland, Denmark, Belgium, and the UK [40,41]. Such precedents disrupt the reliability of the power supply, negatively affect investment, and hinder overhaul processes. It has to be noted that designating RES as the priority energy source for the energy transition poses risks to energy security, even though it has the direct effect of lowering carbon emissions. This proves it necessary to diversify the energy mix, and that a combination of decentralized energy solutions (distributed generation) and large power plants, including coal-burning ones, is needed to form the energy network generation complex. A shortage in their capacity has today become one of the key causes of the energy crisis in the US and European countries.

The latter point requires a short explanation. Of course the COVID-19 pandemic, high inflation, and electricity price growth triggered by political turmoil are far more serious causes of the current energy crisis [42]. It could have been mitigated, though, if there was a sufficient amount of conventional energy capacity kept in reserve.

Electrification is particularly important to the most energy-intensive sectors which require high temperature heat, e.g., the manufacturing of concrete, lime, steel, iron, or aluminium, and in the chemical and petrochemical industries [6]. Together, these seven sectors consume about 38% of all energy, and produce about 8.6 gigatonnes (Gt) or 24% of all CO_2 emissions.

It should be noted that industry is not considered as a separate or independent consumer. For instance, in Europe, the planning of the energy transition is based on the concept of sector coupling: it is proposed to integrate the supply sector with industry, transport, and buildings, with the latter three forming a single end-use sector [43,44]. The idea behind such 'coupling' is that it should stimulate the electrification of a larger number of consumers by offering them a package of clean and economically feasible energy solutions. It is believed that without such 'coupling', the energy transition may be slower, and technological modernization and RES development may stagnate because many consumers will continue using cheaper and more affordable types of fuel.

The coupling of various sectors increases the GHG emissions of the power sector as a result of accelerated mass electrification, while simultaneously reducing the overall volume of emissions caused by the end-use of fossil fuels in transport, buildings, and industry. It is expected that in Europe, by 2050, electricity will be used as the main source of energy in 50–60% of technological processes in the coupled sectors mentioned above [44].

Figure 6 illustrates how the installed capacity of various types of energy generation is going to change in European countries in order to meet the electrification plans.

It should be observed that while European countries are going through an active "cybernetic" phase of electrification, a number of other regions are still struggling to get unrestricted access to electricity. This is particularly true for the southeast coast of Africa and South-East Asia [45,46]. Apparently, the pace of energy transition there will be much slower than in the rest of the world. At the same time, these regions have a crucial importance for the energy transition as they possess large reserves of fossil fuel that will probably be used sooner or later to speed up their economic growth.

