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DIVERSIFICATION OF ENERGY RESOURCES AS ONE OF THE WAYS TO DEVELOP ENERGY SECURITY OF UKRAINE

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Abstract. *The article voices the need to strengthen the country's energy security, in particular through the course towards energy independence. The diversification of energy sources is defined as one of the tools that contributes to the development of the energy sector with specific examples of the implementation of such a policy in developed EU countries, and the main stages of its implementation in Ukraine are also voiced. The potential of Ukraine is characterized in terms of renewable energy sources and the possibilities of their development against the background of the gradual abandonment of imported fossil fuels. The prospects for further research to improve the management process of energy generation sources are voiced.*

Keywords: *alternative energy, energy efficiency, diversification, energy security, energy resources.*

Introduction

Energy independence is a priority for the development of both the Ukrainian economy and the country as a whole, but at the same time, national security challenges threaten plans for the gradual implementation of relevant initiatives.

The energy sector is one of the key sectors of the national economy, and uninterrupted and efficient energy supply has a direct impact on economic growth.

And it is undeniable that only the development of a reliable energy security system will ensure the country's stable economic growth. It is directly depending on the sources of supply, the balance and structure of exports and imports of energy resources, the structure of consumption, political and internal stability and implementation involves a number of organizational, economic and legal measures, such as ensuring the stability of energy supplies, minimizing environmental impacts in the process of operating energy generation sources, diversifying them to reduce dependence, and developing and maintaining a rational pricing policy or tax incentives. The state's chosen course towards energy efficiency is fully correlated with above-mentioned priorities [1].

Taking into account the current conditions, among the above-mentioned areas of development, the most relevant and promising is ensuring the state's energy security through diversification of energy generation sources, as its implementation, among all the obvious advantages, is also conditioned by the foreign policy situation – Ukraine's economy, despite shifts in the right direction, still feels highly dependent on energy imports, not to mention the problems of excessive environmental pollution due to the use of outdated production equipment, energy.

Analysis of recent research and publications

Research into the essence, types and significance of diversification of activities is reflected in the works of such specialists as E. I. Boguslavsky, A. O. Chernychenko [2], Kh. V. Drymalovska [3], M. D. Korinko, O. E. Kuzmin [3], Kh. S. Peredalo and others. The problems and prospects of the development of the energy sector, including alternative energy, as one of the potential and optimal directions of diversification are studied by such scientists as M. D. Domashenko [4], V. S. Domashenko [4], V. V. Garkusha, V. Yu. Shkola [4], Y. N. Shpak, M. Yu. Troyan [4], V. S. Yakovenko, A. S. Zaverbnyi and others. The problems of diversification of energy supply in the economy are devoted to the works of such specialists as O. I.Amosha, N. G. Belopolsky, O. V. Borisyak, V. G. Fedorenko, N. R. Ivanechko, aforementioned Y. N. Shpak [5], D. K. Turchenko, aforementioned A. S. Zaverbnyi [5] and others. The theoretical foundations of energy security as a general economic category and the main factors, that influencing it, are considered in the works of V. P. Kuhar, A. I. Shevtsov, A. K. Shindlovsky, V. T. Shlemko and others.

Defining the goal and objectives of the research

The goal of the research is to study the experience of energy diversification as one of the main tools for achieving the country's energy security. To achieve such goal, there is a need to apply next steps:

- define the concept of energy diversification and its advantages;
- study examples of the implementation of such approach in European Union countries;
- analyze the potential of renewable energy sources in Ukraine as an alternative against the background of a gradual transition from the use of imported fossil fuels, taking into account different regions geographical and climactic features;
- list the prospects for further research to improve the management process of energy generation sources and develop set of recommendations in particular with the involvement of the latest information technologies.

The main part of the study

Energy diversification means using different energy sources, suppliers and routes to reduce dependence on a single resource or supplier. A country that diversifies its energy mix insulates itself from energy disruptions and strengthens its energy security. Of course, diversification cannot sufficiently protect importing countries from market risks (supply or price fluctuations, etc.), but it can reduce the risks associated with political turmoil or natural disasters. The following aspects are among the undoubted advantages of a diversified energy system [6]:

political independence: relying on another country to meet most of its energy needs can lead to intimidation, coercion and manipulation by the supplier in the long run. Dividing energy needs among different suppliers allows the importing country to reduce its dependence on a single supplier and strengthen its independence in global politics;

economic growth: energy diversification promotes economic growth. Obtaining energy from multiple sources and suppliers insulates an importing country from energy disruptions when one source or supplier is unable or unwilling to meet demand. Energy diversification ensures continued energy security, which creates a favorable environment for entrepreneurship, innovation and research and development;

environmental protection: the development of renewable resources, such as solar and wind power, reduces the threat of energy shortages. Renewable resources emit few or no pollutants and have minimal environmental impact. Investments in renewable energy also stimulate innovation and employment growth.

