



Державна служба
геології та надр
України



ДКЗ

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2024 

МАТЕРІАЛИ КОНФЕРЕНЦІЇ

IX міжнародна науково-практична конференція

НАДРОКОРИСТУВАННЯ В УКРАЇНІ. ПЕРСПЕКТИВИ ІНВЕСТУВАННЯ

7-11 жовтня 2024, м. Львів, Україна

IX international scientific-practical conference

SUBSOIL USE IN UKRAINE. PROSPECTS FOR INVESTMENT

7-11 october 2024, Lviv, Ukraine

CONTRIBUTION OF UKRAINE'S RAW MATERIAL BASE TO THE DEVELOPMENT OF CLEAN AND RENEWABLE TECHNOLOGIES

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This article examines the crucial role of Ukraine's raw material base in advancing clean and renewable technologies. It highlights the significance of essential resources such as lithium, nickel, titanium, and rare earth metals, which are vital for producing components in renewable energy systems like solar panels and wind turbines.

The discussion includes the importance of these resources for Ukraine's domestic market and their export potential, positioning the country as a key player in the global transition to renewable energy. However, the article also addresses challenges such as environmental and social risks, infrastructure limitations, and regulatory hurdles that hinder effective resource utilization.

The prospects for improvement are explored, focusing on advancements in extraction and processing technologies, as well as the importance of state and private initiatives and international cooperation.

In conclusion, the article evaluates Ukraine's potential contributions to the renewable energy sector and offers recommendations for maximizing resource utilization. It emphasizes the need for sustainable practices and collaboration to facilitate a responsible transition to a greener economy, underscoring the intersection of raw material management and renewable energy development.

Introduction. The global transition to clean technologies and renewable energy sources has become an urgent necessity in light of environmental degradation, climate change, and the growing depletion of traditional fossil fuels. Nations around the world are intensifying efforts to reduce carbon emissions and adopt sustainable energy practices, leading to a surge in demand for critical raw materials essential for green technologies. Ukraine, with its rich and diverse raw material base, is well-positioned to play a significant role in this transition. The country's vast reserves of minerals like lithium, cobalt, and nickel, which are crucial for renewable energy technologies such as solar panels, wind turbines, and electric vehicles, present unique opportunities for both economic development and environmental sustainability.

This article aims to assess and highlight the contribution of Ukraine's raw material base in supporting the global shift towards clean technologies and renewable energy sources. By analyzing the country's mineral resources and their potential, the article will provide insights into how Ukraine can leverage its natural wealth to foster the development of green technologies and facilitate its own energy transition.

Research tasks:

Analyze the key raw materials available in Ukraine that are critical for the development of renewable energy technologies.

Investigate how Ukraine's raw material base supports the global green economy, particularly in the production of clean technologies.

Discuss the future opportunities and challenges for Ukraine in contributing to the global transition towards renewable energy, focusing on policy, investment, and environmental considerations.

Main material. Ukraine is home to a vast array of critical raw materials that are essential for the development of clean and renewable energy technologies (fig. 1). These resources, which include lithium, nickel, titanium, and various rare metals, have significant potential to support the global green economy. As renewable energy becomes the cornerstone of modern energy systems, these materials are indispensable for the production of technologies such as solar panels, wind turbines, and batteries for energy storage.

Ukraine has large lithium reserves, which are crucial for manufacturing lithium-ion batteries, a key component in electric vehicles (EVs) and renewable energy storage solutions. The rising demand for EVs and grid-scale energy storage makes lithium one of the most sought-after resources worldwide. Ukraine's lithium deposits, particularly in the Donetsk and Kirovohrad regions, position it as a potentially strategic supplier for Europe's transition to cleaner energy.

Nickel is vital for producing high-performance batteries and components used in electric vehicles and renewable energy systems. Ukraine has substantial nickel reserves, which are essential for making battery cathodes that improve energy density and performance in EVs and other renewable technologies.