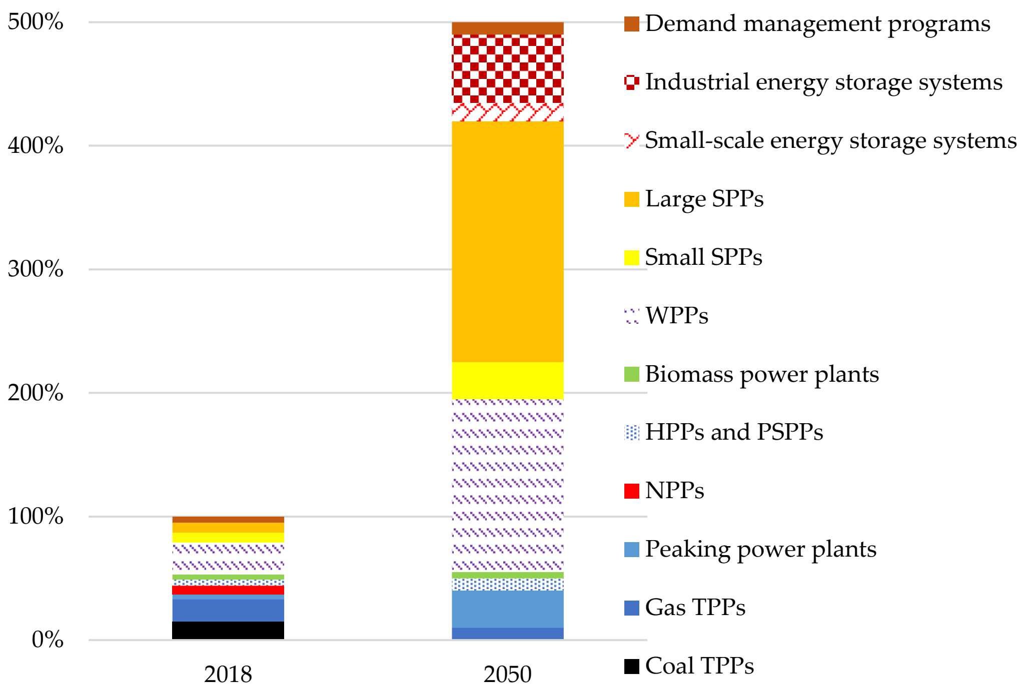

Figure 6. Changes in the installed plant capacity in Europe as a result of the energy transition (the data for 2018 is taken as 100%).

Electrification involves the creation of local facilities (small and microgeneration; microgrids, systems of energy accumulation and storage) to serve active consumers on a real-time basis. This, however, will require a significant increase in the flexibility of all elements of the energy systems, which are traditionally organized around large thermal, nuclear and hydropower stations.

Flexibility of an energy system is understood as the system's ability to respond to changes in supply and demand across various timeframes, from seconds to years. Short-term flexibility is required in order to compensate for power fluctuations in WPPs and SPPs over the course of the day (this is done with the help of energy storage systems and energy demand management programs). Long-term flexibility is provided by maintaining spare generation capacity that can be tapped into in those periods when the output of SPPs and WPPs is extremely low because of the climatic conditions, or in the case of interruptions due to maintenance works.

Table 2 provides an overview of technologies used in different countries to address energy-related problems.

Table 2. Tools to enhance the flexibility of energy systems [28,47–50].

Application Side	Existing Technologies	Emerging Technologies
Side of supply	Controllable power plants (combined-cycle plants, HPPs); peaking power plants (open cycle gas turbine plants)	Infrastructure of electric charging stations and digital platforms for direct energy transactions between consumers and the market; hydrogen fuel cells
Sides of demand and supply	Interconnectors (direct current lines); systems of energy accumulation, including pump storage power plants	Power-to-gas (P2G)–the process of converting surplus renewable energy into hydrogen gas through PEM electrolysis technology
Side of demand	Energy demand management, demand aggregators; virtual power plants	Dynamic and wireless charging stations; smart heating and heat storage systems

3.3. The Key Points of the Energy Transition Manifesto

We analyzed the current goals, programs, and challenges of the energy transition (the latter arising mainly from the overreliance on renewables), and the potential of other sources of energy, both traditional and alternative, and formulated the following key principles which form a kind of manifesto that can be adjusted to various national and regional contexts:

1. The methods (technologies) of electricity generation have various technical, environmental, and economic characteristics. The technical aspect includes the firm capacity of energy facilities, their efficiency, maneuverability, compactness, and conditions that determine their placement. The economic aspect encompasses relative capital spending on power plant construction, fuel consumption per kWh for equivalent fuel and natural fuel, repair and maintenance costs per kWh capacity, and investment parameters (payback period, ROI period, etc.). The environmental aspect deals primarily with the amount of emissions of GHGs and toxic gases, such as oxide of sulphur and nitrogen (estimated as the amount of emissions per kWh of energy), in different sectors and regions;
2. There are no ideal technologies: different methods of energy generation have different characteristics, strengths, and weaknesses. None of the most widely used means of power generation such as RES, NPPs, and TPPs is perfect: a gain in eco-efficiency will come at a cost, and in the case of RES, the output depends on many external, uncontrollable factors;
3. Taking into account public expectations concerning the development of the energy sector, it can be concluded that there is not and cannot be any one-size-fits-all solution;
4. In light of the above, it makes sense to consider the role of nuclear power energy as an alternative to thermal energy and as a valuable complement to RES. In normal operating conditions, NPPs offer some compelling benefits in terms of environmental safety and performance. NPPs do not use non-renewable fossil fuels, such as natural gas. However, there are some constraints to the development of NPPs that will have to be addressed. NPP construction costs exceed those of thermal power plants. The tendency toward reducing the unit capacity of an NPP will contribute to this factor. The maneuverability capabilities of NPPs are lower and they do not have a peak load operating regime. They cannot be equipped with reserve capacity, which, among other things, can be used to compensate for a decrease in the output of renewable energy sources. Despite the general trend of reducing the installed capacity of NPPs, there still remains a problem of siting. The most important question to be addressed is nuclear safety and security (including the minimization of the risks of radioactive contamination of the surrounding territory) in the case of massive capacity additions, variable loads, or when NPPs are located in proximity to load centers;
5. The only way to balance the characteristics (environmental, economic, and technical) of different energy generation technologies is to combine these technologies within energy systems. This is one of the ways that the systems approach can be applied to the organizational and technical transformations inherent in the transition to safer and cleaner sources of energy.

