Ecological disasters as a result of cyber attacks in the energy sector

Alina Prokopieva[1,*,†], Lesya Pobochenko[1,†], Tetiana Smirnova[1,†], Inna Nabok[1,†], Natalia Tatarenko[1,†] and Kateryna Sydorenko[1,†]

[1] *National Aviation University, Liubomyra Huzara Ave. 1, Kyiv, 03058, Ukraine*

Abstract

The increasing reliance on digital infrastructure in the energy sector has made it vulnerable to cyber attacks, with potential far-reaching consequences. This article explores the link between cyber attacks and ecological disasters in the energy industry. The article discusses the ecological aspects of ensuring Ukraine's energy security. The author emphasizes the importance of reducing emissions into the atmosphere and developing renewable energy to ensure sustainable and safe operation of the country's energy sector. The development of research and innovation, environmental impact control, and infrastructure development support are also key aspects of achieving this goal. Ukraine has significant potential for the development of renewable energy, which can become an additional source of income for the local population and contribute to the country's economic development. The article notes that reducing dependence on imported energy resources is a key aspect of ensuring the country's energy security. Developing its own energy resources and diversifying their types can significantly reduce risks to the economy and national security. The article emphasizes the need to increase energy efficiency and implement energy-saving technologies as one of the key means of ensuring energy security. Energy efficiency is an important component of economic efficiency and ensures the environmental friendliness of production. Overall, the article reflects the importance of smart and sustainable development of Ukraine's energy sector, taking into account environmental aspects. The development of renewable energy and energy-efficient technologies can help reduce dependence on imports and ensure the safety and sustainability of the country's economic development while reducing its impact on the environment. The article highlights the problems that stand in the way of achieving this goal. In particular, this includes a high dependence on coal energy and an outdated energy sector infrastructure. The author notes that these problems can be addressed through the development of renewable energy and infrastructure modernization, which requires significant investment and state support. Other problems mentioned in the article include corruption schemes, inadequate legal framework, and insufficient attention to environmental impact. The author calls for the implementation of effective measures to address these issues and create conditions for the sustainable development of the country's energy sector. The work is a theoretical study of the ecological aspects of ensuring energy security. The article discusses the experience of European Union countries in using renewable energy sources as a more environmentally friendly and safer means to ensure the energy security of the state.

Keywords

ecology, ecological disasters, vulnerabilities, critical infrastructure, power grids, cybersecurity measures, renewable energy, environmental contamination, ransomware, mitigation strategies

1. Introduction

The series of shocks in 2022, including the war in Ukraine, created favorable conditions for the increased activity of numerous cybercriminals. For months, perpetrators targeted government institutions, hospitals, cryptocurrency companies, industrial enterprises, critical infrastructure

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* Corresponding author.

† These authors contributed equally.

prokopieva.alina@npp.nau.edu.ua (A. Prokopieva); lesia.pobochenko@npp.nau.edu.ua (L. Pobochenko); t.smirn@gmail.com (T. Smirnova); inna.nabok@npp.nau.edu.ua (I. Nabok); tatarenko.natalia@npp.nau.edu.ua (N. Tatarenko); kateryna.sydorenko@npp.nau.edu.ua (K. Sydorenko)

0000-001-6745-0485 (A. Prokopieva); 0000-0002-3094-6417 (L. Pobochenko); 0000-0001-6896-0612 (T. Smirnova); 0000-0002-3640-9823 (I. Nabok); 0000-0002-8811-3012 (N. Tatarenko); 0000-0003-3231-2247 (K. Sydorenko)

entities, and many other organizations. The cost of data breaches escalated to 4.4 million US dollars, and the success achieved will likely spur cybercriminals to even greater activity in 2023 [1, 2].

The critical infrastructure of Ukraine once again fell victim to cybercriminals, particularly during the initial stages of the extensive Russian invasion. ESET researchers collaborated closely with CERT-UA to counter an attack aimed at the country's energy supply system, utilizing malicious software designed for information destruction.

