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Energy Security of the European Union and Ukraine Since the 2022 Russia's Invasion of Ukraine

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Abstract

Energy security is one of key components of economic growth and sustainable development. During the last decades, the European Union (EU) has made significant efforts to transition its energy sector towards a sustainable, renewables-based, and climate-neutral model. However, Russia's invasion of Ukraine in February 2022 and the subsequent energy crisis throughout Europe revealed a significant dependence of Europe on Russian energy resources. The EU's current strategy on complete replacement of Russian energy supplies and accelerating implementation of renewable sources of energy is challenging now but crucial for Europe's long-term energy security. National energy security is just one of many challenges facing Ukraine. National integrity and determination along with strong international support

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are key elements for both Ukraine's survival and post-war sustainable recovery, including energy sustainability. Following the EU's strategy, Ukraine urgently needs to transform its energy sector in a sustainable manner. Among other approaches, the country should significantly rely on renewables, including biogas and biomethane production, along with radical improvements in national energy efficiency. In this article, we analyze the challenges of energy security for the European Union and Ukraine due to the Russian invasion of Ukraine, and effective strategies, which may be applied.

Keywords: Energy security, sustainable development, renewables, energy resources, the European Union, Ukraine.

List of Abbreviations

AA	Association Agreement
bcm	billion cubic meters
CM	the Council of Ministers (when referring to the EU institution)
CMU	Cabinet of Ministers of Ukraine
EBA	European Biogas Association
EC	the European Commission
EEA	the European Environment Agency
EP	the European Parliament
EU	the European Union
Eurostat	Statistical Office of the European Union
GBA	German Biogas Association
GDP	gross domestic product
IEA	the International Energy Agency
IRENA	International Renewable Energy Agency
LNG	liquefied natural gas
NE	the Office of Nuclear Energy of the US Department of Energy
NEA	the Nuclear Energy Agency
NPP	nuclear power plant
TWh	Terawatt hours
UABIO	Bioenergy Association of Ukraine
UkrStat	State Statistics Service of Ukraine
UNEP	the United Nations Environment Programme
UTC	Ukrainian Technological Company
WB	the World Bank
WBA	World Biogas Association

1 Introduction

Energy security is the protection of national interests in the field of ensuring access to reliable, sustainable, affordable and modern sources of energy in a technically reliable, safe, economically efficient and ecologically acceptable way in normal conditions and in a special or emergency states [1]. This is the definition of energy security from Ukrainian government's Strategy of Energy Security before the Russian invasion of Ukraine. Obviously, sustainability and environmental issues are important parts of the long-term national energy security strategy. But we should agree, that in times of energy crises the demands for sustainable energy resources may be temporarily compromised, at least in the short term, by urgent demands for the nations in available energy resources [2]. Urgent needs for most European countries to replace Russian gas and oil by more reliable alternatives 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, significant part of the REPowerEU strategy of the European Commission for overcoming the EU's dependence on Russian gas envisages renewable sources [3]. The first reactions of German government to the possible energy crisis caused by the Russia's invasion of Ukraine was moving the deadline for achieving full renewable energy supplies from 2050 to 2035 [2].

According to preliminary data, 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 [4]. Instead, the renewables demonstrate significant growth during these last years throughout the EU (see below).

The Russian invasion deeply affects not only Ukraine but also neighboring countries in many ways, including the refugee crisis, risk of energy crisis, and even global food market distortion. Among others, Ukraine is a significant player on the global food market, as the largest exporter of sunflower oil, the fourth largest exporter of maize and the fifth largest exporter of wheat [5].

Meanwhile, Ukraine is becoming an integral part of the European Union 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. On the other hand, Ukraine must work hard to solve its energy problems and collaborate with other European countries to overcome the energy challenges of Europe in general.

2 Energy Security of the European Union

The European Union is undoubtedly a global leader in sustainable development and combating climate change. More than a decade ago, in response to the global financial and economic crisis of 2008, the EU strengthened sustainable development approaches through the implementation of the Europe 2020 strategy on smart, sustainable and inclusive growth [6]. 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 [7]. Further climate / energy goals of the EU were set in the European Green Deal [8] and in Fit for 55 Communication [9], including, e.g., 40% of renewables in the EU energy mix in 2030. Finally, according to the Directive (EU) 2023/2413 (the revised Renewable Energy Directive) [10], the EU binding renewable target in all energy consumption for 2030 was set as 42.5%.