Studied critical mineral deposits in Ukraine

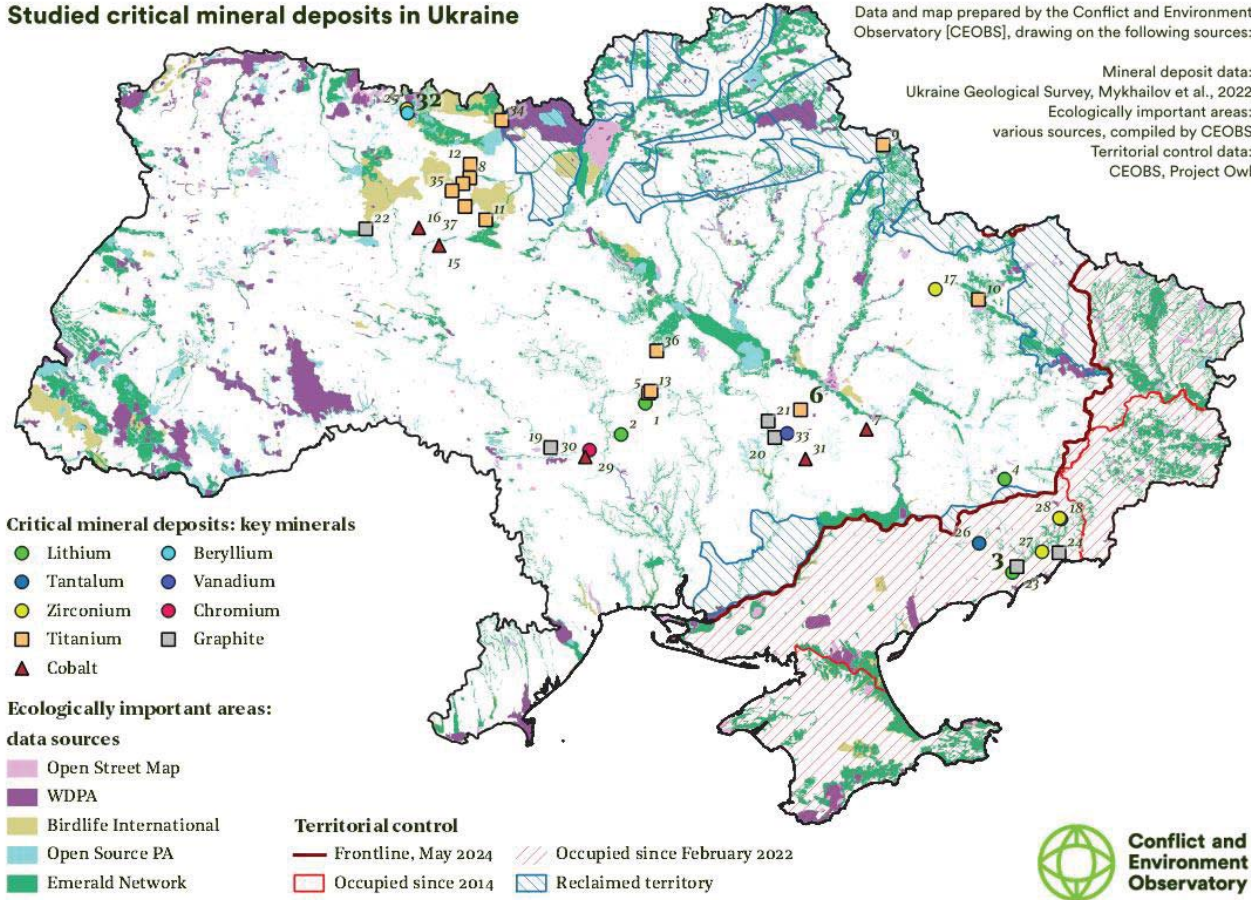


Fig. 1. Studied critical mineral deposits in Ukraine [1]

Known for its strength and lightweight properties, titanium is used in wind turbine blades and other components of clean technology infrastructure. Ukraine is one of the world's largest producers of titanium, and its reserves are integral for the production of strong yet lightweight materials necessary for renewable energy systems, including aerospace applications linked to cleaner transportation methods.

Ukraine also holds rare earth elements and metals like gallium and indium, which are critical in the production of solar panels, photovoltaic cells, and semiconductors. These materials are indispensable in the development of efficient, low-carbon energy sources and play a major role in the advancement of solar energy technologies.

Ukraine’s raw material base plays a pivotal role in supporting the global clean energy transition. These critical resources contribute to the production of the key components necessary for renewable energy technologies:

- Rare metals such as gallium and indium are crucial for the efficient functioning of photovoltaic cells in solar panels. Ukraine’s deposits of these materials enable the manufacturing of high-efficiency solar technology, which is a major pillar of global renewable energy systems.
- Titanium and rare earth elements are used in the production of wind turbines. Ukraine’s titanium reserves contribute to the production of strong and durable turbine blades, while rare earth elements are used in turbine generators to convert wind into electricity.