   The economic and organizational integration of the processes of energy generation, supply, and consumption to manage energy demand is another example of the systems approach. Consumer energy conservation has a strong environmental and economic impact because energy saving can in fact be much cheaper than building new power plants.

   The electrification of heating and replacement of direct-use fuel with electricity is also part of the systems approach. First, promoting energy conservation in electrification will contribute to the supply of clean energy to the consumer sector. Second, electricity will replace natural gas, which in turn can be saved and redirected for use in thermal power stations. Finally, the resulting expansion of the resource base will help lower natural gas prices for thermal power stations.

6. The starting point for the energy transition should be the development of a system of environmental standards (norms) aligned with the transition's goals—to move to a sustainable and climate-compatible economy through structural and technological transformations in the energy sector aimed at ensuring an affordable, reliable, and sustainable energy supply. This way we can maintain a healthy balance between environmental benefits and economic efficiency in consumer energy prices. To control energy prices, the following tools are used:
   - A structural and technological maneuver based on the optimization of the share of gas power stations in the structure of generation capacities;
   - Effective natural gas pricing policy stabilization or the reduction of gas prices in the energy sector, on the one hand, and, on the other, price increases for industrial consumers (provided that there is a sufficient level of competition among them to neutralize inflation);
   - Energy demand management;
   - Development of energy conservation as part of electrification.

The development of effective energy transition strategies plays a special role in a period of economic downturn or recession. In this case, there are two possible approaches. The first approach is to 'put on pause' the energy transition. However, if the pause becomes protracted, it may result in a loss of momentum, competencies, and those intermediary results that have already been attained, which will eventually lead to the key stakeholders' growing apathy and loss of interest in this task. As a result, when the economy recovers after the recession, everything will have to be started all over again, but at a much greater cost.

To mitigate the consequences of a severe economic crisis, it is crucial to ensure the accelerated development of the energy sector. The key areas of such accelerated development are modernization, upgrade, and expansion of production facilities (intelligent energy systems, distributed and autonomous generation, integrated organization and technical solutions in energy generation and consumption, increased electrification). Only if these conditions are met will the sixth technological revolution be completed in the 21st century. The forthcoming transformations based on the use of cutting-edge technologies should go hand in hand with the energy transition and align with its goals, with the possible exception of a few super-expensive projects.

We conducted a questionnaire survey among 60 executives and top specialists of energy companies and university researchers, and found that most of them are not sufficiently aware of the energy transition, its meaning, and its colossal costs (social costs). There was, however, a visible consensus among our respondents about the need to halt the active phase of the energy transition in the conditions of the global economic recession. They also agreed that it is important to continue pursuing the energy transition goals on the local level, combining these activities with technological modernization measures (Figure 7).

The analysis indicates that European experts have better awareness of the issue than their Russian counterparts (none of the respondents replied "yes"). As for the experts' opinion on costs and the priority scenario of energy transition, similar response patterns were observed: 90% of all experts said that the cost of energy transition was "very high" or "considerable"; almost 80% said that major transformations should be put on hold due to the crisis and spoke of the need to redirect funds to other purposes, such as welfare.

Thus, our opinion coincides with that of most experts. In this regard, the realistic scenario of the energy transition described in the manifesto fits easily into the processes of technological modernization, which needs to continue even in the most developed countries, due to the critical role that the energy infrastructure plays in the economy. We would like to emphasize that the energy transition will continue nonetheless, and its objectives will be reached in one way or another; the only question is how quickly and when.

