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МІНІСТЕРСТВО ЗАХИСТУ ДОВКІЛЛЯ ТА ПРИРОДНИХ РЕСУРСІВ УКРАЇНИ
ДЕРЖАВНА ЕКОЛОГІЧНА АКАДЕМІЯ ПІСЛЯДИПЛОМНОЇ ОСВІТИ ТА УПРАВЛІННЯ

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ENERGY SECURITY AND RENEWABLE ENERGY POTENTIAL OF THE EU AND UKRAINE IN TERMS OF THE RUSSIA'S AGGRESSION

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Russia's full-scale invasion of Ukraine in February 2022 and the subsequent energy crisis throughout Europe revealed a dangerous dependence of European countries on Russian energy resources. This resulted in a crucial change in energy strategy of the European Union (EU). Following the REPowerEU strategy, the European Union already decreased Russian gas import by two-thirds (from 45% to 15% of total natural gas import) and plans to totally refuse Russian energy supplies "well before the end of the decade". The EU strategy on complete replacement of Russian energy supplies and accelerating implementation of renewable sources of energy is challenging right now but crucial for Europe's long-term energy security. The EU's current binding target to achieve 42.5% of renewable energy sources in the total energy mix by 2030 is in line with the European Green Deal strategy and works on the independence of the EU from Russian energy resources.

Ukraine is currently withstanding the worst of the war, including thousands of deaths, millions of refugees, occupied territories, and destroyed infrastructure. National energy security is just one of many challenges facing the country. Following the EU's strategy, Ukraine urgently needs to transform its energy sector in a sustainable manner. Ukraine's current plan to achieve 27% renewables in total energy production by 2030, while less ambitious than the EU's goal, is still a compelling strategy given the country's wartime situation. The country can and should rely heavily on renewable energy sources, including solar and wind generation. Biogas and biomethane production can also play a significant role in replacing natural gas in Ukraine, given the country's vast agricultural potential. Along with a radical increase in energy efficiency, this will transform Ukraine's energy sector into a sustainable and secure one. *Key words:* energy security, sustainable development, renewables, energy resources, Russia's war in Ukraine.

Енергетична безпека та потенціал відновлюваної енергетики ЄС та України в умовах російської агресії. Якименко І.Л., Бублієнко Н.О., Салавор О.М., Ніччик О.В., Шаповалов Є.Б., Хеншель Д.

Повномасштабне вторгнення Росії в Україну в лютому 2022 року та подальша енергетична криза по всій Європі виявили небезпечну залежність європейських країн від російських енергетичних ресурсів. Російське вторгнення в Україну призвело до кардинальної зміни енергетичної стратегії Європейського Союзу (ЄС). Реалізуючи стратегією REPowerEU, ЄС вже скоротив імпорт російського газу на дві третини (з 45% до 15% загального імпорту газу у ЄС) та планує повністю відмовитися від російських енергетичних поставок «задовго до кінця десятиліття». Стратегія ЄС щодо повного заміщення російських енергетичних поставок та прискорення впровадження відновлюваних джерел енергії є складною на даний момент, але має вирішальне значення для довгострокової енергетичної безпеки Європи. Поточні зобов'язуючі цілі ЄС щодо досягнення 42,5% відновлюваних джерел енергії в загальному енергетичному балансі до 2030 року відповідають стратегії Європейського зеленого курсу та спрямовані на незалежність ЄС від російських енергетичних ресурсів.

Наразі Україна несе основний тягар війни, включаючи тисячі смертей, мільйони біженців, окуповані території та зруйновану інфраструктуру. Національна енергетична безпека – це лише один із багатьох викликів, що стоять перед країною. Дотримуючись стратегії ЄС, Україні терміново потрібно трансформувати свій енергетичний сектор у сталий спосіб. Поточний план України щодо досягнення 27% відновлюваних джерел енергії в загальному виробництві енергії до 2030 року, хоча й менш амбітний, ніж цілі ЄС, але є переконливою стратегією, враховуючи воєнну ситуацію в країні. Країна може і повинна значною мірою поклатися на відновлювані джерела енергії, включаючи сонячну та вітрову генерацію. Виробництво біогазу та біометану також може відігравати значну роль у заміні природного газу в Україні, враховуючи величезний сільськогосподарський потенціал країни. Поряд із суттєвим підвищенням енергоефективності, це перетворить енергетичний сектор України на сталий та безпечний. *Ключові слова:* енергетична безпека, сталий розвиток, відновлювані джерела енергії, енергетичні ресурси, війна Росії в Україні.