The European Union is systematically switching to renewable energy sources and diversifying its natural gas suppliers to reduce dependence on a single importer in the event of a disruption or political conflict and increase the region's energy security. The EU countries are increasing the capacity of renewable energy sources, reducing the share of fossil fuels in their energy sector, and diversifying natural gas suppliers (in particular, by attracting developers of fields in Eastern Europe, Cyprus and Israel) in order to reduce dependence on a single importer in the event of a failure or political conflict and increase the region's energy security. As part of the diversification of its energy consumption structure, the EU is implementing the following strategies:

1) promotion of renewable energy sources;
2) securing energy supplies from abroad (signing contracts with various suppliers);
3) large investments in research and development of energy technologies.

In January–June 2024, wind turbines and solar panels became the main source of energy in Europe for the first time, overtaking traditional energy sources (gas, coal, and oil) [7]. According to experts from the Ember climate think tank, their share is 50 %, taking into account other renewable energy sources such as hydropower. Experts note that electricity generation from the combustion of coal, oil and gas fell by 17 % in the first six months of 2024 compared to the same period a year earlier. Ember's report shows that 13 member states generated more electricity from wind and solar than from fossil fuels in the first half of the year. Germany, Belgium, Hungary and the Netherlands reached this milestone for the first time. The EU pays priority attention to energy security and, as part of its energy diversification, aims to reduce CO2 emissions by 40 % by 2030 (as part of its renewable energy commissioning strategy). Countries' strategies to achieve their climate goals and comply with legislation by 2030 will determine the role of conventional and clean energy technologies in Europe. Experts predict that the total energy consumption in the EU will remain relatively unchanged over the next three decades. The International Energy Agency (IEA) estimates that by 2040, electricity demand in the EU will increase by 12–26 %. To meet this growing demand for electricity, the use of clean energy technologies will have to increase.

It is worth noting that the process of implementing energy sector diversity is heterogeneous and differs from case to case, as each country has a unique combination of natural resources, energy needs and geopolitical constraints and other factors that are constantly changing. It is necessary to determine objective trends in

energy consumption, analyze its structure and volumes and the main contradictions between the needs of economic growth and energy security.

Fig. 1. Map of the distribution of natural zones in Ukraine [8]

It is crucial for Ukraine to increase investment in the large-scale deployment of decentralized renewable energy sources, given that around 40 % of its energy infrastructure has been damaged by the fighting and the trend is unlikely to abate in the near future. The Kyiv School of Economics estimates direct losses in the electricity sector as a result of Russian attacks at USD 56.2 billion [9], and this amount is constantly growing. The economic potential for the development of renewable energy sources in Ukraine remains quite significant. The large areas of undeveloped territories, geographical and natural diversity create very favorable conditions for further diversification of the structure of energy generation sources

Diversification in the energy sector of Ukraine should be carried out in accordance with European standards, principles, and norms, taking into account the close interrelationships between the diversification of natural energy resources, their supply routes, etc. and the level of energy security of the country [10]. The most promising for development in Ukraine are the following types of renewable energy: solar energy, wind energy, small river energy, geothermal energy and biomass energy;

solar energy. Ukraine has sufficiently favorable conditions for the implementation of solar power plants. The average annual amount of total solar radiation received per 1 m² of surface in Ukraine ranges from 1070 kWh/m² in the northern part of the country to 1400 kWh/m² and above in the south of Ukraine. The distribution of the main climatic indicators is as follows: the radiation regime of the territory is characterized by a change in the duration of sunshine on average per year from 1690–1850 hours in the western regions of Polissya and Forest-Steppe to 2150–2450 hours in Crimea and on the coasts of the Black and Azov Seas.

Speaking about the disadvantages, it is worth noting that the use of solar energy requires the allocation of large areas of land for the construction of solar power plants, and the photocells used to make solar panels contain toxic substances such as lead, cadmium, gallium, arsenic, etc.

Wind energy. In the national RES sector, wind energy is second only to solar energy in terms of total installed capacity. The distribution of wind energy potential across the territory is rather uneven and depends primarily on the:

- distribution of wind speed and direction near the earth's surface;
- vertical wind profile, which depends on the type of underlying surface;
- the relief of the underlying surface and the distance to large bodies of water.