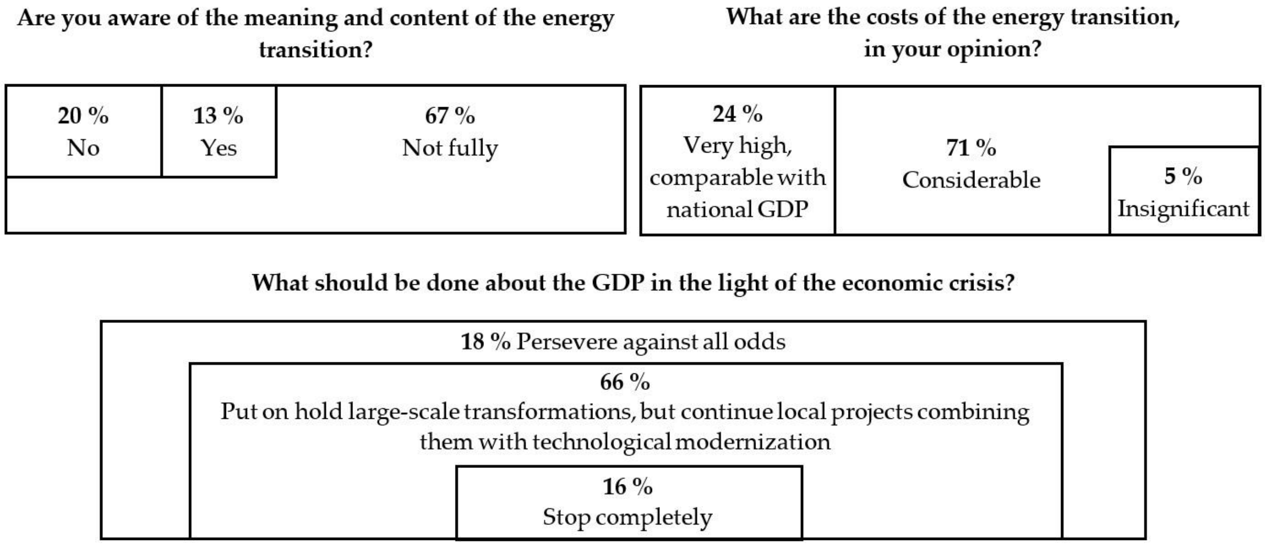

Figure 7. Experts' opinions on the nature, costs, and feasibility of energy transition measures in the time of economic recession.

The second approach implies a modification of the energy-transition management paradigm in accordance with the changes in the external economic environment. This approach is based on the dialectical assumption that certain factors of economic destabilization motivate managerial decision-making in the general context of the energy transition. In our view, it is the second approach that holds most promise.

4. Discussion

In practice, the provisions described in this manifesto come down to solving one complex task: to ensure a reliable energy supply for the economy during the transition period. This task comprises environmental, technological, and economic aspects and is much broader in comparison with traditional modernization. The complexity of this task is determined by the following:

- New problems piling up on top of each other, high uncertainty, and a shortage of expertise needed to design and organize appropriate measures and interventions and to manage the energy transition process in general (e.g., the use of RES, which are seen as the technological core of the transition to carbon neutrality, brings enormous uncertainty into the forecasting of the dynamics of energy prices and the reliability of the energy supply in general);
- The fundamental change of the structures, which is the most inert parameter in the energy sector; there are many, sometimes quite unpredictable, constraints to their transformations;
- The need to consider multiple regional factors, which vary considerably depending on local conditions.

The organizational and technical aspect of the energy transition is complicated by the need to avoid the following problems:

- The average electricity prices rising above the real inflation rate; it is particularly important to prevent an increase in prices in the public utilities sector;
- Falling energy supply reliability (volume of energy supply, continuity, voltage and frequency standards);
- 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.

The process of energy transition could also be hindered due to certain contradictions regarding goal setting and expected outcomes. The international community represented by authoritative energy associations initially declared the reduction of energy-related carbon emissions to absolute zero as the ultimate goal. In line with the first version of energy transition, the goal was to be achieved exclusively by means of RES. Later, nuclear energy was added to the mix once the limitations of the original versions became obvious. The scenario still ruled out the use of thermal power plants, both coal and gas-and-oil ones, for electricity production. This concept of energy transition ignores the peculiarities of power production and patterns in the development of electric power systems, which makes it unfeasible.

