UDC 330.1; 330.3; 338.4 DOI 10.62034/2815-5300/2024-v1-i2-007

CONCEPTUAL ASPECTS OF ENERGY GENERATION MARKET DEVELOPMENT ON THE PRINCIPLES OF SUSTAINABILITY

Mariia Dykha[1], Valerii Dykha[2], Vitalii Zyma[3]

[1]*Doctor of Economics Sciences, Professor, Professor of the Department of Economics, Analytics, Modeling and Information Technologies in Business, Khmelnytskyi National University, Ukraine*
Email: dyha-mv@ukr.net , ORCID: https://orcid.org/0000-0003-4405-9429
[2] *PhD Student (Economics), Khmelnytskyi National University, Ukraine*
Email: dyhavalera@gmail.com , ORCID: https://orcid.org/0009-0004-2398-3692
[3] *Master's student (Economics), Khmelnytskyi National University, Ukraine*
e-mail: zima.vitalick@gmail.com , ORCID: https://orcid.org/0009-0002-6694-3311

ABSTRACT. The article offers a conceptual vision of the development of the energy market based on the principles of sustainability, which should be characterized by safety, environmental friendliness, adaptability and stability, efficiency (including economic) and accessibility (including social), transparency. The importance of ensuring the adaptability of the development of the energy system due to uneven energy consumption throughout the day and throughout the year, stability, safety of energy generation, and transparency is substantiated, which will be facilitated, among other things, by the synchronization of the energy system of Ukraine with the energy system of continental Europe. The expediency of increasing the use of ecologically neutral sources of electricity, which is important for ensuring sustainable development, is substantiated . The possibilities and features of the development of energy generation from renewable sources are characterized, which include: solar, wind, hydrogen generation , the use of biogas, obtaining energy from household waste, as well as hydrogen and nuclear generation. Despite the ecological neutrality of solar and wind power plants, the need for disposal and processing of individual components at the end of their service life is described, the need to work out such issues in advance, which corresponds to the principles of sustainability. The adaptability of the operation of hydropower plants and their different productivity depending on the methods of using water energy are noted. The types of hydrogen production and the features of hydrogen generation are described, as well as the feasibility of developing biogas energy generation, which will contribute to the "smart" disposal of waste and the rational use of such resources. The dangers associated with nuclear power plants are summarized, the leveling of which will contribute to the safety and stability of their operation. Attention is also paid to types of energy generation that are not environmentally friendly (thermal power plants), which generate electricity by burning fuel (coal, gas). Their share in the energy-generating balance is decreasing, but today they still provide the necessary adaptability in the energy market. To ensure stable, adaptive, efficient operation of

the energy market of Ukraine, it is important to ensure the diversification of generation; to maximally realize the potential for the use of renewable energy sources, to generate ecologically clean energy.

Keywords: energy generation, ecology, environmental friendliness, stability, adaptability, sustainable development, energy market, energy security.

INTRODUCTION. Energy is an open dynamic system. For the energy industry of Ukraine, the war caused enormous challenges. Aware of the threats caused by the shelling of the Zaporizhzhya NPP, its seizure by Russian troops on March 4, 2022, and despite the consequences of missile attacks on energy facilities, we note that the Ukrainian energy system creates opportunities for the functioning of all other branches of the national economy and the daily life of household consumers. Threats to the energy system in the autumn-winter period of 2022-2023 as a result of massive, targeted missile attacks by the Russian Federation on the energy infrastructure of Ukraine were critical. Thanks to international support, as well as due to the redistribution of internal resources, Ukraine's energy system has survived and has become more responsive, but not qualitatively new. The issue of modernization measures in the industry, the introduction/increase of the share of ecologically clean energy sources in the balance of the energy market is urgent, besides, today the threats to the functioning of the national energy system of Ukraine are high.

Analysis of research and publications. Numerous studies are devoted to highlighting issues of the functioning of the energy system, the need for its modernization, and the development of renewable energy sources. In particular, the author of the publication [1] describes the issue of limited possibilities of using solar panels in winter. Certain aspects of wind energy were reflected in the publication [2], and hydropower - in publications [3; 4]. The issue of electricity generation from hydrogen; publications [5; 6]. The range of issues related to the functioning of Ukraine's energy system and aspects related to the importance of ensuring energy security in the national security system were reflected in publications [7; 8]. To ensure energy security and development of the energy system, it is necessary to implement energy modernization, implement effective energy management, and make maximum use of the possibilities of renewable energy, which is described in publications [9; 10].

Responding to the challenges and needs of modern realities, on April 21, 2023, the Cabinet of Ministers of Ukraine adopted the "Energy Strategy of Ukraine for the period until 2050" [11]. The previous Energy Strategy of Ukraine for the period until 2035 "Security, energy efficiency, competitiveness" [12] became invalid. The energy strategy of Ukraine until 2050 provides for the restoration of the energy sector using the most modern technologies, strengthening the stability of the system and strengthening the energy security of Ukraine and the European continent as a whole. The key task of the Strategy is to transform Ukraine into the energy hub of Europe, which will help the continent finally get rid of dependence on Russian fossil fuels thanks to the clean energy produced in Ukraine [13]. Despite the adoption of a number of documents at the legislative level, the implementation of a set of measures aimed at Ukraine's accession to the EU, measures to synchronize the work of the Ukrainian and European energy systems, which have already been implemented, we note a range of issues that need to be resolved in order to bring Ukraine closer to the goals of carbon neutrality.

