

Oleksiy Zabarylo¹, Yulia Korotkykh², Pavlo Zabarylo³

DIVERSIFIED SOURCES OF ENERGY GENERATION AS AN ALTERNATIVE TO FOSSIL FUELS

¹ *Department of Higher Mathematics,*

² *Department of ITDAM,*

³ *Department of Architectural Structures*

Kyiv National University of Construction and Architecture

zabarylo_po-2023@knuba.edu.ua

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The article voices the importance of the energy sector for the development of the country and indicates the need to strengthen measures aimed at strengthening energy independence. The importance of a reliable energy security system is substantiated and measures for its phased implementation are listed. The main aspects of the advantages of using a diversified energy supply system are noted. The need to reorient the domestic system of using energy generation sources to one that is based on alternative energy at its core, in terms of economic losses in recent years in particular, was identified. A detailed description of the untapped potential of Ukraine in the context of the most promising sources of renewable energy. Prospects for further research are considered, including in the context of the issues of post-war economic and industrial and the possible involvement of the latest information technologies.

Keywords: alternative energy; energy efficiency; diversification; energy security; energy resources, energy generation.

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. 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highly dependent on energy imports, not to mention the problems of excessive environmental pollution due to the use of outdated production equipment, so implementing new, diversified energy system is becoming more and more crucial task.

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.

Research into the essence, types and significance of diversification of activities is reflected in the works of various specialists and in different directions, such as: choosing the optimal method of enterprise

diversification (Boguslavsky E. I. et al., 2013); studying the factors influencing the diversification of enterprises (Drymalovska Kh. V. et al., 2013). The problems and prospects of the development of the energy efficiency, including alternative energy as one of the potential and optimal directions of diversification, are studied by various researchers, but for Ukraine it is crucial to point out the European experience in alternative energy sources exploitation (Domashenko M. D. et al., 2021) and add the context of European integration and the possible challenges associated with it (Shpak Y. N. et al., 2019). Solar energy and its development might be one of the vital parts of current trends in energy diversification (Seymur Ağazade, 2023).

Materials and methods

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. The following aspects are among the undoubted advantages of a diversified energy system:

Political independence. 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.

Environmental protection. The development of renewable resources, such as solar and wind power, reduces the threat of energy shortages. Investments in renewable energy also stimulate innovation and employment growth.

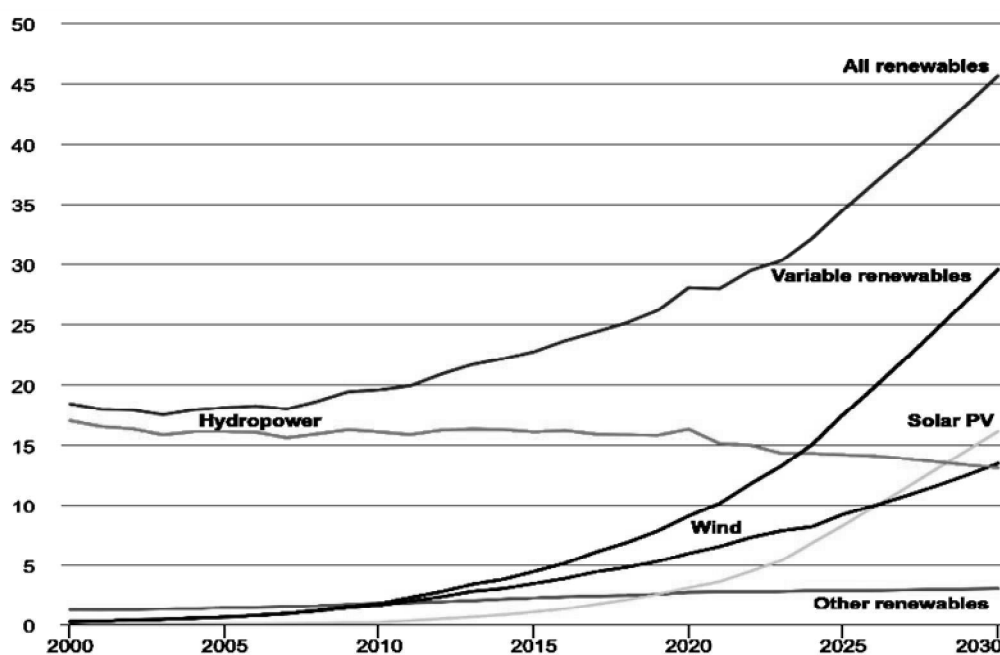


Fig. 1. Share of renewable electricity generation by technology, 2000–2030 (IEA, 2024)

The European Union was systematically switching to renewable energy sources and diversifying its natural gas suppliers for decades to reduce future dependence on a single importer in the event of a disruption or political conflict and increase the region's energy security. Full-scale invasion in 2022 only strengthen Europe's priorities on energy security and diversification. As for more actual initiatives, on February 2023 the European Commission published the "Green Deal Industrial Plan", aimed at increasing the long-term

competitiveness of European industry with net-zero emissions and facilitating the transition to climate neutrality; as part of this strategy, on May 2024, the Critical Raw Materials Act (CRMA) was passed, aiming to increase the resilience of the supply chains of critical minerals in the EU and reduce dependence on third countries for critical raw materials needed for the green transition (Pokryshka D. S., 2024).