The threat was orchestrated by the cybercriminal group Sandworm, attempting to deploy the malware, Industroyer2, on high-voltage electrical substations. Named after a threat previously used to cut off electricity in Ukraine in 2016, this time, the program was combined with a new version of the CaddyWiper threat to obliterate information. This tactic likely aimed to conceal the group's traces, delaying response and recovery efforts for energy company operators [3, 4].

CaddyWiper was not the sole tool for data destruction identified in Ukraine just before or in the early weeks of the Russian invasion. On February 23, 2022, ESET telemetry detected another threat with similar functionality named HermeticWiper on hundreds of machines across multiple organizations in Ukraine. The following day witnessed a second destructive attack on the Ukrainian government network using IsaacWiper, emphasizing the intensification of information destruction threats.

Approximately an hour before the Russian invasion, a massive cyber attack targeted the commercial satellite provider Viasat, causing disruptions in Internet access for thousands of people in Ukraine and even in other European countries. The attack, using a misconfigured VPN device to access the satellite network's management section, was believed to have aimed at impairing the communication capabilities of the Ukrainian command in the initial hours of the invasion. However, its repercussions extended well beyond Ukraine's borders.

Russian hackers have invested significant efforts in disrupting the normal operations of critical infrastructure in Ukraine, particularly in the energy and financial sectors, as well as in the provision of government services.

According to the State Special Communications Service and Information Protection of Ukraine, which regularly provides data in response to inquiries, occupiers made nearly 800 attempts to infiltrate Ukrainian networks during the first four months of the full-scale war. The primary targets of these attacks were government and local authorities, the security and defense sector, the financial industry, commercial organizations, and the energy sector. Cybercriminals also inflicted damage on transportation infrastructure and telecommunications. Notably, on June 6, 2023, a cyber attack occurred during the sabotage of the Kakhovska Hydroelectric Power Station, resulting in a global environmental catastrophe in Europe.

Ukraine, like many other countries in the world, constantly faces challenges related to energy security. One important aspect of ensuring this security is the environmental impact. Climate change, air and water pollution, soil contamination, and their impact on human and animal health are just a few of the problems that arise from energy production and consumption.

One of the main environmental security problems in the energy sector is the use of coal as a fuel. Ukraine has significant reserves of coal and other minerals, but its use is accompanied by air and water pollution, which has a negative impact on human health and the environment. One way to reduce the impact of coal-based energy is to transition to alternative sources such as wind and solar power.

Furthermore, energy efficiency is an important element of ensuring environmental security in the energy sector. Ukraine has significant potential for reducing energy costs by increasing efficiency in construction, industry, and transportation. It is also important to consider energy efficiency in the development and implementation of new technologies and equipment.

Another environmental aspect of ensuring energy security is protecting biodiversity and preserving ecosystems. The development of the energy sector can have a negative impact on natural ecosystems and biodiversity, so it is important to consider these aspects in the planning and development of energy projects.

Overall, ensuring environmental security in the energy sector is an important component of ensuring energy security in Ukraine as a whole. The development of ecological energy in your article can help reduce the negative impact of the energy sector on the environment and increase the level of energy security. The National Strategy for Energy Efficiency and Renewable Energy Development until 2035, approved in 2019, identifies the main directions for the development of ecological energy in Ukraine and contains specific goals and tasks for ensuring the sustainable development of the energy sector.

Among the numerous crises that have caused instability in the world in 2022, special attention is focused on the energy and environmental crisis. Due to high prices and supply problems caused by the cooling of relations with Russia, energy security is at the top of the agenda for leading countries worldwide. Environmental hazards are also a major concern as they pose a serious threat to human life and health [5].

At the same time, governments of most countries are increasingly recognizing the growing role of renewable energy sources in ensuring energy and environmental security. The Russian aggression against Ukraine has led to an unprecedented global energy crisis. To protect consumers from rising energy prices, many countries are attempting to reduce their dependence on Russian energy resources by implementing a policy of accelerated transition to carbon-free technologies.

Transitioning to renewable energy sources provides significant potential for reducing prices and dependence on fossil fuels in both the short and long term.