Taking into account modern challenges, threats to national security and, in particular, energy security, it is necessary to implement a new paradigm, a new philosophy of the functioning and development of the Ukrainian energy system, which will adequately confront challenges and threats to Ukraine, as well as comply with the system of achieving the goals of sustainable development. It is necessary to carry out the maximum possible transformational changes of the energy system of a structural nature, including at the expense of foreign capital. Therefore, it is expedient to analyze the conceptual aspects of the development of the power system in the context of ensuring its effective functioning, the ability to fully provide electricity needs on the principles of sustainability.

The purpose of the article is to outline the conceptual vision of the characteristics of the development of the energy generation market, to substantiate the key aspects of the modern paradigm of the development of the energy system based on the principles of sustainability.

Contribution of the main research material. The energy system development paradigm, the modern strategy for the functioning and development of the Ukrainian energy system must correspond to the realities of today, cope with challenges, eliminate threats, and be implemented on the principles of sustainability.

We offer our Meta-vision , a conceptual vision of the development of the energy generation market, which should be characterized by safety, environmental friendliness, adaptability and stability, efficiency (including economic) and accessibility (including social), transparency (Fig. 1). Types of energy generation have certain characteristic features. To ensure the efficient operation of the energy market, it is necessary to achieve an energy balance by types of energy generation, to ensure the development of the energy market based on the principles of sustainability.

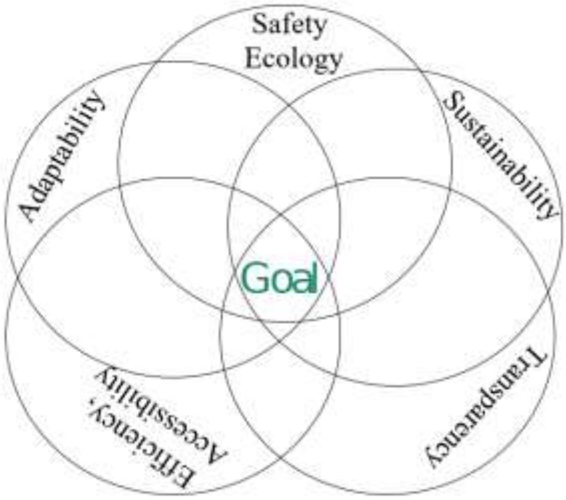

Fig. 1. Conceptual aspects of energy market development, *compiled by the authors.*

The dynamics of electricity consumption in Ukraine during 2019-2021 is shown in Fig. 2.

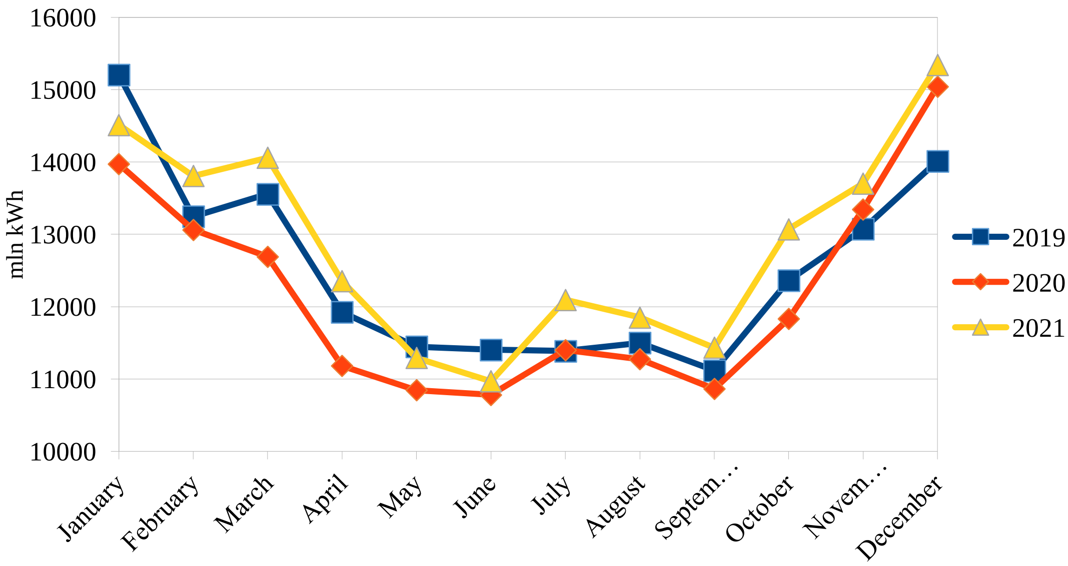

Fig. 2. Dynamics of electricity consumption in Ukraine in 2019-2021

Source: [14]

Volumes of energy consumption in Ukraine for the months of 2019-2021 indicate a certain pattern of behavior of demand for energy generation. The increase in energy consumption in March is objectively explained by the greater number of days in this month than in February, as well as, usually, the cold beginning of spring in Ukraine; increase in energy consumption in July-August - due to hot weather and energy consumption by air cooling devices, which are actively used by business entities, in particular, trade; household consumers also use air conditioners, which leads to an increase in energy demand. We also note fluctuations in energy demand throughout the day.

Traditionally, peak energy consumption occurs at 8-10 p.m., and minimum energy consumption requests from 2 to 4 a.m.