2.1 Dependence of the EU on Russian Energy Resources

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 was also implied. The EU authorities had strong evidence of the risks of the EU's dependence on Russia. For example, in 2018, the European Parliament authorized research on EU vulnerability in its energy dependence on "authoritarian Russian regime" [11]. The analysis clearly demonstrated that for many years Russia used its energy resources as a powerful tool in its foreign policy. The approaches included:

- manipulating the pricing policy of energy supplies to third countries;
- controlling energy assets, such as pipelines and gas operators in key countries;
- cutting or disrupting gas supplies;
- agreeing restrictive supply contracts;
- developing alternative supply routes to divert gas flows.

The analysis [11] concluded that there were high risks for EU member states due to their dependence on Russian natural gas.

Russia does have significant energy resources, with 24% of global natural gas reserves, following by Iran (17%), Qatar (13%) and the USA (5%).[1] Russia also has 5% of global oil reserves, being the eighth in the rating of oil richest countries after Venezuela (18%), Saudi Arabia (16%), Canada (10%) and few other countries.[2] For comparison, the USA has only about 2% of global oil reserves.[2]

For European countries, Russian gas was cheaper than from other sources. And European countries, particularly Germany only increased their dependence on Russia's energy supplies during the early part of the 21st century. This resulted in more than half of natural gas imports of many EU member states coming from Russia, e.g., in Germany and Hungary – 57%, in Austria – 64%, in Greece, Slovakia, Latvia and Estonia – about or over 80%, Bulgaria and Finland – 100% [11]. The important issue here is also the share of natural gas in the total energy mix of particular countries. In Germany and Austria it was about 22%, but in Hungary and Italy natural gas covered 37–38% of all national energy demands [11].

2.2 First Effects of the Russian Invasion of Ukraine on the EU Energy Sector

Although being ten times weaker compared to the EU in terms of GDP, Russia managed to influence the EU energy market significantly [12], and due to its vast energy resources, Russia received significant financial resources for its exporting of energy. For example, in 2021 Russia's global revenue from fuel sales reached about $250 billion [13].

It seems that Russian aggression against Ukraine became a game changer for most European countries and for the European community in general. Just a few days after the invasion, the International Energy Agency (IEA), a Paris-based intergovernmental organization of 31 developed countries, including the USA, UK, Japan, Germany, Canada and the European Union's representatives, issued recommendations for the EU to urgently reduce its reliance on Russian natural gas [14]. Among 10 steps recommended by the IEA for the nearest year, there were:

– Replace Russian supplies with gas from alternative sources, including pipeline imports from Azerbaijan and Norway, up to an additional 10

[1] https://www.worldometers.info/gas/gas-reserves-by-country.
[2] https://www.worldometers.info/oil/oil-reserves-by-country.

billion cubic meters (bcm), and liquefied natural gas (LNG) imports, up to 20 bcm.
- Accelerate the deployment of new wind and solar projects, which may bring down gas use by 6 bcm.
- Maximise generation from bioenergy, reducing gas use by 9 bcm.
- Encourage a temporary thermostat adjustment by consumers. Turning down the thermostat for buildings' heating by just 1°C would reduce gas demand over the EU by some 10 bcm a year.

A few days later, the European Commission issued the REPowerEU, communication on energy security of the EU member states increasing the level of demands [3]. The communication had a clear purpose of solving 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 (Figure 1), 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 Russian gas by two thirds to the end of the 2022 and cease Russian gas imports by 2030. It is a radical plan for energy security of the EU and it needs coordinated efforts from 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 the EU dependence on fossil fuels faster 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 the next measures:

- LNG diversification – 50 bcm replacement;
- Pipeline import diversification – 10 bcm replacement;
- Increasing wind and solar deployment and green hydrogen production – 20 bcm;
- Energy saving – 14 bcm;
- Boosting biomethane production – 3.5 bcm replacement [3].

On June 2022, four months since the Russian invasion, the President of the European Commission Ursula von der Leyen issued the statement giving her analysis of the situation on energy security in the EU.[3] The document indicated that, 12 EU member states had been hit by a partial or total cut-off of

[3]https://ec.europa.eu/commission/presscorner/detail/en/STATEMENT_22_4626.