Problem statement. Sustainability and environmental issues are important parts of the long-term national energy security strategy, but in times of energy crises the demands for sustainable energy resources may be temporary compromised, at least in the short-term, by urgent demands for the nations in available energy resources [1]. Urgent needs for most European countries

to replace Russian gas and oil forced the nations search other options, including, e.g., returning to coal, which is obviously not the environmentally friendly choice. On the other hand, the energy challenges over Europe due to Russian invasion of Ukraine will accelerate the transition of the EU member states to renewables, and change the situation in the long-term. For example, sig-

nificant part of the REPowerEU strategy of the European Commission for overcoming the EU's dependence on Russian gas envisages renewable sources [2].

In 2023, the EU's natural gas supply already decreased by 7.4% compared with 2022, marking the lowest value since 1995. Moreover, in 2023 brown coal supply decreased by 24.2%, and hard coal supply dropped by 20.4% compared to 2022. Both figures are the lowest recorded since the Eurostat data series began [3].

Meanwhile, Ukraine is becoming an integral part of the EU community, which means Ukraine may and should be a part of energy sector of the EU, sharing all challenges and approaches of the Union for its energy security.

In this article, we analyze the challenges of energy security for the EU and Ukraine due to the Russian war against Ukraine.

Energy sector of the European Union. More than a decade ago, in response to global financial and economic crisis of 2008, the EU strengthened sustainable development approaches through the implementation of Europe 2020 strategy on smart, sustainable and inclusive growth [4]. In terms of this strategy, among other priorities, the EU was determined to reach 20% renewables in the total energy mix of the Union in 2020. The goal was achieved as in 2020 renewable energy represented 22.1% of energy consumed in the Union [5]. Further climate / energy goals of the EU were set in the European Green Deal [6] and in Fit for 55 strategy [7]. Finally, according to the Directive (EU) 2023/2413 (the revised Renewable Energy Directive) [8], the EU binding renewable target for total energy consumption was set as 42.5% by 2030.

While renewables were the EU's priority for many years in terms of global warming, restriction of dependence of the Union on Russian energy supplies also implied. And the EU authorities had strong evidence on the risks of the EU significant dependence on Russia. Yet in 2018, the European Parliament authorized the analytical research on the EU vulnerability in its energy dependence on "authoritarian Russian regime" [9]. The analysis clearly demonstrated that during many years Russia used its energy resources as a powerful tool of its foreign policy for geopolitical motives. The analysis concluded on high risks for the EU member states due to its dependence on Russian natural gas supplies.

For European countries, Russian gas was cheaper than from other sources. It was not only due to geographical reasons, but it was one of Putin's geopolitical tricks. This resulted in more than half share of Russian gas in natural gas imports of many EU member states, e.g., in Germany and Hungary – 57%, in Austria – 64%, in Greece, Slovakia, Latvia and Estonia – about or over 80%, Bulgaria and Finland – 100% [9].

Being ten times weaker compared to the EU in terms of GDP, Russia managed to control the EU energy market significantly [10]. And due to vast energy resources, Putin's regime received significant financial resources for its war crimes. For example, in 2021 Russia's global revenue from fuel sale reached about \$250 billion [11].

But just in a few days after the beginning of the war, the European Commission issued the communication on energy security of the EU member states REPowerEU, increasing the level of demands [2]. The communication had a clear purpose to solve the problem of energy dependence of the EU on Russia as soon as possible. The Commission confirmed that Russia provided about 45% of the EU's total natural gas consumption, 27% of oil imports and 46% of coal imports of the EU.