Therefore, we state the importance of ensuring the adaptability of generation capacities. By the concept of adaptability, we understand the possibilities and terms of increasing or reducing capacities, deployment of additional or new capacities, mobility in the energy generation system. Adaptability is an important aspect that must be taken into account in the energy development system by types of energy generation due to the volatility of electricity demand. If the aggregate capacities of energy generation facilities are not sufficiently flexible, situations will arise with possible energy shortages, the impossibility of meeting the demand for energy during periods of "peak" requests for it; and the opposite situation – the generated energy that is not demanded in full volumes in periods of minimal requests for its consumption requires technical and technological solutions regarding its accumulation for further use in periods of increased demand, solutions/opportunities for its export, etc. It should be noted that the synchronization of the Ukrainian energy market with the EU energy market strengthened the aspect of its further transparent functioning, market pricing, introduction of risk management tools, hedging. Also, within the framework of the synchronized energy market, opportunities for adaptability are created by exporting surplus energy when it is not in demand to the energy market of Ukraine, and vice versa - importing it when there is a lack of energy generation by domestic capacities.

The stability of the development of the energy system includes important aspects of the safety of energy generation, networks and products of its activity, as well as the ability to provide power regardless of the operating conditions of the facilities.

In the system of ensuring sustainable development, it is important to increase the use of environmentally neutral sources of electricity. Therefore, under the prism of environmental friendliness, it is necessary to consider the operation of solar power plants (SPP), wind power plants (WPP), hydroelectric power plants (HPP), in one generation and production of hydrogen, biogas, energy generation by nuclear power plants (NPP). In addition to the implementation of ecologically neutral power plants, in our opinion, the issue of disposal of used parts and products is relevant.

Below we will present a more detailed **description of the characteristics of the energy market development** (adaptability, stability, safety, environmental friendliness, efficiency, etc.) and the possibilities of their provision in terms of types of energy generation.

Solar power plants. Due to the relatively low price, ease of operation and ease of installation, SESs provide an opportunity for territorial communities and individual citizens to establish "independent" local electricity supply. In addition, the physical separation of the panels and built-in batteries allow the installations to work and provide electricity to consumers independently of the state of the rest of the network, autonomously. Solar power plants (SPP) can be assembled (install solar panels) relatively quickly. According to [15], it will take 2-3 days to install the panels for a 10 kW ground power plant, 3-4 days to install a similar power plant on the roof, 5-6 days for a 20 kW power plant on the ground, 6-8 days on the roof days; installation of a 30 kW HPP on the ground will take 6-7 days, on the roof - 12-14 days. It is worth noting that the installation of such SES capacities is more relevant to households (the installation of one 10 KW power plant can meet the needs, at best, of one household with an area of up to 100 m^2). Characterizing the aspect of "adaptability", it is important to note that SPPs cannot "forcibly" increase capacity. An increase in the energy flow from the SES can be achieved only by installing additional units / panels, however, seasonality and weather conditions should also be taken into account; in the winter period, take into account the reduction of the nominal value declared per SES unit. Therefore, the ability to produce SPP power depends on the weather conditions and geographical location. In cloudy weather, the efficiency of the SES decreases by 80%. Ukraine is also characterized by a drop in generation in the autumn-winter period due to the shortening of the daylight hours, as well as snowfall. In addition to the above-mentioned SES, it does not work at night, but can only provide electricity stored in the battery. In Fig. 3 shows the fluctuations of SES generation throughout the year [1].

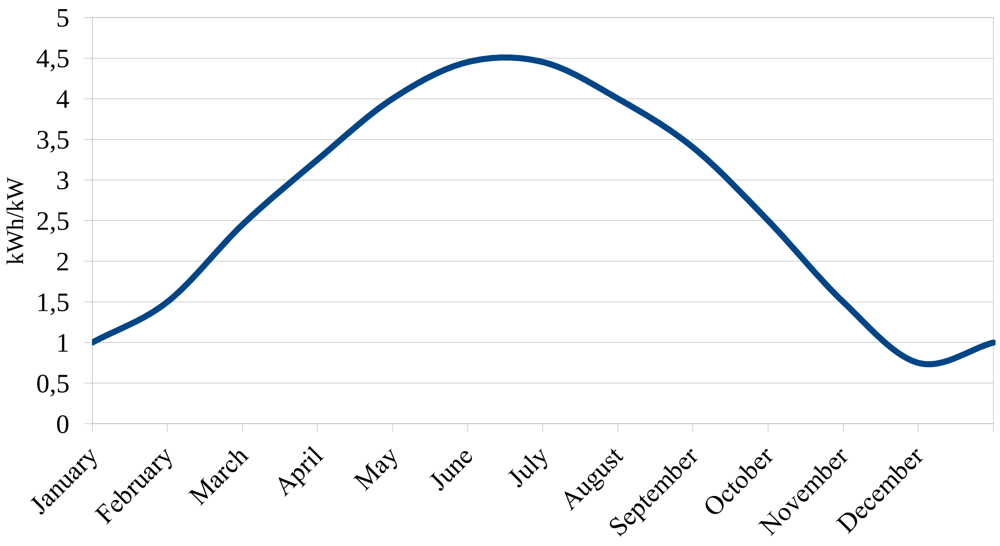

Fig. 3. Energy generation of a SPP with a capacity of 1 kW during the year

Source: [1]

The operation of SES is safe, problems may arise in the batteries, but with proper operation, installation and timely revision, the risk of this is minimal.