First of all, power plants of various types that are incorporated in an electric power system generate electricity under a set schedule that is determined by their maneuverability and fuel efficiency. This is necessary for balancing the load schedule within the grid, while maintaining reliability and efficiency standards. By contrast, renewable energy installations operate under an alternating schedule due to the intermittent availability of renewables. The task is to maximize the supply of green energy to the grid or to individual consumers in case of off-grid power supply (which can be partly solved through the installation of accumulators).

Nuclear power plants deliver the most stable and efficient performance at constant power with a maximum capacity factor; that is, they meet base load demand.

There is, therefore, a task to cover the fluctuating part of the load schedule (in the peak and semipeak zones), which can be solved by building highly maneuverable CHPPs with gas turbines and combined cycle gas turbines. Naturally, carbon dioxide emissions in the area will increase, especially in case of a trend towards a looser electrical load schedule when, for example, the share of industrial consumers in overall power consumption decreases.

Second, the development high-capacity wind farms and nuclear power plants is impeded by site restrictions. That is why expanding energy systems will inevitably cover a part of the base load with thermal power plants, both coal-burning and gas-fired ones (depending on what fuel is available in the region). The share of coal-burning power plants also depends on the demand for highly maneuverable installations that usually utilize natural gas only. Eventually, carbon emissions are determined by economic growth that either drives local electricity production up or down.

Third, construction of "a system-level" RES facility with a set capacity requires the allocation of a mobile operational reserve within the grid that is usually installed at highly maneuverable thermal power plants. This, too, adds to carbon emissions.

Finally, DG installations and consumers' own small yet numerous generators, that are de facto thermal power plants, contribute to the concentration of carbon dioxide in the atmosphere.

The massive investments that the energy transition requires are worth special notice: by some experts' estimates, the amount of annual investment needed worldwide for the energy transition is $4.0–4.4 trillion (provided that the global average temperature does not rise above the threshold of 1.5 °C in the next 30 years) [19,51]. McKinsey Global Institute's estimates are even higher: in the period from 2021 to 2050, the Net Zero 2050 scenario suggests that about $275 trillion in cumulative spending on physical assets, equivalent to about 7.5 percent of GDP for this period, would be needed [52]. The annual spending on the net-zero transition will rise to $9.2 trillion over the next 30 years. Of course, the energy transition is also expected to yield positive macroeconomic effects in the mid-term run that could manifest in new jobs in the energy sector and, consequently, in bigger tax revenue and higher buying capacity, etc. [53,54]. For now, however, energy transition remains an extremely capital-intensive process, even for economically developed countries [55].

The systems approach methodology has proven indispensable for tasks of this kind because it places the main emphasis on multi-faceted structural and technological diversification in the energy sector, resulting from the innovation in energy supply and energy consumption. As a result, the spectrum of primary energy sources is broadened while the share of RES and nuclear energy in power generation continues to rise [56]. TPPs are equipped with gas turbine and gas steam units to enhance their environmental safety, cost-efficiency, and technical reliability [57,58]. The energy capacity scale is being expanded with a special focus on small and medium-scale power generation [59]. Wider use is made of such supplementary and highly effective ways of energy supply as decentralization based on small-scale (distributed) generation. Energy conservation becomes a viable alternative to building new generating plants and elements of power grids. Electrification leads to the replacement of natural gas by electricity in industrial production and thus contributes to the accumulation of natural gas, which can then be used to gasify regions (including the development of small-scale power generation) [60–62]. It should be noted that regional factors have a crucial impact on the degree and direction of diversification [10,63].

Governmental regulatory bodies play an important role in energy transition management, especially in what are regarded as politically significant areas of the carbon issue: building policy frameworks, setting energy policy goals and priorities, development of national programs, regulation and monitoring of the outcomes of energy transition measures.

It is also essential to involve energy companies and consumers into the energy transition by addressing the following tasks:

- The establishment of direct agreements between large energy-consuming enterprises and energy companies about the supply of clean energy [64–66]. Such arrangements may be of interest not only to industrial companies, but also to companies in the telecommunications sector, whose energy consumption is rising fast, together with the increasing amount of processed data;
- Companies' investment of their own funds in the development of clean technology. Such oil giants as ExxonMobil and Chevron have drastically increased their investment in clean technologies of refining and utilization in order to retain their export levels. Another example is the decision of the biggest car manufacturers to phase out the sale of internal combustion engine vehicles and to transition instead to hybrids and EVs (in EV-ready countries) [67];
- The creation of autonomous generation facilities to meet the needs of large businesses. For example, in recent years, IKEA and Walmart have been consistently transitioning to the use of on-site renewables, such as solar power and biomass [68,69];
- The organization of global consortia to address the challenges of the energy transition [1,12]. For example, the Hydrogen Council, a global CEO-led initiative [70], comprises more than 100 large companies from different sectors (ALSTOM, Audi, BOSCH, Electricity de France, Kawasaki, Microsoft) and 10 investment groups for discussion, accelerated development, testing, market launch, and utilization of organizational and technical solutions in the field of hydrogen energy;
- Support of small energy-services firms and startups realizing projects that contribute to the energy transition [71].

In the new reality created by the energy transition, generation companies, power grid companies, and electricity suppliers will acquire new functions. For example, retailers are advised to implement advanced mechanisms of interaction with energy consumers [72,73].

In most countries, energy transition should be also supported on the regional level, especially in such spheres as the development of non-conventional and small-scale power generation; the use of local fuel and energy resources to promote advanced energy technologies; and the construction of energy-efficient residential and commercial buildings. The above-described tasks can become part of comprehensive territorial development programs and realized by local and regional authorities.

5. Conclusions

The energy transition encompasses profound technical and economic transformations in energy generation, supply, and consumption aimed at minimizing the environmental impact of the energy industry. This paradigm shift involves the following:

1. An increase in the share of RES and nuclear energy in the structure of generation capacities;

2. The optimization of the percentage of environmentally friendly and highly efficient thermal power plants;
3. The enhancement of energy-use efficiency through energy demand management programs;
4. The electrification of energy consumption to foster the replacement of fossil fuels with clean energy sources.

The implementation of the main phase of the energy transition will coincide with a period of significant socio-economic and geopolitical turbulence, and increasing uncertainty in the general context. By all accounts and purposes, many projects initiated by national governments and international organizations, such as the UN, International Energy Agency (IEA), International Renewable Energy Agency (IRENA), and others, will have to be revised, especially in the parts dealing with their costs and timeframes.

Nevertheless, the general agreement about the need to transition to a clean energy-based economy, the growing public awareness of the true cost of fossil fuels, and the rising demand for clean energy from different groups of consumers gives us sufficient grounds to expect that the goals of the energy transition will be reached. Despite the current economic downturn and shortage of investment resources, it would be short-sighted to halt this process since the continuous modernization of the energy sector is essential for the future of any national economy. A more balanced, down-to-earth perspective on renewable energy sources is necessary. Instead of seeing RES as a panacea for climate change, it would be more productive to focus attention on low-carbon production technologies.

Energy transition is a monumental challenge involving a large number of stakeholders (the public, politicians, investors, energy companies, national governments) with different and often conflicting interests. It should be noted that the sheer scale of the task precludes the possibility of its being handled by a single team, organization, or government agency. Therefore, our primary purpose in this paper is to present our conceptual ideas, initiate a discussion across international and disciplinary boundaries, and turn these general principles into specific measures and conventions.

Two key limitations were identified in the course of the research. First of all, no analysis was previously performed on the specific features of the energy transition in all regions of the world, e.g., Latin America, the Caribbean, or Africa. Country-specific peculiarities of the energy transition could be the subject of a series of targeted pieces of research. The authors believe, however, that this constraint has little impact on the general conceptual premises and conclusions of this article. Indeed, the organization of the energy industry in each country has its own differences. However, when planning and implementing an ET, a country relies on a certain universal sequence of steps, assessing, for example, the current and potential structure of generating and network capacities, prospective shifts in energy demand, reserves for improving environmental efficiency, and other significant indicators. In this regard, the author's recommendations focus on a set of top-priority areas (actions) that are essentially necessary for any region, regardless of its energy specifics.

Another limitation could be found in the engagement of mainly Russian experts in the surveys. It should be noted that the respondents' professional and academic background, their experience of participation in energy innovation projects, and broad scope of general knowledge were the key selection criteria employed by the authors. This is why the majority of the surveyed experts are top managers of large energy companies. It is worth saying that, in order to boost the validity of our conclusions, numerous opinions were collected from international experts, summarized from scientific publications and analytical reports, as well as collected independently.