- Lithium and nickel are key to the development of energy storage systems and electric vehicles. With global demand for clean energy storage rapidly increasing, Ukraine's lithium and nickel reserves are essential for the production of batteries that power both renewable energy systems and EVs.

Research and Discussion. Ukraine's rich deposits of critical raw materials - such as lithium, nickel, titanium, and rare metals - position the country as a key player in the green energy transition, both domestically and globally. These resources are essential for the development of clean technologies, which are at the heart of efforts to reduce carbon emissions and promote sustainability.

As Ukraine looks to modernize its economy and transition toward more sustainable energy systems, the role of its raw materials is becoming increasingly significant. The development of clean technologies, such as solar energy, wind power, and electric vehicles (EVs), depends heavily on a steady supply of these critical resources. By harnessing its own raw material base, Ukraine can reduce reliance on imported components, foster local industries, and accelerate its transition to renewable energy sources.

The increasing demand for energy storage solutions (fig. 2), particularly in renewable energy systems and electric vehicles, places Ukraine's lithium and nickel reserves at the forefront of domestic green technology development. By capitalizing on its own resources, Ukraine can stimulate local production of batteries, reducing costs and driving growth in the domestic renewable energy sector.

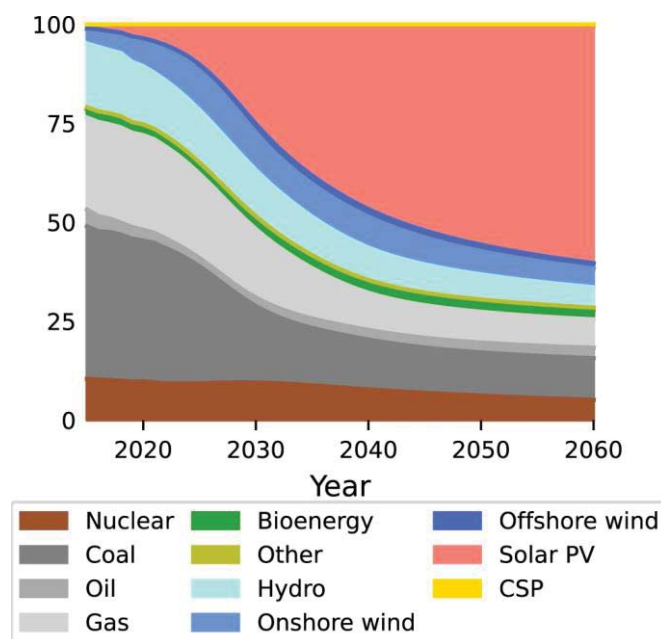


Fig. 2. Worldwide share in electricity production of various technologies [2]

Wind turbines, solar panels, and other renewable energy infrastructure rely on materials like titanium and rare earth elements, which are abundant in Ukraine. Using domestic resources will help Ukraine build its clean technology infrastructure more affordably, while also creating jobs in mining and manufacturing sectors.

Investing in local clean technology development using domestic resources not only boosts energy security but also strengthens Ukraine's role in the global green economy. By processing and refining its raw materials domestically, Ukraine can foster industries focused on high-tech, sustainable products and services, further advancing its position in the transition to green energy.

While Ukraine's rich raw material base presents a significant opportunity for the development of clean and renewable technologies, several challenges must be addressed to ensure sustainable and efficient utilization of these resources. These challenges span environmental, technological, and regulatory domains, and overcoming them is crucial for Ukraine to fully realize its potential in the global green economy.

The extraction of critical raw materials, such as lithium, nickel, and titanium, comes with inherent environmental and social risks. Mining activities often lead to significant environmental degradation, which can have long-lasting effects on ecosystems and local communities [3].

Mitigating these risks will require Ukraine to adopt stringent environmental regulations and promote community engagement, ensuring that mining activities are conducted in a way that balances economic growth with environmental preservation and social responsibility.

Ukraine faces significant infrastructure and technological limitations that hinder the efficient extraction and processing of its critical raw materials. While the country is rich in resources, its ability to fully capitalize on them is constrained by outdated mining infrastructure and a lack of advanced processing technologies.