According to data [16], the service life of solar power plant panels is 20-25 years on average. In the context of the argumentation of the "environmental" aspect, we note that SES can be disassembled into constituent elements (silicon plates, aluminum base, polymer substrate and glass), which are potentially 100% recyclable. Since photovoltaic SESs have become widespread, it is appropriate to note that their components are batteries, which are difficult to dispose of in Ukraine. Batteries belong to the second class of danger due to the content of heavy metals, alkalis, acids, etc. The complexity of disposal varies depending on the type of device. In particular, lead-acid batteries with a service life of up to 5 years are processed by Ukrsplav LLC, which is currently in the process of bankruptcy. As for the disposal of lithium-ion and lithium-polymer accumulators, the service life of which is 20 years, there are currently no companies in Ukraine that specialize in such activities on an industrial scale due to the lack of demand for this type of activity. However, the latter will acquire significant parameters in 5-10 years, since we can predict a significant increase in the types of electric transport accumulators used, the number of which increases from year to year. In Europe, the process of disposal and recycling of batteries under the principle of extended producer responsibility is entrusted to the manufacturer's company, which monitors the life cycle of the product.

Wind power plants. Energy generation by wind turbines is characterized by geographical limitations depending on the wind regime of the territories. That is, it is not advisable to build wind turbines in all areas due to the potentially low return. Due to energy losses during transmission over networks, excessive concentration of production is not advisable. Wind turbines have the same characteristics as SES for energy generation - dependence on natural conditions. The potential generation of wind turbines increases in the presence of wind and decreases to zero in its absence. Of course, there are constant winds at high altitudes, but the strength of the wind has a significant effect on generation. The construction of a wind farm is a long-term process, which is preceded by a survey of the area for a period of 1-2 years. First of all, anemometers are installed at a height of 30-100 meters, a study of sound transmission in the area is carried out, etc., based on the results of the study and a decision on the installation of the wind turbine - the construction of a concrete foundation, the construction of a station and the installation of a power grid.

The ecological aspect of the operation of wind turbines can be characterized by their negative impact on fauna and soils when they are incorrectly designed and placed. Among such negative impacts can also be the collision of birds with the elements of wind turbines, the migration of animals due to sound pollution and vibration, the creation of a barrier effect that disrupts the internal connections of the biome. Placing wind turbines on peatlands can cause their degradation, which will lead to an increase in carbon emissions. [17] The main danger from the operation of wind turbines is manifested in the impact of low-frequency noise of 20-200 Hz on human health. The level of negative impact decreases with increasing distance from the installation, improvement of noise insulation of the building with specialized materials. As for noise in the audible range, it will be 43 decibels at a distance of 300 meters (according to the order of the Ministry of Health No. 463, the permissible range of noise in residential premises is: 40-55 dBA during the day, 30-45 dBA at night) [18; 19; 20].

The context of problems of disposal of components for wind turbines is similar to SPP. Most components of wind turbines can be recycled or safely disposed of, but the blades, which are made of fiberglass and carbon plastics, are difficult to recycle, so they are mostly taken to specialized landfills. Disposal problems, requests for processing cause the birth of start-up projects, enterprises of the corresponding profile. In particular, "Global Fiberglass Solution" and "Carbon Rivers" develops and implements methods for processing electric turbine blades. [2]

Hydroelectric power stations. Hydroelectric power plants do not create harmful emissions when producing electricity, so this energy is considered green. But some types of hydroelectric power plants have a negative impact on the environment. It is possible to distinguish two major types of hydroelectric power plants and methods of using water energy that do not involve the construction of stations [3; 4]:

- large HPPs. The production of electricity involves dredging the river to obtain the planned volume of water at a certain height. The greatest efficiency of hydroelectric power stations of this type is shown at significant height differences, for example, in mountainous terrain. The highest in Ukraine is the Tereble-Ritska HPP with a height difference of 45.8 m, and most of the large HPPs in Ukraine are flat with small height differences. The Dnipro HPP has a drop of about 40 m, the Kyiv HPP only 10. At the same time, the construction of lowland HPPs is accompanied by the flooding of large areas of fertile land suitable for agricultural use. In addition, the construction of a dam significantly changes the behavior of groundwater, because around the flooded areas the groundwater level rises significantly, which can lead to waterlogging, but below the dam, the groundwater level falls with the opposite consequences. The construction of the dam leads to a significant change in the relief, as well as to a change in the direction of the winds. In addition, the reservoirs of Ukraine have a shallow depth, which allows the water to warm up to a considerable depth and creates conditions for the reproduction of gray-green algae, which actively consume oxygen from the water, as a result - the mass death of fish, the creation of an excess of carbon dioxide and methane. It is worth noting that the reclamation of lands under the reservoir after drainage is impossible or significantly difficult;

- small- micro hydroelectric power plant. These floating and submersible hydropower plants do not block the current, but are built into it, and can generate enough electricity at low current speeds (from 3 km/h);

- tidal turbines. Produce the least amount of electricity compared to the above-mentioned generation, can be located exclusively on seas that have sufficient tidal effect for generation;

- wave energy. These are lever- type systems that utilize the energy of waves on large reservoirs - rivers, reservoirs, etc. These systems can work not only from natural waves created by the wind, but also from waves produced by water transport.

Tidal turbines and wave energy are completely ecological ways of generating energy, but they are not very productive. They can be used as an additional source of local energy generation.

Since 2006, the second wave of HPP reconstruction has been underway in Ukraine. According to the projects, the normative period of use of hydraulic structures is 100 years. Of course, for equipment, this term is significantly shorter not only due to wear and tear, but also due to moral aging. The second stage of reconstruction aims to extend the operational life of existing hydroelectric power plants and increase their capacity. Unfortunately, a full-scale invasion disrupted the planned schedule of events. In addition, the destruction of the Kakhovskaya HPP showed the danger of dam breaks, as well as the possibility of using the HPP as a weapon of mass destruction.