The communication proposed a detailed list of actions, which could decrease the EU demands in Russian gas by two thirds to the end of the 2022 and totally refuse Russian gas imports by 2030. It is the most radical plan in energy security of the EU that needs coordinated efforts of the EU member states and their partners. Two key strategies of the plan are:

- Diversifying gas supplies via higher LNG and pipeline imports from non-Russian suppliers, higher levels of biomethane and hydrogen;
- Reducing faster the EU dependence on fossil fuels by boosting energy efficiency and increasing the share of renewables.

According to the document, by the end of 2022 the EU was able to replace over 100 bcm of Russian gas, following such measures as:

- LNG diversification – 50 bcm replacement;
- Pipeline import diversification – 10 bcm replacement;
- Increasing wind and solar deployment and green hydrogen production – 20 bcm.

In further response on Russian blackmailing, the European Commission called for energy saving in every member state through the reducing gas consumption by 15%. That was the equivalent of 45 bcm of natural gas saving. As a result of concerted actions of the EU member states, in 2023 the import of Russian natural gas into the EU fell to less than 15%, including LNG [12].

Renewable energy potential of the EU. Share of renewable energy more than doubled between 2004 and 2020 through the EU member states. Sweden had 60% of energy from renewable sources in its gross final consumption of energy in 2020, following by Finland (44%) and Latvia (42%) [5]. The share of energy consumed in the EU during 2022 generated from renewable sources was 23% [13], demonstrating slight growth compared with previous year, but not significant enough to reach the ambitious EU goals for renewables till 2030.

Solid biomass is the largest among renewable energy sources throughout the EU, widely used in electricity generation, industry and residential heating. It represented 40% of the total renewable energy supply in the EU in 2022, followed by wind (15%), hydropower (10%) and liquid biofuels (7%). Solar photovoltaics and heat pumps each represented around 7% of the EU renewable supply. Other significant renewables sources were biogases, renewable waste, geothermal and solar thermal [13].

To be clear, in electricity generation throughout the EU, which is only a part of the total energy mix. And in

2023, renewable energy already accounted 44.7% of all electricity production in the EU, marking an increase of 12.4% compared with 2022 [3].

As for Russian natural gas physical replacement, biomethane is an important renewable alternative with a big potential throughout the EU. Even before the current challenges with Russian energy supplies, some EU member states demonstrated great potential of these renewables. For example, Germany had estimated about 9,700 biogas plants operating as of 2018. That was the highest number of biogas plants in any country in Europe and the world. There was a total installed capacity of 4.8 GW, and about 32,500 GWh of electricity and 17,200 GWh of heat generation in Germany in 2017 using biogas [14].

As for the progress in the field, according to the European Biogas Association [15], in 2022 Europe produced 21 bcm of biogas, including 18 bcm of biogas produced in 27 EU member states. And 20% of biogas produced in Europe in 2022 were upgraded to biomethane. From this 4.2 bcm of biomethane, 3.4 bcm were produced in the EU. Thus, biomethane production doubled in Europe from 2018 to 2022. The fastest growth was demonstrated in France, Italy, and Denmark.

The Hydrogen Strategy for a Climate Neutral Europe was adopted in the EU in 2020 [22] as a part of ambitions of the European Green Deal [6]. The priority is the use of green hydrogen, which is produced due to electricity from renewable sources. The proposed phased approach assumed that in 2020 – 2024, at least 6 GW of electrolyzers should be installed in the EU and up to one million tons of hydrogen will be produced from renewable energy sources.

Energy sector of Ukraine. Before the Russian war against Ukraine, energy production in Ukraine was mostly provided by fossil fuels and nuclear power. In 2020, Ukraine had the following structure of primary energy sources: natural gas – 27.5%, coal – 26.4%, nuclear energy – 23.1%, oil – 16.4%, renewables – 6.6% [16]. Thus there was a significant dependence on natural gas and nuclear energy, and extremely low share of renewables in energy sector of Ukraine.