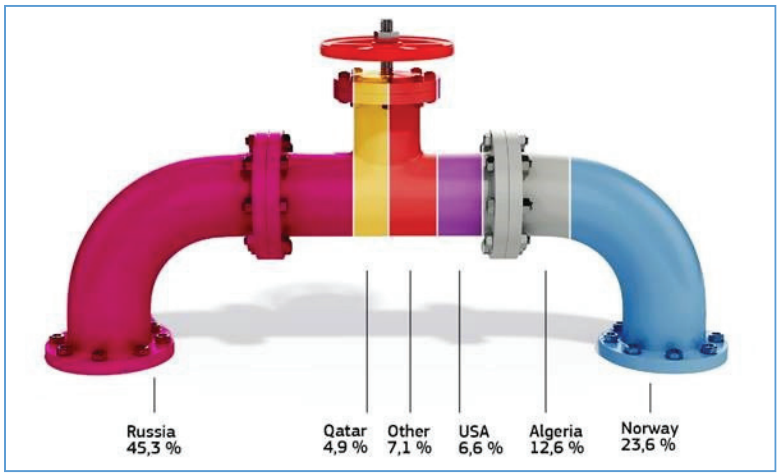

Figure 1 Share in EU natural gas imports in 2021 [3].

Russian gas supply. The statement underlined a "quite impressive" increase in gas supply from other sources than Russia since January that year by 35 bcm to the EU member states. It included LNG supplies from the USA, Norway, Qatar, the Gulf States, and Algeria. Renewables also provided additional energy to the member states, replacing about 4 bcm of natural gas from the beginning of the year. In a further response, the European Commission called for energy saving in every member state by 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 imports of Russian natural gas into the EU fell to less than 15%, including LNG [15]. Therefore, while the EU is looking for new energy markets, improving its energy efficiency, and investing in new energy infrastructure, Russia has now lost Europe as its main export market for its gas [16].

2.3 Renewables for Energy Security of the EU

The strategy of the EU on accelerated installation of renewables in the next years is in line with previous EU strategic plans and the EU has proved its achievement and effectiveness. 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%). At the opposite end of the scale, the lowest proportions of renewables were registered in Malta

(11%), Luxembourg (12%) and Belgium (13%) [7]. The share of energy consumed in the EU during 2022 generated from renewable sources was 23% [17], 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, it is 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 [17].

In the EU, in electricity generation, which is only a part of the total energy mix, 37.5% was generated from wind, 29.9% – from hydropower, 18.2% – from solar power, 6.9% – from solid biofuels, and 7.5% – from other renewable sources [18]. And according to the preliminary data, in 2023, renewable energy already accounted for 44.7% of all electricity production in the EU, marking an increase of 12.4% compared with 2022 [4]. Meanwhile, electricity generated from fossil fuels decreased by 19.7% compared with the previous year, contributing 32.5% of the total electricity production. And nuclear generation covered 22.8% the EU energy production, with a 1.2% increase in production in 2023 [4]. It is important to keep in mind, that, for example, in 2022, the EU produced (only) around 37% of its own energy. And in the mix of its own produced energy in the EU, 43% came from renewables in 2022 [19].

As for the Russian natural gas physical replacement, biogas and 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 had demonstrated the great potential of these renewables. For example, Germany had an estimated 9,700 biogas plants operating as of 2018. That was the highest number of biogas plants in any country in Europe (and the world), excluding small-scale community plants prevalent in China and South East Asia. 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 [20]. Italy operates more than 1,600 biogas plants. However, in Romania and Bulgaria, for example, the number of such plants is only about 10, despite the relatively large size of these countries.[4] Also, according to the assessment of the IEA, the bioenergy

[4]https://www.europeanbiogas.eu.

power plants in the EU only operated at about 50% of total capacity in 2021, which could have brought an additional 50 TWh electricity, reducing natural gas use throughout the EU by 9 bcm even without installation of new facilities [14].

As for the progress in the field, according to the European Biogas Association [21], 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 [21].

The Hydrogen Strategy for a Climate Neutral Europe was adopted in the EU in 2020 [22] as a part of the ambitions of the European Green Deal [8]. 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. And while technologies, infrastructure and economic issues are still discussed, the important role of (green) hydrogen in energy transition is generally accepted [23–26].