HPPs are capable of producing constant power, provided there is sufficient water pressure. That is, in the context of the stability of generation, power plants of this type are vulnerable to dry seasons, which can potentially cause a decrease in the upper limit of capacities with significant evaporation of reservoirs.

Hydroelectric power plants and hydroelectric storage power plants (HAPP) are adaptive, but note that they respond to changes in demand for electricity with a time lag. Therefore, it is necessary to carefully plan capacities so that there are no stressful stops of the mechanisms. HPPs can accumulate energy with the help of pumps; during off-peak hours, the station pumps water into special pools and during peak hours, an additional turbine is used to cover the shortage.

Hydrogen generation and hydrogen production. The production of electricity from hydrogen and the use of hydrogen as a vehicle fuel are environmentally friendly, since the products of hydrogen combustion are energy and water itself. However, not all hydrogen can be called absolutely ecological. Depending on the production technology, hydrogen is divided into the following types [14]:

- green hydrogen. Completely ecological, it is produced by decomposition into hydrogen and oxygen with the help of electricity from wind, hydro and solar power plants. Such hydrogen acts as an easily transportable battery with a high rate of return, which makes it possible to solve the problems of locality, diurnal regime and seasonality for SES and wind turbines. The cost of such hydrogen in the world in 2021 was 9-10 $ per kg. We predict a decrease in the price in connection with the implementation of measures to reorient the European electricity industry to renewable sources. The production of ecological hydrogen is included in the "Hydrogen Strategy for a Climate-Neutral Europe" from July 8, 2020;

- yellow hydrogen. Produced by electrolysis of water to hydrogen and oxygen; during production, the energy of nuclear power plants is used. Since the European Commission recognized nuclear plants as green, it can be said that this type of hydrogen is also environmentally friendly. The advantage of this method, in our opinion, is the ability to use it to balance the power of nuclear generation in the event of a need to increase or decrease generation. In 2021, the price of this type of hydrogen was 9-10 $ per kg due to the high cost of nuclear energy;

- turquoise hydrogen. Obtained through pyrolysis of water and natural gas; the output is hydrogen and solid carbon, the latter used in the production of batteries and steel. The cost of such hydrogen in 2021 was up to 5 $ per kg;

- gray hydrogen. It is obtained by steam conversion of methane. During the reaction, the volume of carbon dioxide equivalent to the volume of natural gas combustion is released. This is the cheapest type of hydrogen as of 2021 –2-3 $ per kg;

- blue hydrogen. This is enhanced gray hydrogen; in its production, carbon dioxide traps and accumulators are used with subsequent storage at the bottom of the sea or ocean. The cost of such hydrogen as of 2021 is up to 9 $per kg;

- brown hydrogen. Obtained by heating hard coal with water vapor without air access. In the process, a large amount of carbon dioxide is released - twice as much as when burning natural gas. The cost of such hydrogen is up to 2-3 $ per kg;

In the context of safety, it is important to add that gaseous hydrogen is a light gas, lighter than air, has no color and odor, has high explosive and fire resistance, for ignition a rather lower concentration of a hydrogen-air mixture than for air-gasoline vapors; and sparks even from the static electricity of the human body; at the same time, the hydrogen flame is invisible. That is why when producing and storing hydrogen, it is necessary to avoid the accumulation of gas in uncontrolled areas. In open areas, hydrogen quickly evaporates and is not dangerous. Accumulation of hydrogen can occur in underground storages in a liquefied cryogenic state, in porous hydride materials, in cylinders.

Hydrogen can be transported through pipes, cylinders, and metal hydride storage tanks. The problem of transporting hydrogen in pipes for Ukraine is that, due to the small size of the molecules, hydrogen is able to "corrode" untreated steel and cast iron, making the pipe brittle with an increasing risk of leakage. It will not be possible to use the existing gas transportation system to transport hydrogen through the pipelines of our country without upgrading/replacing the pipes with new ones with a special coating. In addition, in order to use hydrogen as a motor fuel, it is necessary to create an infrastructure of specialized hydrogen filling stations. The use of metal hydride accumulators, the principle of operation of which is based on the reversible reaction of hydrogen with some metals, alloys, and intermetallic compounds, looks promising. These accumulators are characterized by a high water capacity, which is 3 times higher than similar containers with liquid hydrogen. In addition, hydrogen is in a bound state, which significantly reduces the risks of damage to the shell. Also, this method does not involve injection of high pressure and compliance with low temperatures in the container, and the simplicity of the design facilitates maintenance.

Ukraine plans to use mostly "green" hydrogen. Its provision depends on the ability to implement ambitious projects for the construction of "green" farms (such as the project for the construction of wind farms on the shelves of the Azov and Black Seas). These regions have access to the GTS, which after modernization will theoretically be able to transport hydrogen as well. An important issue is the creation of a hydrogen market as an auto-regulator of the industry.

Hydrogen power plants work on the principle of thermal power plants (TPP), burning hydrogen as a fuel element. That is why generation of this type is flexible in changing capacities. Hydrogen power plants can both quickly increase generation and quickly reduce it, the question is solely in the sufficiency of hydrogen fuel. In addition, there are many hydrogen generators, for example, the GEH 2 electric generator from Energy Observer Developments, capable of producing 80,000 W of electricity continuously without harming the environment. That is, hydrogen generation is not only adaptive, but also mobile. [15]

Biogas. Biogas is the most universal source of energy among environmental sources. It can be used for cars, heat, electric generation. The generation process can be conditionally divided into two stages:

1. Production of biogas by anaerobic fermentation of organic waste in biogas plants or specially organized landfills; the chemical composition of biogas is shown in table. 1.