During the last before-the-war years, Ukraine produced about 20 bcm of natural gas annually. It covered about two thirds of the national demands in natural gas. The rest of gas supplies, about 8-10 bcm, was imported to the country from some EU member states (Slovakia, Hungary, and Poland). But it was mostly Russian gas by the origin. Ukraine also has been 85% dependent on the imports of petroleum products. And the share of oil products produced in Russia or from Russian raw materials in the structure of Ukrainian imports exceeded 80%. Ukraine also remained significantly dependent on the supply of nuclear fuel from Russia, which met more than 50% of needs of Ukrainian nuclear power plants.

Thus, Ukraine shares the challenges of most European countries in its dependence on Russian energy resources. Russian aggression aggravated the situation for Ukraine. The matter is that the Dnipro-Donetsk region of Ukraine

accounts for approximately 90% of national gas production. Now this region is severely affected by the war. According to the national experts, about 70% of gas production facilities in the country currently may be destroyed or out of operation.

Among the advantages of Ukraine in energy sector, there is a potent gas transportation system, which during decades served as the main transport route for Russian gas to Europe. The other important part of energy infrastructure of Ukraine is the largest in Europe underground natural gas storage facilities (more than 30 bcm), which comprise 21% of total European facilities. And while the gas transportation system will lose its significance for Russian gas transport, Ukrainian gas storage facilities may play important role in energy security of both Ukraine and the EU.

Potential of renewable energy production in Ukraine. Paying attention to the low level of renewables in the total energy mix in Ukraine, in 2021 Ukrainian government proposed National Action Plan for the Development of Renewable Energy until 2030 [17]. According to the plan, in 2030, Ukraine should produce 27% of the whole energy mix from renewables. This level is much lower than updated plans in the EU (42.5% as a binding target), and Ukraine does have the potential to reach more.

It is worth to indicate, that in Ukraine about three quarters of renewables are bioresources [16]. Being one of the largest producers of agricultural crops in the world, Ukraine has a huge potential in bioresources, first of all, in form of agricultural residues. Experts of Bioenergy Association of Ukraine (UABIO) calculated that Ukraine has a biomass potential for energy production in a total of 21.7 million tons of oil equivalent (toe) per year. The main components of the energy potential of biomass are by-products and waste of agriculture, and agricultural residues. The largest shares of the potential of agricultural residues fall on the straw of cereal grain crops (36%) and by-products/waste from the production of grain corn – 33% [18].

Moreover, according to the last UABIO assessment [19], transforming available and potential bioresources, Ukraine may produce about 22 bcm of biogas/biomethane per year. Among the most powerful bioresources for biogas production, the UABIO experts name cover crops and harvest residues from agricultural crops. A bit less potential for biogas production in Ukraine was revealed by experts of Ukrainian Technological Company (UTC). Being one of the major industrial companies in biogas technology in the country, UTC assesses potential of Ukraine in biomethane production in up to 15 bcm annually with new facilities installation in a scale of about one bcm of biomethane production per year. This approach is promising for Ukraine. Because this way Ukraine may use natural gas transportation system and natural gas storage facilities.

Biogas production generates a significant amount of useful side product, digestate, which may be used as an

organic fertilizer. Organic waste treatment has additional benefits for the environment. Organic waste deposited in landfills, produces a significant amount of biomethane as a pollutant of the atmospheric air. Methane is a powerful greenhouse gas, 80 times stronger for greenhouse effect / global warming than carbon dioxide. For Ukraine this question is more than relevant as most of municipal waste is still going to the landfills here. On the other side, being treated in the technological process of anaerobic digestion, organic waste will be transformed into valuable energy resource.

Currently, Ukraine has only about 83 biogas plants with total capacity of 140 MW [19]. For comparison, in 2022, Germany, the main biogas producer in Europe, had 9,876 biogas plants with total capacity of about 13 GW (91 TWh) replacing about 10.8% of natural gas by biogas [20]. Ukraine has both significant bioresources for biogas production and sufficient amount of well-educated professionals in the fields of biotechnology and industrial ecology. Under the financial and technological support of European and American partners, Ukraine may fast reach significant progress in biogas / biomethane production.