This article opens up a horizon of possibilities for scientific research and a broad debate on the results. In broad strokes, possible areas of research include trends of the new phase of electrification; opportunities for demand-side management in manufacturing and domestic energy consumption on the basis of the cutting-edge IT tools; problems of the multi-criterial design of scenarios for energy transition implementation with respect to various options of economic and geopolitical shifts; and ensuring energy security amid energy transition. The latter is arguably the central subject of academic research amid a growing energy crisis.

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Abbreviations

CoP	coefficient of performance
ET	energy transition
GTP	gas turbine plant
HPP	hydropower plant
IES	integral energy system
NPP	nuclear power plant
PDC	power distribution complex
PGC	power generation complex
PSPP	pump storage power plant
PUC	power utilization complex
RES	renewable energy sources
SPP	solar power plant
TPP	thermal power plant
WPP	wind power plant

Appendix A. List of International Partnership Initiatives Promoting the Energy Transition

1. Energy Transition Council, https://ukcop26.org (accessed on 21 November 2022).
2. Energy Storage Partnership, https://www.esmap.org/the_energy_storage_partnership_esp (accessed on 21 November 2022).
3. Renewables for Latin America and the Caribbean, https://www.lac-core.org (accessed on 21 November 2022).
4. The Africa Renewable Energy Initiative, http://www.arei.org (accessed on 21 November 2022).
5. Green Hydrogen Catapult, https://greenh2catapult.com (accessed on 21 November 2022).
6. IRENA's Collaborative Framework on Green Hydrogen, https://www.irena.org/collaborativeframeworks/Green-Hydrogen (accessed on 21 November 2022).
7. IRENA's Collaborative Framework on High-Share of Renewables, https://www.irena.org/collaborativeframeworks/High-Shares-of-Renewables (accessed on 21 November 2022).
8. International Partnership for Hydrogen and Fuel Cells in the Economy, https://www.iphe.net (accessed on 21 November 2022).
9. International Energy Agency's Hydrogen Technology Collaboration Program, https://www.ieahydrogen.org (accessed on 21 November 2022).
10. Hydrogen Initiative of the Clean Energy Ministerial, https://www.cleanenergyministerial.org (accessed on 21 November 2022).
11. Fuel Cells and Hydrogen Joint Undertaking of the European Commission, https://www.fch.europa.eu (accessed on 21 November 2022).
12. Hydrogen Council, https://hydrogencouncil.com/en/ (accessed on 21 November 2022).

13. European Clean Hydrogen Alliance, https://www.ech2a.eu (accessed on 21 November 2022).
14. Powering Past Coal Alliance, https://www.poweringpastcoal.org (accessed on 21 November 2022).
15. Clean Air Fund, https://www.cleanairfund.org (accessed on 21 November 2022).
16. Science-Based Targets Initiative for Oil and Gas, https://sciencebasedtargets.org (accessed on 21 November 2022).
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22. Cool Coalition, https://coolcoalition. org (accessed on 21 November 2022).
23. Super-efficient Equipment and Appliance Deployment, https://www.cleanenergyministerial.org/initiative-clean-energy-ministerial/super-efficient-equipment-and-appliance-deployment (accessed on 21 November 2022).
24. United for Efficiency, https://united4efficiency.org (accessed on 21 November 2022).
25. Global Alliance for Buildings and Construction, https://globalabc.org (accessed on 21 November 2022).
26. Zero Carbon Buildings for All, https://www.worldgbc.org/zero-carbon-buildings-all (accessed on 21 November 2022).
27. District Energy in Cities, https://www.seforall.org/partners/district-energy-in-cities-initiative (accessed on 21 November 2022).
28. Partnership on sustainable low-carbon transport, https://slocat.net (accessed on 21 November 2022).
29. Global Fuel Economy Initiative, https://www.globalfueleconomy.org (accessed on 21 November 2022).
30. Global Bioenergy Partnership, http://www.globalbioenergy.org (accessed on 21 November 2022).
31. Transport Decarbonization Alliance, https://tda-mobility.org (accessed on 21 November 2022).
32. Transformative Urban Mobility Initiative, https://www.transformative-mobility.org.
33. Biofuture Platform, http://www.biofutureplatform.org (accessed on 21 November 2022).
34. Getting to Zero Coalition, https://www.globalmaritimeforum.org/getting-to-zero-coalition (accessed on 21 November 2022).
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