Table 1

Chemical composition of biogas

Substance	Chemical formula	Content, %
Methane	CH_4	40-75
Carbon dioxide	CO_2	25-55
Water vapor	H_2O	0-10
Nitrogen	N_2	<5
Oxygen	O_2	<2
Hydrogen	H_2	<1
Hydrogen sulfide	H_2S	<1
Ammonia	NH_3	<1

Source: [21].

2. Release of energy from biogas using combustion in cogeneration plants.

Biogas plants are a complex solution. First, it is the smart disposal of waste and the rational use of this resource, as well as the reduction of emissions of carbon dioxide and other toxic substances from this waste.

Cogeneration plants are a whole system of interconnected processes that go through certain stages. The following raw materials can be used: sewage sludge, solid household waste, animal manure, plant waste, food waste. The raw material goes further through the stage of fermentation vats, landfills of solid household waste; then - gas purification system, biogas delivery and storage system. Delays in stages / damage or lack of gas reserves stop generation. In addition, methane is an explosive gas, handling it requires compliance with appropriate safety measures.

The most productive is the use of biogas in combined generation, when the cogeneration plant works as an electricity and heat generator. That is, such an installation will provide the greatest efficiency during the heating season. Moreover, biogas can be used as a substitute for natural gas for the population, industry, and fuel for appropriately equipped machines.

Biogas plants are essentially gas-fired thermal power plants. It can be said that they have a high level of adaptability, they can quickly increase and decrease the production of electricity without harming the installation, the limitation is the available amount of biogas, but it can theoretically be replaced by natural gas if necessary, with surpluses of generated biogas - it can be provided as household for the population and industry or use as fuel.

Energy generation by nuclear power plants. NPPs are designed to operate at a constant capacity, that is, technically and technologically, they cannot quickly adapt to changes in demand during the day. That is why it is important to:

- availability of balancing capacities - stations that can quickly and safely increase and decrease capacities, which will compensate for the inflexibility of nuclear generation;

- a well-thought-out structure of generation and a plan for its use, balancing the supply and demand of electricity. This is important, because with a large share of NPP energy generation in the overall energy generation structure, it may be necessary to reduce the power of reactors, which can potentially lead to accidents and emergency situations.

The construction of a nuclear power plant is a long-term and expensive design and construction process. So, the construction of five new power units at the Khmelnytskyi NPP in the project costs more than 30 billion dollars and is designed for a 35-year construction process. But today, new types of reactors and NPP architectures are being developed. In particular, the Westinghouse company Electric [22] is developing a mobile microreactor with a capacity of 15 MW, the deployment period of which is only 30 days, a full commercial launch is planned for the end of the 20s, and the demonstration will be as early as the end of 2024. This type of reactor will allow not only super-fast capacity increase, but also prompt react to "failures"/lack of energy in the network and close them.

The issue of nuclear power plant safety was brought up to date in all contexts (environmental protection, operational stability, etc.) in connection with the capture of the nuclear power plant by Russian troops and the danger of its detonation. There is a need not only for physical protection and resistance of nuclear power plant systems to external influences, protocols for response / actions at the international level to threats of operation in difficult conditions, artificially created threats, but also real actions to ensure the safety / inviolability of nuclear power plants.

In general, the dangers associated with nuclear power plants are as follows:

- threat of radiation leakage. The experience of Chernobyl (Ukraine), Fukushima (Japan) shows radiation threats that can occur for many reasons: design miscalculations, unprofessional actions, an imperfect system for ensuring safe operation, the impact of a natural disaster, etc. Also, potentially, a reactor can melt down as a result of improper operation cooling system, lack of coolant; in Ukrainian nuclear power plants, it is usually water. The result will be the interaction of the radioactive melt with the reinforced concrete floor and its impregnation into the soil;

- growing danger due to the extension of operational periods and increase of capacity above the nominal values, today 12 power units have exceeded the thirty-year planned period and are working overtime. And although the modernization of the nuclear power plant is being carried out, it nevertheless does not involve the replacement of key elements, such as the reactor body [23];

- dangers in the handling of nuclear cycle waste. Currently, there are no underground storage facilities in Ukraine, waste is stored in temporary storage facilities, which poses a threat of leakage and environmental pollution. Until 2022, Ukraine sent spent nuclear fuel to the Russian Federation, where uranium, plutonium and fission products were extracted from it for reuse, and the remnants of processing were to be returned to Ukraine for storage in storage facilities. Among the European countries, only France deals with the processing of nuclear waste. A separate task to be solved is the problem of storage of nuclear cycle products that cannot be reused and processed. In the context of solving this problem, in 2023-2024, Finland is launching a new type of deep storage to ensure reliable protection and leveling of threats to the population. In Ukraine, the Centralized Spent Fuel Storage Facility is located on the territory of the Chernobyl Nuclear Power Plant, where waste from three Ukrainian nuclear power plants accumulates. This storage facility is not designed for long-term storage, so in the future there will be a question of renovating the storage facility, building a new storage facility, or moving waste. A complex for processing nuclear waste at the base of the Khmelnytsky NPP is under construction, the deadline for which is constantly being postponed due to rising costs project [24];

- the use of nuclear power plants as a nuclear weapon or an instrument of terror. As we can see, the IAEA, although it has duties to ensure nuclear power plants from being used in such a context, however, has no influence on countries that do not comply with the principles and norms of international law; or underperforms its tasks and functions;

- the danger of emergency situations depending on the human factor. The above-mentioned dangers are also caused by the human factor. However, we note that the nature of the negative impact of the human factor can be different. From unconscious mistakes to purposeful actions aimed at causing harm of various nature (for example, purposeful actions against the Russian regime's nuclear power plant by the hands of the Russian military caused damage of an ecological, economic, etc. nature).