2. Related paper analysis

This work is a theoretical study of the ecological aspects of ensuring energy security. An analysis of recent research and publications shows that until recently, only the peculiarities of ensuring energy security and environmental safety at the level of individual states were considered in scientific research. Researchers such as V. Barannik, S. Bevz, Y. Bobrov, M. Brown, D. Voloshin, H. de Vries, D. van Vuren, I. Haydutskyi, I. Haliuk, M. Hnatiuk, G. Grenenberg, K. Denchev, G. Jewell, D. Jonsson, O. Dzioba, Y. Dzyadykevych, L. Yefimtseva, O. Zakrevskyi, I. Zaremba, M. Zemlyanyi, B. Johannsson, O. Kalinichenko, O. Kyrylenko, Y. Kolesnyk, Y. Kryzhanivskyi, B. Kruit, V. Ksyonzhenko, A. Lesiuk, V. Loiko, K. Markevych, O. Melnychenko, A. Mensson, V. Mykytenko, O. Mykolyuk, V. Omelchenko, F. Orekhchyni, A. Prokip, O. Romashko, V. Saprikin, V. Svitlychna, A. Sukhorukov, V. Rubanka, B. Sovakul, N. Stuchynska, I. Khilchevska, A. Cherp, I. Shvedziak-Bork, A. Shevtsov, and B. Yanishen have paid increased attention to national energy and environmental security issues [6–13].

The identification of previously unresolved parts of the general problem is also evident. Issues related to increasing energy efficiency do not address environmental aspects. Despite the importance of ensuring the environmental component of enterprise energy security, there is no consensus among theorists and practitioners today regarding its essence. Most scientific papers focus on ensuring the energy security of the state and the separate ecological component. Moreover, there are currently no comprehensive methodologies for assessing the energy and environmental security of the state. Accordingly, many issues related to ensuring the environmental component of the state's energy security, both theoretical and applied, remain unresolved.

3. Concept problems

Energy security and ecological security are interrelated aspects, as the energy sector is one of the most polluting sectors of the economy. The main conceptual problem is that ensuring energy security is often given priority over ecological security, which leads to negative consequences for the environment, human health, and the economy as a whole.

Another conceptual problem is the lack of a unified terminology and methodology for assessing the ecological component of energy security. Many studies are devoted to ensuring the energy security of a country and its individual components, but insufficient attention is paid to assessing

the impact on the environment. It is important to address this issue to ensure sustainable development and preservation of natural resources for future generations.

Additionally, one of the conceptual problems is the lack of interaction between different sectors of the economy related to energy. For example, energy conservation issues in construction, transportation, and industry should be considered together with energy policy. Such interaction can lead to a reduction in energy consumption and a reduction in emissions of harmful substances into the atmosphere.

Moreover, the lack of comprehensive methodologies for assessing the ecological component of a country's energy security complicates the determination of its level and the development of effective measures to improve the ecological security of the energy system. It is necessary to develop new methods and tools for assessing the ecological component of energy security, which would take into account not only the impact of energy technologies on the environment but also their social and economic efficiency. The article discusses the experience of European Union countries in using renewable energy sources as a more environmentally friendly and safer means to ensure the energy security of the state.

Another conceptual problem of the ecological aspects of energy security is the need to ensure effective cooperation between different sectors of the economy, namely energy, transportation, industry, agriculture, and others.

In particular, the issue of reducing emissions of harmful substances into the air requires coordination of efforts between different sectors of the economy. For example, the development of public transport and the use of environmentally friendly fuels can significantly reduce emissions from the transportation sector. Similarly, the use of renewable energy sources can reduce emissions from the energy sector.

In conclusion, ensuring energy security and ecological security are interconnected and should be addressed together. It is essential to develop comprehensive methodologies and tools for assessing the ecological component of energy security, as well as to promote effective cooperation between different sectors of the economy to reduce emissions of harmful substances and achieve sustainable development.