The analysis of the long-term dynamics of the average annual wind speed in recent years has shown that the average long-term wind speed in Ukraine varies from 2.5 m/s to 5.7 m/s at the height of the weather vane (≈10 m). The highest wind speeds are typical for the Azov Upland, the Black Sea Lowland, the Crimean and Carpathian Mountains, and the Volyn and Donetsk Uplands. Western winds are predominant in the western, central and northern regions, while eastern and northern winds prevail in the eastern and southern regions, including the temporarily occupied areas.

Mountainous areas are the most challenging for the construction of wind farms. Construction in these areas requires a significant increase in time and money spent on selecting wind farm sites, laying roads and power lines, delivering construction materials and cranes, maintenance, etc. Forest areas are also unattractive for wind farm construction (forests are natural barriers to wind flows. Even significantly lower than the lower edge of the wind turbine wheel, they increase the turbulence of the corresponding wind flow, which reduces the electricity output of the wind turbine and accelerates its wear and tear). The territory of the forest-steppe zone, which remains after the removal of forest areas and anthropogenic obstacles, is quite suitable for the implementation of cost-effective wind farm investment projects. The steppe zone is the most attractive for such projects. Strong winds in the cold season and in the warm season reduce their strength, but compensate for this reduction with additional local winds – breezes. The presence

of powerful seaports and motorway networks in the steppe zone simplifies the solution of logistics problems [11].

It is also worth noting that wind farms generate high-frequency noise, interfering with nearby settlements, and the generators of large wind turbines rotate at a speed close to the TV synchronization frequency, so large wind turbines can interfere with the reception of broadcasts at a distance of up to 1.6 kilometers;

hydropower. Hydropower has the lowest cost among conventional and most unconventional technologies (efficiency of about 70–90 %) and is also characterized by a significant operational life.

According to the results of scientific research, the technical potential of small rivers alone in Ukraine is 1270 million kWh/year. And about 1000 million kWh/year of them have not yet been developed. The construction of small hydropower cascades provides an opportunity to efficiently convert hydropower potential into electricity and participate in managed flood protection. The highest values of technical potential in terms of hydropower in our country are concentrated in the following regions: Zakarpattia (35 %), Ivano-Frankivsk (16 %), Lviv (12 %), Chernivtsi (6 %), Kirovohrad (4 %), and Ternopil (3 %). The lowest values are inherent in the following regions: Odesa (0.37 %), Volyn (0.27 %), Kherson (0.18 %), Chernihiv (0.16 %), Zaporizhzhia (0.05 %) [12].

The disadvantage of small hydropower is the flooding of territories, the drying up of small rivers, and if the location of a dam or dams is not planned correctly, ecosystems may be altered and biodiversity may be lost, so it is worth taking a particularly responsible approach to the location of hydropower plants, taking into account all possible consequences;

geothermal energy. It is conventionally divided into sub-geothermal, hydrothermal and petrothermal. Unlike other renewable energy sources, the pace of expansion of geothermal energy production capacities in Ukraine is much slower, despite the fact that geothermal energy sources have certain advantages. They do not depend on the day or season, and the cost of thermal and electric geothermal energy is low due to the high utilization rate (0.8–0.95) and low operating costs.

The development of geothermal technologies for the exploitation of deep underground energy sources was concentrated on the Crimean Peninsula, as well as partially in Kherson and Zakarpattia regions.

At this stage, the most favorable conditions for the development of hydrothermal resources are characterized by the Precarpathian (Lviv, Ivano-Frankivsk, and partially Chernivtsi regions) and Zakarpattia (Zakarpattia region) troughs, the Dnipro-Donetsk depression (Chernihiv, Poltava, Sumy, Kharkiv, and Dnipro regions), the Steppe Crimea, and the Black Sea coast (Kherson and Odesa regions). Petrogeothermal resources are distributed throughout Ukraine, but their shallowest depths are observed in Zakarpattia, the inner Carpathian region and the southern part of Odesa and Kherson regions.

The disadvantages of developing geothermal energy sources are high capital investments in the early stages, such as the cost of energy equipment for converting geothermal energy sources or the cost of drilling.

Biomass energy. In recent years, there has been an upward trend in the potential of solid biomass, driven by increased agricultural productivity, changes in forestry, and changes in the management of domestic and industrial waste. The annual technically achievable energy potential in Ukraine in pre-war times was equivalent to 35 million tons, and its use would have saved about 40 billion cubic meters of natural gas annually. The largest potential of solid biomass is concentrated in Vinnytsia, Dnipropetrovs'k, Zhytomyr, Kyiv, Odesa, Poltava, Sumy, Kharkiv and Chernihiv regions and amounts to about 2.0 million tons per year [13]. The main suppliers of raw materials for energy needs are agriculture and forestry, in particular the cultivation of energy crops, which are certain types of trees and plants specially grown for the production of solid biofuels. Peat accounts for a significant share of solid biomass. The annual growth of the peat layer is about 1 mm, and the corresponding amount of peat can be considered renewable. Three Polissya regions have the largest peat deposits: Volyn, Rivne and Chernihiv. In their territories, 836 deposits have been discovered and explored (38 % of all deposits in the country), and geological reserves of peat amount to 1.0 billion tons.