Ensuring the stability of NPP operation consists in eliminating the dangers described above.

Therefore, the generation of energy according to the above types is considered ecologically neutral. However, as we can see from the results of the analysis, the products of their cycle and their components can pose a danger to the environment. At the same time, risks and threats with an integrated approach can and should be leveled. When developing projects of energy generation facilities, it is necessary to calculate and plan the solution of issues related to the processing of used materials and/or the disposal of components after the completion of the cycle of use of the respective facilities.

With an insignificant share of the generation of nuclear power plants and other ecologically safe generation facilities in the overall structure, it will be necessary to use balancing non-ecological generation, such as thermal stations operating on coal, etc.

Thermal power plants (TPP) generate electricity by burning fuel (coal, gas). It should be noted that despite the adaptability of this type of energy generation, in recent years its share in the overall structure of generation has decreased both due to high prices for natural gas and insufficient coal, and due to the unecological nature of energy generation in this way.

Power transmission lines. We will separately address the issue of the stability of Ukrainian power transmission lines and supporting infrastructure. According to [25], as of 2021, 89% of the length of overhead power lines have a service life of more than 30 years, 69.3% have a service life of more than 40 years, and networks continue to age. The increase in the length of power transmission lines with a term of more than 30 years amounted to +0.9% compared to 2018; with a term of more than 40 years – +3.9%. It can be argued that at the moment 86% of networks are operated beyond the regulatory term, which leads to an increase in the risks of the destruction of networks, as well as an increase in energy transmission losses, which is especially noticeable in long-distance transmission. For example, in 2020, technological losses amounted to 10.13% of the total generated power.

CONCLUSIONS. The conceptual vision of the power system development is substantiated. The characteristics of development and the possibilities of their provision in terms of types of energy generation are highlighted. Among the peculiarities of the operation of solar power plants, the influence of seasonality, dependence on weather conditions was noted; impossibility of increasing energy generation of existing facilities "in manual mode". The positive aspects include simplicity and short installation time, relatively low price, ease of operation. Despite the ecological neutrality of solar power plants, the need for disposal and processing of individual components at the end of their service life is described. A similar context of argumentation for the operation of wind turbines, which is characterized by restrictions depending on the wind regime of the territories, which causes the narrowing of the aspects of stable and adaptive operation of such energy generation facilities. Also, the issue of disposal of components of wind power plants at the end of the operational period of the objects, the need to work out such issues in advance, which corresponds to the principles of sustainability, is not left aside. Features of HPP energy generation are characterized. Ways of using water energy give different returns. Some of them can be used as an additional source of local energy generation. Among the positive characteristics of hydroelectric power stations, their ability to produce constant power under the condition of sufficient water pressure is singled out. HPPs and HAPPs are adaptive, although they respond to changes in electricity demand with a time lag. The types of hydrogen production and the features of hydrogen generation are described, as well as the feasibility of developing biogas energy generation, which will contribute to the "smart" disposal of waste and the rational use of such resources. The dangers associated with nuclear power plants are summarized, the leveling of which will contribute to the safety and stability of their operation. Attention is also paid to types of energy generation that are not environmentally friendly (thermal power plants), which generate electricity by burning fuel (coal, gas). Their share in the energy-generating balance is decreasing, but today they still provide the necessary adaptability in the energy market.

In general, in order to ensure the stable, adaptive and efficient operation of the energy market of Ukraine, it is important to ensure the diversification of generation; to maximally realize the potential for the use of renewable energy sources, to generate ecologically clean energy.

References

1. Yivzhenko, D. (2022). Chomu soniachni paneli – pohane rishennia dlia rezervnoho zhyvlennia na zymu? [Why are solar panels a bad solution for backup power in winter?]. Available at: https://ain.ua/2022/12/29/sonyachni-paneli-pogane-rishennya-dlya-rezervnogo-zhyvlennya-na-zymu/

2. Lopushanska, M.R., & Ivanov, Ye.A. (2022). Vitrova enerhetyka u Lvivskii oblasti ta problemy pereroblennia neprydatnykh vitrovykh ustanovok [Wind energy in the Lviv region and problems of recycling unsuitable wind installations]. Ekolohichni nauky, 2(41), 156-163.

3. Sydorov, V.I. (2020). Molekuliarna enerhetyka. Teoriia ta tekhnichni rishennia [Molecular energy. Theory and technical solutions]. Cherkasy: Vertykal, vydavets Kandych S.H., 486 pp.

4. Klishchov, P. (2023). Hidroelektrostantsii maiut zghubni naslidky dlia ekolohii – ekspert [Hydroelectric power stations have detrimental effects on ecology – expert]. Available at: https://freedome.org.ua/hidroelektrostantsii-maiut-zghubni-naslidky-dlia-ekolohii-ekspert/

5. Kuzmin, A. (2021). Enerhonosii maibutnoho. Shist vidtinkiv vodniu [Energy carriers of the future. Six shades of hydrogen]. Available at: https://glavcom.ua/new_energy/publications/energonosiy-maybutnogo-shist-vidtinkiv-vodnyu-808311.html

6. Kuzmin, A. (2020). Prezentovano naikompaktnishyi vodnevyi henerator u sviti [The world’s most compact hydrogen generator presented]. Available at: https://glavcom.ua/new_energy/news/prezentovano-naykompaktnishiy-vodneviy-generator-v-sviti-707046.html