4. Results

The concept of sustainable development involves meeting human needs while preserving natural resources and ecosystem services for future generations. This means that society should have access to resources that do not destroy natural systems and maintain their integrity and stability. In 1987, the Brundtland Report defined sustainable development as a process that meets the needs of the present without compromising the ability of future generations to meet their own needs. Today, sustainable development aims at economic and social development, as well as environmental protection for future generations. The Sustainable Development Goals (SDGs), adopted by the United Nations General Assembly in 2015, contain 17 goals that address global issues such as poverty, inequality, climate change, and environmental degradation. The concept of sustainable development is related to the concept of sustainability, which describes many ways to achieve a more sustainable world in the future.

Sustainable development requires six key abilities, namely:

1. Integrated thinking: this means understanding the interdependence between the economy, social issues, and the environment, and solving problems while maintaining this balance.

2. Risk management: it is necessary to know the risks that may arise from our actions and develop strategies to prevent their occurrence and mitigate their consequences.

3. Innovation: it is necessary to develop new technologies and approaches that allow solving environmental and social problems while ensuring economic development.

4. Ecological thinking: it is necessary to know how our actions affect the environment and act in such a way as to reduce the negative impact.

5. Global thinking: it is necessary to take into account the global consequences of our actions and interact with other countries and organizations to achieve common sustainable development goals.

6. Social justice: it is necessary to ensure equal opportunities and share the benefits of economic development among all population groups to ensure social stability and harmony.

They are all listed in Figure 1.

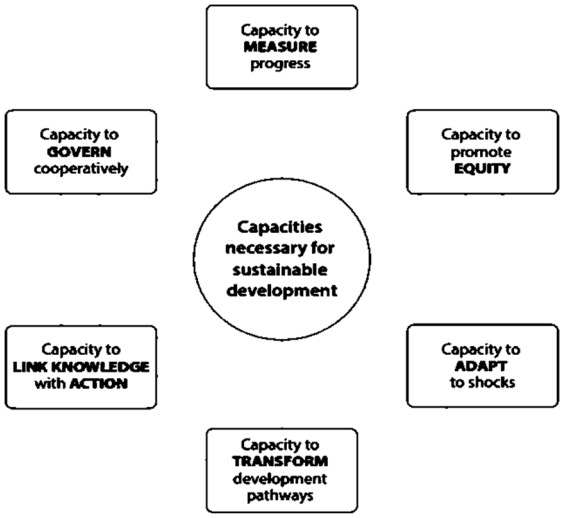

Figure 1: Sustainable development requires six central capacities [1].

It is the concept of sustainable development that emphasizes the importance of the environmental component in combination with economic development, which is not possible without the energy component.

The concept of sustainable development encompasses economic, social, and ecological aspects. To ensure sustainable development, it is necessary to consider various characteristics such as per capita gross domestic product, employment, poverty, disease, and life expectancy. Ecological factors, such as the quality of food and drinking water, air cleanliness, and contact with nature, play an important role in meeting physiological and social needs of humans. However, the ecological functions of nature are also important in their own right and should be considered separately in the context of sustainable development [14, 15].

Thus, the problem of ensuring sustainable development of society lies in the plane of three basic spheres: social, economic, and ecological (Figure 2).

The more effectively each of the mentioned functions is performed, the more effective the activity of the entire system, and the higher the possibility of the system accumulating "free energy". Efficiency in this case can be determined by the ratio of the amount of energy used directly to implement a given function and the total energy costs. This is a kind of energy efficiency coefficient (EEC). In turn, the efficiency of the system and its subsystems will be higher, the lower the energy losses (dissipation) are.

One of the main goals of the concept of sustainable development is to preserve the state of the environment at the maximum possible level, which exists today for future generations. For a long time, natural resource use was carried out by human society in an irrational manner. Nowadays, the global community has realized that ensuring sustainable socio-economic development is impossible without rational consumption, preservation, and maintenance of vital ecological processes. The end of the era of cheap raw materials and free consumption of natural resources has led to increased costs in mining and processing industries, increased costs for the implementation of purification technologies, and the adoption of nature conservation and natural restoration measures. Based on the above, the ecological factor can be defined as a system of specialized types of labor activity and expenses aimed at rational use of natural resources, environmental protection, and its restoration.