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). According to experts from the Ember climate think tank, their share is 50 %, taking into account other renewable energy sources such as hydropower. 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 %.

It is also worth mentioning, that aforementioned CRMA in its core aims to ensure a secure, diverse and sustainable supply to the EU of critical raw materials, including rare earth elements, needed for strategic sectors and technologies linked to the green and digital transformations and potentially can provide an opportunity to deeper cooperation between Ukraine and European Union.

Results and discussions

Before full-scale invasion the most important aspect of alternative energy sources was its purity and environmental friendliness – unlike thermal power plants, solar, wind, and hydroelectric power plants produce almost no greenhouse gas emissions. But in current times, against the backdrop of the refusal to imported energy carriers using renewable energy sources is vital alternative to fossil fuels, as it can cover large part of energy consumption and has great potential for development. 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, of which 16 is due to direct physical damage, and 40 – indirect financial losses (Kyiv School of Economics, 2024), 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 (Zabarylo O. V. et al., 2024).

The main advantage of using renewable energy resources as an alternative to fossil fuels is their inexhaustibility and ecological purity, which contributes to improving the ecological situation and does not lead to a change in the energy balance on the planet. When using renewable energy sources, there is no need to extract, process, enrich and transport fuel, and the problem of disposing of or disposing of harmful waste from traditional energy production is eliminated. Given that renewable energy uses energy flows that already exist in the surrounding space, thermal pollution of the environment caused by dumping some part of the converted energy there is negligible. Other types of air and water pollution, as well as waste volumes, are also insignificant. For environmental reasons, renewable energy has an advantage over conventional fuels and nuclear energy.

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 (Sotnyk I. M., Kulyk L. A., 2016). The current war has affected significantly both the energy security of the European Union and its policies in this area with the loss of traditional energy supply. In response to these challenges, the EU has developed ambitious initiatives “RePowerEU” and “Fit for 55”, aimed at accelerating the energy transition and reducing dependence on fossil fuels, and Ukraine, by integrating into the EU energy system, can become an important supplier of “green” energy and contribute to the diversification of energy supply sources for the EU (Kostyuchenko Y. M., 2024).

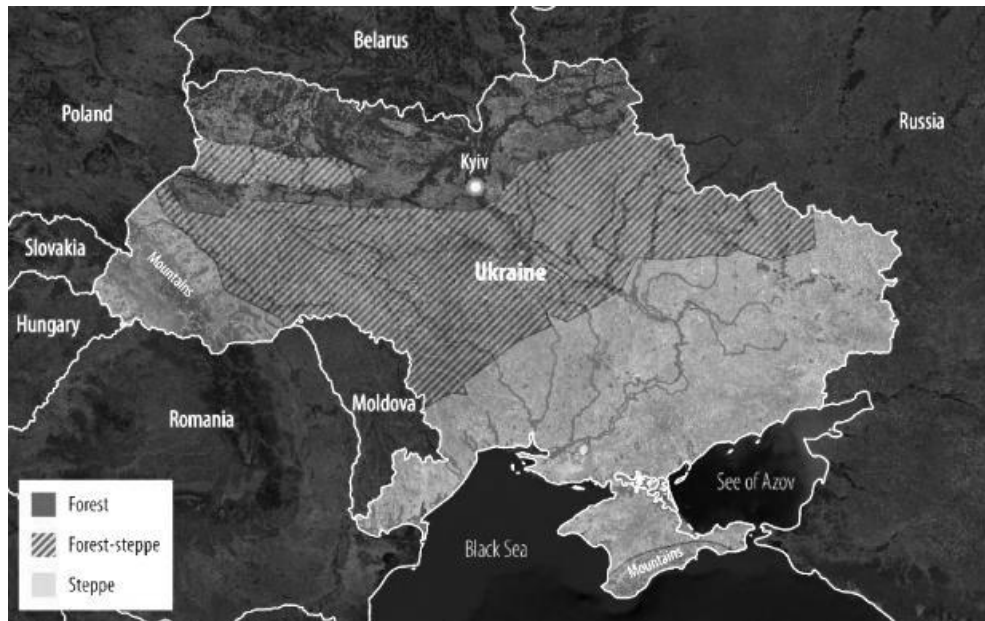


Fig. 2. Map of the distribution of natural zones in Ukraine

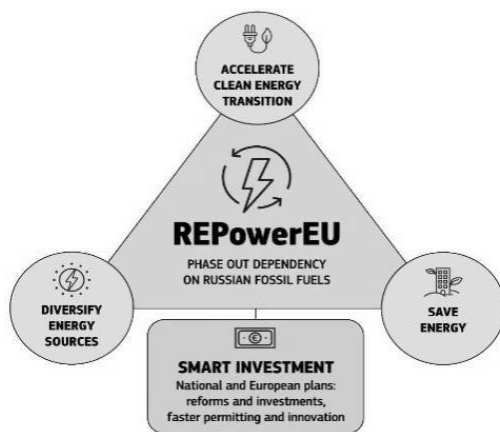


Fig. 3. REPowerEU plan summarizing

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 (if taking temporarily occupied territories into account).