7. Dykha, M., & Dykha, V. (2023). Bezpieczeństwo energetyczne Ukrainy pod pryzmatem wojny [Energy security of Ukraine in the context of war]. Prace naukowe. WSZiP, 53(1), 71-84. Poland: Wałbrzych. Available at: https://pracenaukowe.wwszip.pl/prace/PN_53.pdf

8. Dykha, M.V., & Dykha, V.V. (2021). Enerhetychna bezpeka Ukrainy u konteksti zahroz zapusku «Pivnichnyi potik-2» [Energy security of Ukraine in the context of the threat of launching "Nord Stream-2"]. Instrumenty rehuliuvannia natsionalnoi ekonomiky ta natsionalnoi bezpeky v umovakh suchasnykh hlobalnykh vyklykiv: zb. nauk. prats za mater. VI Mizhnar. nauk.-prakt. konf., 60-63. Khmelnytskyi: KhNU. Available at: https://elar.khmnu.edu.ua/handle/123456789/10862

9. Dykha, M.V., Dykha, V.V., & Zyma, V.M. (2023). Ekolohichnist yak skladova suchasnoi paradyhmy rozvytku enerhetychnoi systemy [Ecology as a component of the modern paradigm of the energy system development]. Aktualni problemy upravlinnia sotsialno-

ekonomichnymy systemamy: materialy IX Mizhnar. nauk.-prakt. konf., 52-54. Lutsk: LNTU. Available at: https://elar.khmnu.edu.ua/handle/123456789/15268

10. Dykha, M.V., & Dykha, V.V. (2021). Enerhomenedzhment u systemi stratehichnoho upravlinnia [Energy management in the system of strategic management]. Rozvytok Ukrainy ta yii rehioniv: realii i perspektyvy: materialy VII Vseukr. nauk.-prakt. internet-konf., 52-56. Khmelnytskyi: KhTEK KNTEU. Available at: https://elar.khmnu.edu.ua/handle/123456789/11539

11. Pro skhvalennia Enerhetychnoi stratehii Ukrainy na period do 2050 roku (2023). Dokument 373-2023-r. Available at: https://zakon.rada.gov.ua/laws/show/373-2023-p

12. Pro skhvalennia Enerhetychnoi stratehii Ukrainy na period do 2035 roku «Bezpeka, enerhoefektyvnist, konkurentospromozhnist» (2017). Dokument 605-2017-r, vtratyv chynnist 21.04.2023. Available at: https://zakon.rada.gov.ua/laws/show/605-2017-p

13. Uriadovyi portal. (n.d.). Stratehiia maibutnoho: Ukraina tse enerhetychnyi khab, iakyi dopomoze Yevropi pozbutysia zalezhnosti vid Rosii. Available at: https://www.kmu.gov.ua/news/stratehiia-maibutnoho-ukraina-tse-enerhetychnyi-khab-iakyi-dopomozhe-ievropi-pozbutysia-zalezhnosti-vid-rosii

14. Vseukrainska enerhetychna asambleia. (n.d.). Dynamika i struktura spozhyvannia elektroenerhii v Ukraini. Available at: https://uaea.com.ua/dysp/ee-cons.html

15. 7 zapytan ta vidpovidei pro robotu SES. (n.d.). Available at: https://smarteco.biz.ua/blog/korysno-znaty/7-zapytan-ta-vidpovidej-pro-robotu-ses/

16. Chy ye problemoiu pererobka vidpratsovanykh soniachnykh panelei ta akumuliatoriv v Ukraini? (n.d.). Available at: https://ucn.org.ua/?p=4750

17. Chy bezpechni VES dlia dykoi pryrody. (n.d.). Available at: http://epl.org.ua/wp-content/uploads/2019/10/VES.pdf

18. Chun-Hsiang Chiu, & Nathan Chen. (2021). Effects of low-frequency noise from wind turbines on heart rate variability in healthy individuals. Scientific Reports, 11, Article 16151. Available at: https://www.nature.com/articles/s41598-021-97107-8

19. Dopustymi normy shumu v zhytlovykh ta hromadskykh prymishchenniakh onovyly. (n.d.). Available at: https://biz.ligazakon.net/news/185362_dopustim-normi-shumu-v-zhitlovikh-ta-gromadskikh-primshchennyakh-onovili

20. How loud is a wind turbine? (n.d.). GE Reports. Available at: https://www.ge.com/news/reports/how-loud-is-a-wind-turbine

21. Biohazovi elektrostantsii. (n.d.). Madek. Available at: https://madek.ua/ua/biogas-ua

22. 5 Advanced reactor designs to watch in 2030. (n.d.). U.S. Department of Energy. Available at: https://www.energy.gov/ne/articles/5-advanced-reactor-designs-watch-2030

23. Ekodiia. (n.d.). Shcho varto znaty pro «konflikt» mizh atomnoiu ta vidnovliuvalnoiu enerhiieiu. Available at: https://ecoaction.org.ua/renewables-vs-nuke.html

24. Skilky vidkhodiv produkuie atomna enerhetyka ta yak yikh pererobliaiut. (n.d.). Ecoaction. Available at: https://ecoaction.org.ua/iaderni-vidkhody.html

25. Kyryk, V.V., & Rybka, O.O. (2021). Analiz stanu ta tekhnolohichnoi vidpovidnosti elektrychnykh merezh OEM Ukrainy vymoham ENTSO-E. Available at: https://uhe.gov.ua/sites/default/files/2021-12/16.pdf