Ukraine has relatively good climate conditions for wind and solar power generation. Today not only Ukraine has low level of renewables in the national energy mix (about 6.6%), but most renewables (75% of them) are represented by bioresources, mostly solid biofuels [16]. Meanwhile international experts assess the potential of wind power generation in Ukraine in stunning 320 GW [21], which technically may cover the all national energy demands. Of course, this potential should be restored yet through the deoccupation of southern regions of the country. Because the most promising wind power regions are the southern and southeastern parts of Ukraine.

Solar generation also has a high potential in Ukraine. Even though Ukraine is in the lower part of the list of countries according to its photovoltaic power potential, the country is ahead of many European states, including Germany, Austria, Czech Republic and Poland [22].

The National Renewable Energy Action Plan of Ukraine implies the construction of 10 GW of electrolyzers for the production of green hydrogen on the territory of Ukraine, the country can become an integral part of the implementation of the ambitious goals of the European Green Deal [23]. In addition to Ukraine's role as a producer of green hydrogen on the European market, the EU may be also interested in adapting the Ukrainian gas transportation system to supply a mixture of hydrogen and natural gas. As experts note, there is no infrastructure for hydrogen in Eastern Europe. Its creation will take ten or more years. The possibility of using existing gas pipelines for the transfer of hydrogen or hydrogen mixtures requires research and practical tests but are promising.

Nuclear power generation in Ukraine. The important issue for Ukrainian energy sector is the challenge

of nuclear power. Ukraine is the third European country after France and Slovakia with highest share of nuclear power in energy mix. Before the war, Ukraine generated about 55% of its electricity in 15 nuclear reactors. The challenge here is that most nuclear reactors exhausted its operation life (30 years). Meanwhile, Nuclear Energy Agency (NEA) experts concluded that if nuclear utilities implement enhanced ageing management programmes using readily available technical evidence, while performing the necessary repairs and replacements, long-term operation should not face any major generic technical barriers [24].

Nevertheless, Ukraine has a bad historic background being the country affected by the biggest nuclear accident in the world, the Chernobyl (Chernobyl) disaster. See, for example, [25]. So, the country needs both strict international technological control during the operation of its nuclear reactors and research-based decisions on its further operation.

The challenges in energy sector for Ukraine. Energy infrastructure of Ukraine is worn and outdated in general. Almost all power units of thermal power plants have exhausted their park resource, are technologically outdated. The power units of nuclear power plants formally should be decommissioned due to the end of their service life. Electrical networks are experiencing significant deterioration, with some components exhibiting over 70% degradation. All these facilities need to be rebuilt and modernized in nearest years in terms of national energy security.

Due to the war, many national industrial sites, including Azovstal in Mariupol city, one of the largest steel rolling companies in the country, were destroyed or occupied. This situation will result in different consequences for the national energy sector. On one side, Ukraine will need huge energy resources to restore the national economy and to rebuild the country after the war. On the other side, before the war, Ukrainian economy was one of the most energy inefficient in Europe. For example, energy consumption per unit of national GDP in Ukraine was about 3 times higher than average throughout the EU [26]. And the country should use postwar economic recovery for radical technological modernization of all branches of the economy to make it much more energy efficient. In turn, it may significantly reduce the national demands in energy resources, including natural gas.

The war added new risks and challenges in energy security both for Ukraine and for whole Europe, e.g., currently the largest Ukrainian nuclear power plant, the largest in Europe, with 6 nuclear reactors, Zaporizhzhia NPP, is under the control of Russian invaders. Energy infrastructure of Ukraine was significantly affected due to permanent Russian terrorist attacks (see, for example, [27]).

Conclusions. A long-term dependence of most European countries, including Ukraine, on Russian energy resources was a significant risk, which European community should overcome. The EU's strategy on a total replacement of Russian natural gas, acceleration of renew-

ables' installations, and energy saving / energy efficiency strengthen European energy security in middle and long terms, being challenging at the moment. Ukraine being an integral part of European community and defending European democratic values and freedoms, meets huge challenges in all fields of the country's life, including energy security issues. Strong international support is crucial both for Ukrainian victory and for successful postwar recovery of the country. Ukraine itself has a significant potential in energy sector, e.g., developed infrastructure

for natural gas transportation and storage, great potential in biogas / biomethane production, and a significant electricity production due to the nuclear power generation.

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