2.4 The Nuclear Power Generation in the EU

The EU has significant nuclear energy potential and it seems to be a valuable option in current situation despite public concerns about public and environmental risks. The EU covers about a quarter of its electricity needs by nuclear energy. One hundred and three nuclear reactors (100 GW) operate in 13 of the 27 EU member states. And more than half of the EU's nuclear electricity is produced in France.[5] At the same time, 9 out of 13 EU countries that operate nuclear power plants receive 30 or more percent of their electricity from nuclear power plants.[6] Accepting the strategy for nuclear power as a transition option for clean and independent energy, the EU may need to prolong the operation life of its nuclear reactors, as, e.g., the USA has done. The USA is the largest producer of nuclear energy in the world. The average age of US reactors is approaching 40 years, but experts believe there is no technical limit to producing power from these plants for perhaps an

[5]https://world-nuclear.org/information-library/country-profiles/others/european-union.aspx.

[6]https://infoatom.news/2022/02/08/960220221615.

additional 40 years or longer. Research conducted over the past decade by the US Department of Energy and the Electric Power Research Institute, USA implies that nuclear power plants can apply for the next 20-year operating license. And 88 of America's 92 reactors have been approved for the (first) 20-year extension, with most of them not expiring until the 2030s [27].

While refusal of Russian gas is a huge challenge for most EU member states now, in the long-term it is a critically important step for the energy security of the Union. Diversification of gas supplies, speeding up renewables rollout and energy saving may make Russian gas unnecessary for the European market. It will stabilize the energy sector of the EU and deprive the current Russian regime with a main financial lever. In 2020, renewable energy sources made up 37.5% of gross electricity consumption in the EU. Wind and hydropower accounted for more than two-thirds of the total electricity generated from renewable sources (36 and 33%, respectively). Solar power (14%), solid biofuels (8%) and other renewable sources (8 %) generated the rest of renewable energy [7]. And according to the preliminary data, in 2023, renewable energy already accounted for 44.7% of all electricity production in the EU, marking an increase of 12.4% compared with 2022 [4]. Meanwhile, electricity generated from fossil fuels decreased by 19.7% compared with the previous year, contributing 32.5% of the total electricity production. And nuclear generation covered 22.8% the EU energy production, with a 1.2% increase in production in 2023 [4]. It is important to keep in mind, that, for example, in 2022, the EU produced (only) around 37% of its own energy, while 63% was imported. And in the mix of its own produced energy in the EU, 43% came from renewables in 2022 [19].

3 Energy Security of Ukraine

Before the Russian invasion of 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% [28]. Thus, there was a significant dependence on natural gas and nuclear energy, and an extremely low share of renewables in energy sector of Ukraine.

During the 2010's, Ukraine produced about 20 bcm of natural gas annually.[7] It covered about two thirds of the national demand with natural gas.

[7] https://expro.com.ua/novini/vidobutok-gazu-v-ukran-znizivsya-na-2-do-198-mlrd-kub-m.

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 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 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 [1].

Thus, Ukraine shares the challenges of most European countries in its dependence on Russian energy resources. Russian aggression aggravated the situation for Ukraine. The Dnipro-Donetsk region of Ukraine accounts for approximately 90% of national gas production [29] and this region is severely affected by the ongoing situation. According to recent estimates from national experts, about 70% of gas production facilities in the country currently may be destroyed or out of operation.

Among the advantages for Ukraine in the energy sector, is a potent gas transportation system, which for decades served as the main transport route for Russian gas to Europe. The other important part of energy infrastructure of Ukraine is the largest underground natural gas storage facilities in Europe (more than 30 bcm), which comprises 21% of total European facilities.[8] And while the gas transportation system will lose its significance for Russian gas transport, Ukrainian gas storage facilities may play important role in the current and future energy security of both Ukraine and the EU.

3.1 Potential of Renewable Sources in Ukraine

Paying attention to the low level of renewables in the total energy mix in Ukraine, in 2021 the Ukrainian government proposed a National Action Plan for the Development of Renewable Energy until 2030 [30]. According to the plan, in 2030, Ukraine should produce 27% of its whole energy mix from renewables. This level is much lower that updated plans in the EU (42.5% as a binding target), and Ukraine does have the potential to reach more.