Much of Ukraine's mining infrastructure relies on older, less efficient technologies that are not suited for the high-volume extraction of critical materials like lithium and rare earth metals. This inefficiency can increase production costs, reduce profitability, and lead to higher environmental impact due to less efficient resource use.

Extracting raw materials is only one part of the equation; processing them into usable forms for clean technologies (such as refining lithium for batteries) requires advanced technological capabilities that Ukraine currently lacks. Without significant investment in these areas, Ukraine may remain dependent on foreign processing, limiting the added value from its resource exports.

Addressing these challenges will require substantial investment in modernizing mining technologies and developing domestic processing capabilities. This will not only improve resource extraction efficiency but also allow Ukraine to move up the value chain by exporting processed materials rather than raw commodities.

Ukraine's current legislative and regulatory framework presents several obstacles to the effective and sustainable exploitation of its raw material base. These challenges stem from outdated laws, bureaucratic inefficiencies, and gaps in regulations related to environmental protection and sustainable mining practices.

To overcome these legislative and regulatory challenges, Ukraine needs to reform its mining laws, streamline the permitting process, and enforce stricter environmental and social protections. By creating a more transparent and efficient regulatory environment, Ukraine can attract greater investment in its raw materials sector while ensuring that extraction activities are conducted responsibly.

The utilization of Ukraine's raw material base for the development of clean and renewable technologies faces several critical challenges. Addressing the environmental and social risks of extraction, overcoming infrastructure and technological barriers, and reforming the legislative framework are all essential steps in ensuring that Ukraine's rich resource potential can be harnessed sustainably. Solving these challenges will not only enable Ukraine to support its own green economy but also strengthen its position as a key supplier of critical raw materials for the global energy transition [4].

Results. Ukraine holds significant potential in contributing to the global green economy, thanks to its vast reserves of critical raw materials essential for clean technologies. However, to unlock this potential, it is crucial to enhance technological processes, encourage both state and private sector involvement, and foster international cooperation. These factors collectively will shape Ukraine's ability to contribute effectively to the development of clean technologies and renewable energy sources.

To fully leverage Ukraine's rich deposits of lithium, titanium, and rare earth metals, the country must focus on improving its extraction and processing technologies. Modernizing these processes is essential for reducing environmental impacts and enhancing the sustainability of resource utilization.

- Developing new, more sustainable methods of extracting raw materials can significantly reduce the negative effects on ecosystems and local communities. Innovations such as bioleaching, where microorganisms are used to extract metals from ores, offer promising solutions that are less harmful to the environment compared to traditional mining practices.

- In addition to sustainable extraction, improving the processing of raw materials into usable forms for technologies like solar panels, wind turbines, and electric vehicle batteries is critical. Investment in advanced refining and production technologies will ensure that Ukraine can move beyond raw material exports to supply higher-value, processed products for the green economy.

- Incorporating digital technologies and automation in mining and processing can increase efficiency, reduce waste, and optimize resource use. This shift will not only improve environmental outcomes but also make Ukraine's mining sector more competitive globally.

The development of Ukraine's raw material base requires a coordinated effort between the government and private sector to provide the necessary infrastructure, investment, and policy framework.

- The Ukrainian government has a crucial role to play in fostering an environment conducive to sustainable mining. This includes offering incentives for the adoption of green technologies in the extraction and processing of critical materials, implementing environmental regulations, and providing financial support for research and development in clean technology applications.

- Ukrainian and international companies are key drivers of innovation and technological advancement in the mining sector. Private investment in clean mining technologies, as well as partnerships with universities and research institutions, can lead to breakthroughs that minimize environmental impact while maximizing output and efficiency. Programs like public-private partnerships (PPP) can stimulate growth in critical material production while ensuring sustainable practices.

- Engaging the public and local communities in these initiatives is vital for maintaining social license to operate. Ensuring that local populations benefit from the economic opportunities brought by resource extraction, while minimizing disruptions to their lives, will be key for the long-term sustainability of the mining sector in Ukraine.

International partnerships are essential for accelerating the development of Ukraine's raw material base and positioning the country as a global leader in supplying critical materials for clean technologies.

- Ukraine's geopolitical position and rich resource deposits make it an attractive partner for countries in the European Union and North America, particularly as these regions seek to reduce dependence on non-renewable energy sources. Collaborative agreements focused on resource extraction, technology transfer, and investment can provide Ukraine with the technical expertise, capital, and market access needed to scale its production of critical materials.