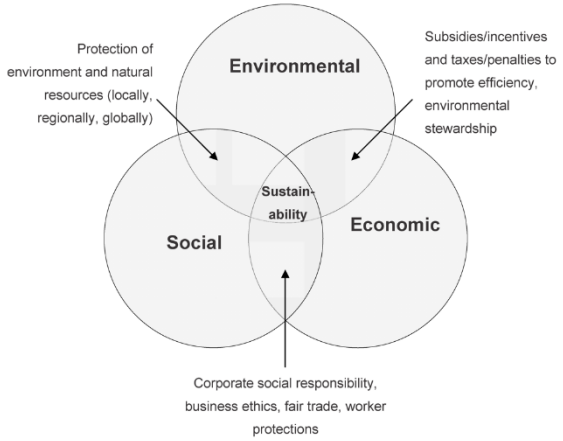

Figure 2: The main components of sustainable development concept [2].

In addition to implementing resource-efficient technologies, an important step in realizing the concept of sustainable development is the application of treatment systems by companies for water, air, soil, and other natural resources that are affected by harmful production processes.

The second important component of the concept of sustainable development is the resource component. Companies use a large amount of various resources, which can be divided into renewable and non-renewable - this is a part of natural resources that do not self-renew in the process of material circulation in the biosphere or renew hundreds and thousands of times slower than they are used (coal, oil, most other minerals, many sedimentary rocks, species composition of organisms). Special attention should be paid to those resources that cannot be renewed, and it is necessary to seek substitutes for these resources that have the ability to regenerate. In the case where there is no such analogue, it is necessary to seek the most efficient technologies for using such resources in order to preserve them for future generations.

According to the United Nations Global Compact (a voluntary international initiative that brings together companies with UN agencies, labor, and civil society to support universal social and environmental principles), three of the ten principles relate to the environment:

Principle 7: Businesses should support a precautionary approach to environmental protection.

Principle 8: Businesses should undertake initiatives to promote greater environmental responsibility.

Principle 9: Businesses should encourage the development and diffusion of environmentally friendly technologies.

We believe that adopting principles of corporate social responsibility not only benefits society, but also helps companies improve their reputation, increase competitiveness, and enhance risk management systems. It is necessary to establish partnerships between government and local self-government bodies, science, education, business, and civil society organizations to improve the state of the environment.

Priorities of the partnership include:

- integrating the environmental component into industry and regional strategies and programs;
- creating eco-economic conditions for balanced development;
- shaping environmental awareness and worldview of the population of Ukraine based on the principles of balanced development;
- preserving biodiversity and ecosystems;
- creating conditions for the reproduction of natural resources;
- guaranteeing environmental safety for the health and lives of the population;
- expanding public participation in the formation and implementation of state environmental policy.

Ukraine has not yet approved a Sustainable Development Strategy, although national and regional consultations on the draft Strategy for Sustainable Development until 2030 were held in Ukraine during June-December 2016. These consultations involved representatives of government bodies, local self-government, scientists, educators, representatives of civil society organizations, professional associations, business, media, and experts from international organizations.

The goal of the strategy is to achieve integrated economic, social, and environmental development in Ukraine by 2030. The National Action Plan (roadmap) will be approved after the adoption of the Strategy.

The Strategy establishes a comprehensive system of strategic and operational objectives for achieving the goal, defines institutional principles, directions for inter-industry and inter-sectoral cooperation, key driving forces, and tools for its implementation. Target indicators are indicated for three stages of the Strategy implementation: 2017-2020, 2021-2025, 2026-2030.

In the Sustainable Development Strategy, the innovative direction of development is key, based on active use of knowledge and scientific achievements, stimulation of innovative activities and creation of a favorable investment climate. In addition, there is a renewal of production assets, formation of high-tech types of activities and sectors of the economy, increased energy efficiency of production, stimulation of balanced economic growth based on attracting investments in the use of renewable energy sources and environmentally safe production, as well as the use of "green" technologies.

Economic growth will no longer be associated with the exploitation of natural resources but rather with the widespread adoption of "green" economic models. Waste accumulated in the past will gradually be recycled and disposed of, leading to a reduction in the scale and elimination of a significant number of landfills. Export will shift from raw materials and their primary processing products to products with a high added value.