It is worth indicating, that in Ukraine about three quarters of renewables are bioresources [28]. Being one of the largest producers of agricultural crops in the world, Ukraine has a huge potential in bioresources, first, in the form of agricultural residues. Experts from the Bioenergy Association of Ukraine (UABIO) calculated that Ukraine has potential for biomass energy production of a total of 21.7 million tons of oil equivalent (toe) per year. The main

[8] https://utg.ua/img/menu/company/docs/2021/buklet/%D0%91%D1%83%D0%BA%D0%BB%D0%B5%D1%82_%D0%A3%D0%A2%D0%93_ua_30112021.pdf.

components of the energy potential of biomass are by-products and waste from agriculture, and agricultural residues. The largest shares of the potential of agricultural residues come from the straw of cereal grain crops (36%) and by-products/waste from the production of grain corn (33%) [31].

Moreover, according to the last UABIO assessment [32], by transforming available and potential bioresources, Ukraine may produce about 22 bcm of biogas/biomethane per year. Among the most powerful bioresources for biogas production, comes from cover crops and harvest residues from agricultural crops. A lower potential for biogas production in Ukraine was revealed by experts of Ukrainian Technological Company[9] (UTC). Being one of the major industrial companies in biogas technology in the country, UTC assessed the potential for Ukraine in biomethane production as being up to15 bcm annually. This approach is promising for Ukraine. Because this way Ukraine may use its 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 [33]. 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 atmosphere. Methane is a powerful greenhouse gas, 80 times stronger for the greenhouse effect and global warming than carbon dioxide [34]. For Ukraine this question is more than relevant as most of municipal waste still goes to the landfills. On the other side, being treated through anaerobic digestion, organic waste will be transformed into a valuable energy resource.

It is interesting that during methane fermentation of organic waste, e.g., manure, a significant amount of ammonia may be extracted and used as an alternative energy resource too [35]. The potentials of ammonia as a carbon-free fuel are discussed nowadays. For example, hydrogen as a fuel has an extremely low density, which means that its energy density on a volumetric basis remains distinctly substandard to most liquid fuels. Ammonia is 50% denser compared to compressed or liquefied hydrogen. One major advantage is that there is an existing infrastructure for transport and distribution of ammonia worldwide [36].

Currently, Ukraine has only about 83 biogas plants with total capacity of 140 MW [32]. For comparison, in 2022, Germany, the main biogas producer in Europe, had 9,876 biogas plants with total capacity of about 13 GW

[9] https://utc.bio.

(91 TWh) replacing about 10.8% of natural gas by biogas [37]. Ukraine has both significant bioresources for biogas production and a 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 quickly deliver 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 [28]. Meanwhile international experts assess the potential of wind power generation in Ukraine at a stunning 320 GW [38], which technically would cover all national energy demands. The most promising wind power regions are the southern and southeastern parts of Ukraine, where the average wind speed at the height of the rotor axis of the modern wind power turbines reaches 7 m/s and higher.[10]

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 [39].

The National Renewable Energy Action Plan of Ukraine for the period up to 2030 foresees an increase in the installed capacity of solar and wind power plants – up to 9,947 MW and 5,033 MW in 2030, respectively [30]. Compared to the indicators of 2020 (6,872 MW of solar generation and 1 314 MW of wind power plants), this is an increase of 1.5 times for solar and 3.8 times for wind power plants.

Due to the plans for the construction of 10 GW of electrolyzers to produce green hydrogen in Ukraine, the country can become an integral part of the implementation of the ambitious goals of the European Green Deal [40]. 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 currently no infrastructure for hydrogen in Eastern Europe and its creation will take ten or more years. The possibility of using existing gas pipelines for the transfer of hydrogen or hydrogen mixtures requires more research and practical tests but is promising.

[10]https://uwea.com.ua/ua.

3.2 Nuclear Power Generation in Ukraine

A vital issue for the Ukrainian energy sector is the challenge of nuclear power. Ukraine is the third largest European country after France and Slovakia by share of nuclear power in energy mix. Before the invasion, Ukraine generated about 55% of its electricity in 15 nuclear reactors. Moreover, in autumn and winter nuclear generation covered up to 70% of the national electricity generation.[11] The challenge here is that most nuclear reactors have exhausted their operational life (30 years). However, Nuclear Energy Agency (NEA) experts have concluded that if nuclear utilities implement enhanced age management programmes while performing the necessary repairs and replacements, then long-term operation should not face any major generic technical barriers [41].