- Ukraine has the potential to become a significant player in global supply chains for clean technologies by supplying raw materials to manufacturers of solar panels, wind turbines, and electric vehicle batteries. Integrating Ukrainian resources into international supply chains will require collaboration with multinational companies and participation in global sustainability initiatives aimed at responsible sourcing of critical materials.

- Cooperation with global organizations and adhering to international environmental and social governance (ESG) standards will be crucial for Ukraine's reputation as a responsible supplier. Aligning with international best practices in mining and processing will make Ukrainian materials more attractive to foreign buyers, ensuring that the country becomes a key player in the global green economy.

Ukraine's raw material base plays a pivotal role in supporting the country's renewable energy initiatives. By leveraging its vast resources, Ukraine has embarked on various projects aimed at enhancing energy sustainability and reducing reliance on fossil fuels. This section will explore notable Ukrainian projects in wind, solar, and other renewable energy sectors while providing a comparative analysis of Ukraine's raw material base in relation to other countries.

When comparing Ukraine's raw material base and its contributions to renewable energy development with other countries, several key points emerge:

1. Ukraine is rich in various minerals and raw materials critical for renewable energy technologies, such as lithium, titanium, and rare earth metals. Countries like China and Australia dominate the global supply of these resources, but Ukraine's potential for local production can create a competitive edge, especially for European markets seeking to diversify their supply chains.

2. While countries like Germany and Denmark have made significant investments in renewable technologies and infrastructure, Ukraine is catching up quickly. The support from international investors and organizations, alongside domestic policies encouraging renewable energy, positions Ukraine favorably to enhance its renewable energy capacity. However, it still lags in terms of infrastructure development and technology adoption compared to these frontrunners.

3. Nations such as Sweden and Finland have established comprehensive policy frameworks that support the transition to renewable energy through incentives and subsidies. Ukraine is in the process of implementing similar measures, yet ongoing political and economic challenges may hinder swift progress.

4. According to the International Renewable Energy Agency (IRENA), Ukraine has significant potential for both wind and solar energy, like countries like Spain and Italy. However, the effective realization of this potential depends on the continuous development of its raw material base, investments in technology, and favorable regulatory conditions.

Conclusion. Ukraine's transition to renewable energy is fundamentally supported by its rich raw material base, which includes critical resources such as lithium, nickel, titanium, and rare earth metals. These materials are essential for developing clean technologies like solar panels, batteries, and wind turbines. The assessment of Ukraine's potential indicates that the country possesses significant opportunities to enhance its role in the global renewable energy market while simultaneously addressing domestic energy needs.

The contribution of Ukrainian resources to the renewable energy transition is multifaceted. Ukraine's strategic geographical location, combined with its abundant natural resources, positions the country as a potential hub for renewable energy production in Eastern Europe. By capitalizing on its raw material base, Ukraine can significantly reduce its dependence on fossil fuels, enhance energy security, and contribute to global sustainability efforts. The ongoing projects in wind, solar, and biomass energy exemplify how these resources can be harnessed effectively, paving the way for a greener economy.

To maximize the potential of Ukraine's raw material base in supporting the transition to renewable energy, several steps are needed at both the state and business levels:

1. The government should implement robust policies that promote renewable energy initiatives and create a favorable investment climate. This includes providing incentives for research and development, facilitating access to financing for clean technology projects, and streamlining regulatory frameworks.

2. There is a pressing need for investments in infrastructure to support the extraction, processing, and distribution of raw materials. Enhancing transport and logistics networks will be vital for ensuring that resources can be efficiently utilized in renewable energy projects.

3. Encouraging collaboration between the public sector and private enterprises can foster innovation and expedite the development of clean technologies. Joint ventures can leverage the expertise and resources of both sectors, driving efficiency and sustainability.

4. Investing in workforce training and education programs will be crucial for developing the necessary skills to support the renewable energy sector. This includes technical training for sustainable extraction methods and the operation of advanced clean technologies.

5. Establishing strict environmental regulations and best practices for resource extraction can mitigate the ecological impacts associated with mining and processing activities. This approach will ensure that Ukraine's transition to renewable energy is both sustainable and responsible.

Ukraine stands at a crossroads where its rich raw material base can significantly contribute to the global shift toward clean energy. By taking decisive action at the state and business levels, the

country can not only harness its potential but also establish itself as a key player in the renewable energy landscape, ultimately leading to a more sustainable future.

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