Significant reductions in energy intensity of gross domestic product will be achieved through energy-saving measures and the application of energy-efficient practices. The proportion of ecologically clean energy production will inevitably increase, replacing traditional carbon technologies. This will significantly reduce greenhouse gas emissions and other pollutants into the atmosphere, contributing to the fight against climate change. All of these will contribute to the improvement of the quality of the environment and the health of the population.

Sustainable development is primarily focused on improving the quality of life in a favorable socio-economic environment, with an ecologically clean, healthy, and diverse natural environment. The high intellectual level of human potential should ensure the country's competitiveness in the future.

One of the main objectives of the Strategy is to promote the implementation of projects for the recovery of the economy in the regions of Ukraine affected by the hostilities, based on innovative industrial development that utilizes environmentally friendly, resource- and energy-saving technologies, renewable energy sources, and non-material natural resource management and also to create a national infrastructure of geospatial data on the impact of industrial enterprises on the environment (registers of emissions, discharges, and transfer of pollutants).

One of the operational goals defined in the Strategy is to ensure access to economically viable, reliable, and low-carbon sources of energy for all, as well as to improve energy efficiency.

The Strategy outlines several key objectives for achieving the operational goal of ensuring access to economically feasible, reliable, and low-carbon energy sources for everyone, as well as improving energy efficiency. By 2030, the aim is to increase the share of energy produced from renewable sources in Ukraine's total final energy consumption to 17.1% and redirect subsidies for fossil fuels to programs supporting renewable energy production, energy conservation, and energy efficiency.

The Strategy also includes the activation of international cooperation to attract investments for the development of infrastructure and technologies for producing clean energy, as well as ensuring the creation of infrastructure and accumulation of resources needed for decommissioning Ukrainian nuclear power plants. Moreover, it aims to modernize existing nuclear power plant units to enhance and maintain ecological and radiation safety in line with international standards.

One of the key strategic goals of the Strategy is to achieve a balance between production and consumption, efficient use of natural resources, and enhancing resilience to climate change by taking necessary measures.

Regarding environmental safety, measures will be taken to eliminate the most hazardous storage facilities for toxic waste, reduce the volume of their formation, and prevent their illegal disposal.

By 2030, legislative acts will be developed for handling the slags and slimes of the fuel and energy complex and metallurgical enterprises, which can be used as a substitute for natural materials. Stimulating the processing and use of large-scale enterprise waste (such as ash and slag waste, rock, etc.) will be ensured.

Let's look at the experience of the European Union countries in using renewable energy sources, which are more environmentally friendly and relevant for the military economy of Ukraine.

Reducing the use of fossil fuels through the use of renewable energy sources such as wind turbines, solar panels, and other technologies for electricity production has become a key goal of the energy policies of the European Union countries. Increased use of renewable energy sources has countless advantages for society, such as mitigating the effects of climate change, reducing emissions of pollutants into the atmosphere, and improving energy security. The EU aims to ensure that by 2020, 20% of gross final energy consumption comes from renewable sources, and by 2030, this share will increase to 32%.

The technology of renewable energy is not new and has firmly established itself in Europe. Denmark installed the world's first offshore wind farm "Vindeby" in 1991, which included 11 wind turbines. That same year, Germany introduced Europe's first "green tariff" for renewable energy sources, a political mechanism designed to accelerate investment in renewable energy technologies.

Since 1985, the supranational influence of the EU on energy issues has steadily increased as the EU's environmental and competitive policies have become more established and widespread. These efforts can be placed in the hierarchy of restructuring energy sector flows (Figure 3).