Nevertheless, Ukraine has a bad historic background being the country affected by the biggest nuclear accident in the world, the Chornobyl (Chernobyl) disaster [42]. So, the country needs both strict international technological control during the operation of its nuclear reactors and research-based decisions on its further operation.

3.3 The Challenges Ukraine Should Overcome

Unfortunately, the energy infrastructure of Ukraine is worn and outdated in general. Almost all power units of thermal power plants are technologically outdated. The power units of nuclear power plants should be decommissioned due to reaching the end of their service life. Electrical networks are experiencing significant deterioration, with some components exhibiting over 70% degradation [1]. All these facilities need to be rebuilt and modernized in the next years in terms of national energy security.

Due to the invasion, 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 the one side, Ukraine will need huge energy resources to restore the national economy and to rebuild the country. On the other side, before the invasion the 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 [43]. And the country should use any postwar economic recovery for a radical technological modernization to make it much more energy efficient.

[11] https://www.energoatom.com.ua.

In turn, it may significantly reduce the national demands on energy resources, including natural gas.

The invasion added new risks and challenges to 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 Russia. Energy infrastructure of Ukraine was significantly affected due to Russian attacks (see, for example, [44]). According to the official data, Ukraine lost about 9 GW of generating capacity (mostly thermal and hydroelectric plants) because of targeted Russian air attacks in spring and summer of 2024 [45]. Ukraine needs not only to urgently restore this capacity, but to provide their protection from future possible attacks. For example, one way to protect the national energy system is due to the construction of distributed generation facilities. Decentralization of small power plants will make the country's power system more resilient [45].

4 Discussion

The EU undoubtedly confirmed its global leadership in sustainable development strategy and global warming overcoming, taking binding obligations to make Europe the first climate-neutral continent. On this way, the EU plans to produce 42.5% (binding target) or 45% (non-binding target) of its total energy mix from renewables in 2030. The Russian aggression against Ukraine in February 2022 became not only a threat for Ukraine's independency, but for European sustainability as a whole. The first and most obvious risks for most European countries from Russian actions were the risks in energy security and challenges of significant dependence on Russian energy supplies. The next months and years have demonstrated that the EU member states successfully overcame the risks of the acute energy crisis.

Ukraine makes great efforts to follow the strategies and policies of the European Union in all the fields of sustainable development. The precise plan for implementation of the EU regulatory principles and norms in Ukrainian legislation was developed in the terms of the Association Agreement between the European Union and Ukraine [46]. The Agreement had a crucial effect on effective transformation of Ukrainian legislation towards European Union norms and social standards [47]. During the last few years, Ukraine has made a significant progress in its sustainable development strategy, see, for example [48]. However, since the invasion there is no doubt that the energy

infrastructure has been significantly damaged causing losses of over $153 billion [49].

In the meantime, the Ukrainian government has presented an ambitious plan for the postwar recovery of Ukraine at the conference in Lugano, Switzerland [50]. According to the plan, the total amount of financing in the next ten years should amount to about $750 billion. In the field of energy security, it is expected to attract about $130 billion from that figure. Among the energy infrastructural projects, there are the construction of hydroelectric power plants and hydroelectric storage power plants, power plants based on renewable energy sources with a capacity of 5–10 GW, completion of two power units of the Khmelnytskyi NPP, modernization of other NPPs, and construction of infrastructure for the production of green hydrogen. It is planned to attract another $150–250 billion to increase the energy efficiency of residential buildings, build new ones and repair damaged buildings.

5 Conclusions

The Russian invasion of Ukraine threatens European values and undermines the European deep development in many ways, including European energy security. A long-term significant dependence of most European countries, including Ukraine, on Russian energy resources is a significant risk, which the EU should overcome as soon as possible. The EU's strategy on a total replacement of Russian natural gas, acceleration of renewables' installation, and energy saving/energy efficiency strengthen European energy security in middle and long terms, is the key thrust at the moment. Ukraine has a significant potential within the energy sector, e.g., developed infrastructure for natural gas transportation and storage, great opportunities in biogas / biomethane production, and significant electricity production due to nuclear power generation. All these aspects may be effectively used for long-term mutually beneficial collaboration of Ukraine and the EU.

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