Wind energy. In the national RES sector, wind energy is second only to solar energy in terms of total installed capacity. 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 Carpathian Mountains and the Volyn Upland, before full-scale invasion Azov Upland, the Black Sea Lowland, the Crimean Mountains and Donetsk Uplands also were taken into account. 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 (Kudrya S. O. et al., 2024).

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. The development of small hydropower contributes to reducing the fuel component of the energy system, reducing the man-made burden on the environment, and attracting additional investments to local budgets.

According to the results of scientific research, the technical potential of small rivers alone in Ukraine is 1270 million kWh/year and only approximate 20 % of this power is currently developed.

Geothermal energy. It is conventionally divided into sub-geothermal, hydrothermal and petro-thermal. 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 is currently made more complicated because of active military operations – the exploitation of deep underground energy sources was concentrated on the Crimean Peninsula, as well as partially (in less amount) in Kherson and Zakarpattia regions.

<u>Strengths:</u> – Rich natural resources – Growing interest in green energy – Qualified specialists	<u>Weaknesses:</u> – Limited financing – Old infrastructure – Regulatory barriers
<u>Opportunities:</u> – European integration – Growth of the global market – Improving energy security	<u>Threats:</u> – Political and military instability – Competition with traditional energy sources – Climate change

Fig. 4. SWOT-analysis of alternative energy sources implementation in Ukraine

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 43,1 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 (Plosky V. O. et al., 2024). It is also worth noting that the 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 (Andrusyak A. A., 2024).

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.

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. Already existing tools, such as Multilayer Perceptron (MLP), are used in energy sectors to solve different tasks such as creating a model of energy consumption, prediction of energy needs in different conditions and optimization of energy system overall, but it needs some adjustments to be used for diversified systems with large dependency on alternative energy sources.

Conclusions

Concept of energy diversification and its advantages was defined and examples of this policy's implementation in European Union countries were studied. 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.

Ukraine has the promising potential of renewable energy sources, having vast territories with different conditions, despite the fact that full-scale invasion creates big challenges on the path to energy transformation. Nevertheless, it is advised to use develop alternative energy sector in order to diversify our country's power production and strengthen energy security and independence, which is more and more crucial for our benefit for the last few years. Such approach will provide an availing alternative to imported fossil fuels, which coincides

with current government policies and eurointegrational process. But in order to increase effectiveness, there is a need for further research to improve the management process of energy generation sources.

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

- 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.
- Develop set of recommendations, in particular with the involvement of the latest information technologies.

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О. В. Забаріло¹, Ю. А. Коротких², П. О. Забаріло³

Київський національний університет будівництва та архітектури,
кафедра вищої математики,
кафедра інформаційних технологій проектування і прикладної математики,
кафедра архітектурних конструкцій

ДИВЕРСИФІКОВАНІ ДЖЕРЕЛА ГЕНЕРАЦІЇ ЕНЕРГОРЕСУРСІВ ЯК АЛЬТЕРНАТИВА ВИКОПНОМУ ПАЛИВУ

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Підкреслено важливість енергетичного сектору для розвитку країни та вказано на необхідність посилення заходів, спрямованих на зміцнення енергетичної незалежності. Обґрунтовано важливість надійної системи енергетичної безпеки та перелічено заходи для її поетапного впровадження. Подано визначення диверсифікації джерел енергоресурсів як одного із інструментів, що сприяє розвитку енергетичного сектору. Наведено конкретні приклади впровадження вищезазначеної політики енергетичної диверсифікації та енергоефективності в розвинених країнах Європейського Союзу, стратегії, що реалізуються у межах упровадження комплексних структур енергоспоживання як основний орієнтир для розгортання аналогічних ініціатив на теренах України. Зокрема, проаналізовано досягнення у цьому напрямі на 2024 р. й окреслено основні перспективи на майбутнє. Означено критичну необхідність переорієнтації вітчизняної системи користування джерелами енергогенерації на таку, що спирається на альтернативну енергетику. Подано розгорнуту характеристику неосвоєного потенціалу України в контексті найперспективніших джерел відновлюваної енергетики – сонячної, вітрової, гідроенергетики, геотермальної, енергії біомаси – та можливостей їх освоєння у різних регіонах країни з урахуванням їхніх географічних, кліматичних та територіальних особливостей на фоні поступової переорієнтації сектору енергетики до диверсифікованішої структури та відмови від імпортного викопного палива. Висвітлено перспективи подальших досліджень, зокрема в контексті питань повоєнного відновлення економіки і промисловості, підвищення екологічної чистоти та енергоефективності, енергетичної безпеки та можливого залучення новітніх інформаційних технологій для оптимізації менеджменту джерел енергогенерації.

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