It is also worth noting the trend in recent months of using the infrastructure of gas storage facilities previously used to store imported natural gas from Russian fields to accumulate biomethane. In synergy with the research of the American startup Quino Energy on the transformation of oil reservoirs into a cluster of flow batteries, this direction looks more than promising. Existing equipment adapted to the new realities will help reduce costs and promote the development of this area of green energy, which

in turn will only strengthen the course towards diversification of energy generation sources.

Effective diversification of resources and ways of obtaining them in the energy sector will help it reach a qualitatively higher level of functioning and, accordingly, reduce energy risks, increase profitability, etc. This process on a countrywide scale should be evolutionary (clearly synchronized with economic development), structured (step by step, analyzing the business environment, favorable market trends in the global energy sector, assessing the sector's potential, risk level, etc.), and comprehensive (combining goals, motives, and conditions for energy diversification), multidimensional (combining different areas of development), targeted (identifying diversification goals), emergent (updating the energy system, acquiring new properties, etc.), dynamic (continuous development of the country's energy sector), synergistic (interaction with the country's development strategies).

Conclusions

The massive use of renewable energy sources to achieve effective energy diversification has a number of undeniable advantages and will only strengthen the task of the national strategy to ensure energy security. According to EU's countries experience, renewable energy sources are expected to become a key component of the country's post-war recovery and, as it was shown, Ukraine has a huge potential to harness, distinguishing in different regions. However, without appropriate support for the introduction of alternative energy sources at the state level, without an effective energy diversification policy, the pace of capacity expansion in the country, despite its considerable potential, will be insufficient.

The following steps should be considered for the gradual introduction of a diversified energy supply system [14]:

- establish a legal framework for energy policy that attracts investment, rewards entrepreneurship and innovation, and limits inefficiency and waste;
- enter into partnerships with the private sector to identify and develop alternative energy sources;
- work with experts to determine the best mix of available domestic and foreign energy sources;
- work with the international community to introduce and enforce environmental standards related to energy exploration and production.

It is also worth noting that under current conditions, key element of promoting the development of the green energy sector is an implementation of an appropriate energy generation sources rational distribution model with implementation of the latest information technologies [15].

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Диверсифікація енергоресурсів як один із напрямів розвитку енергетичної безпеки України

Анотація. *У статті наголошується на важливості енергетичного сектора для розвитку країни та зазначено на необхідності посилення заходів, спрямованих на зміцнення енергетичної незалежності. Обґрунтована важливість надійної системи енергетичної безпеки та перелічені заходи для її поетапного впровадження. Подано визначення диверсифікації джерел енергоресурсів як одного з чинників, що сприяють розвитку енергетичного сектора. Зазначено основні аспекти переваг застосування диверсифікованої системи енергопостачання. Наведено конкретні приклади впровадження вищезазначеної політики енергетичної диверсифікації та енергоефективності в розвинутих країнах Європейського Союзу, стратегії, шо реалізуються в межах впровадження комплексних структур енергоспоживання як основний орієнтир для створення аналогічних ініціатив на теренах України. Здійснено аналіз досягнень цьому напрямі станом на 2024-й рік і визначено основні перспективи на майбутнє. Зазначено на критичній необхідності переорієнтації вітчизняної системи користування джерелами енергогенерації на таку, що спирається на альтернативну енергетику на фоні негативних наслідків від ведення бойових дій на території України впродовж останніх років, зокрема з погляду економічних збитків. Подано розгорнуту характеристику неосвоєного потенціалу України в контексті найбільш перспективних джерел відновлювальної енергетики – сонячної, вітрової, гідроенергетики, геотермальної, енергії біомаси – та можливостей їх освоєння в різних регіонах країни з огляду на їхні географічні, кліматичні та територіальні особливості через поступову переорієнтацію сектора енергетики до більш диверсифікованої структури та відмовлення від імпортного викопного палива. Зазначено перспективи подальших досліджень, зокрема в контексті питань повоєнного відновлення економіки та промисловості, підвищення екологічної чистоти та енергоефективності, енергетичної безпеки та можливого залучення новітніх інформаційних технологій для оптимізації процесу менеджменту джерел енергогенерації.*

Ключові слова: *альтернативна енергетика, енергоефективність, диверсифікація, енергетична безпека, енергетичні ресурси.*

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