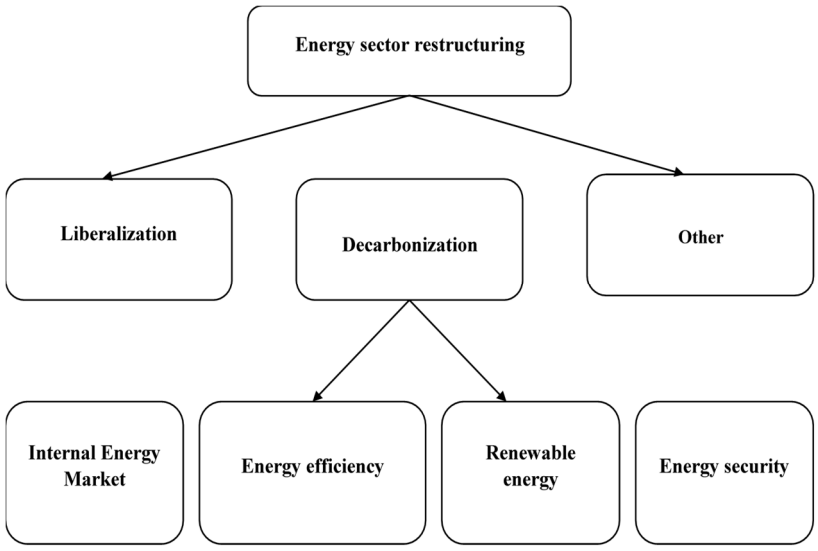

Figure 3: Hierarchy of energy sector restructuring flows in the EU [3].

Since the beginning of 1985, the influence of the EU on the energy sector has become increasingly noticeable as the EU actively developed an ecological and competitive policy. This contributed to the restructuring of the energy sector, which can be represented in the form of a hierarchy of flows (Figure 3). By 2000, over 70% of all wind energy installed in the world and 20% of global solar photovoltaic installations were in Europe. In 2000, the first large-scale wind farm "Horns Rev" was launched in Denmark, which used technologies that later became industrial standards for offshore wind installations.

Europe also became the largest market for solar photovoltaic energy, covering over 70% of the market by 2008. In the same year, the Olmedilla photovoltaic power station with a capacity of 60 megawatts was launched in Spain, making it the largest in the world. This station provides enough solar energy to power 40,000 homes per year [16, 17].

Europe remains a leader in the use of renewable energy sources, as the rest of the world also increasingly uses them. In July 2019, Portugal achieved the lowest cost of a solar photovoltaic park in the world - a record that still stands today [16].

Since 2010, the world has witnessed a significant shift in the competitiveness of renewable energy production options. The global weighted average normalized cost of electricity (LCOE) for newly commissioned large-scale solar photovoltaic projects has decreased by 88% between 2010 and 2021, while concentrated solar power (CSP) has decreased by 67% and offshore wind by 60%.

It is predicted that the growth of renewable energy capacity will accelerate over the next five years, accounting for nearly 95% of the global increase in electricity capacity by 2026. Between 2020 and 2026, renewable energy capacity is expected to increase by over 60% and reach over 4,800 GW. This is equivalent to the current global capacity of fossil fuel and nuclear energy combined.

According to the forecast, China will remain the leader for the next five years, accounting for 43% of global renewable energy capacity growth, followed by Europe, the United States, and India. These four markets account for 80% of the world's renewable energy capacity expansion. A significant advantage is that 25% of Europe's electricity can come from offshore sources by 2050.

The term "offshore renewable energy technologies" includes several clean energy technologies that are at various stages of development.

To harness the potential of renewable energy, the European Union is exploring various innovative technologies for offshore power generation. Some of these technologies include stationary wind turbines, which are more efficient than onshore wind generators, floating wind turbines that are more flexible in adapting to wind direction and different ocean basins, and technologies for transmitting large volumes of marine renewable energy to the mainland through high-voltage direct current converters. Other technologies being researched include wave energy, tidal energy, floating solar power, and algae as a source of biofuels.

The European strategy also aims to address the entire chain of offshore wind energy, including the production process of wind turbines and the development of port infrastructure.

The EU has the largest maritime territory in the world. Thanks to the diversity and complementarity of its maritime basins, it has unique opportunities for the development of renewable energy at sea.

The North Sea, the Baltic Sea, the waters of the Atlantic Ocean in the EU, the Mediterranean Sea, the Black Sea, EU islands, as well as many European outermost regions and overseas countries and territories have natural potential for hosting various renewable technologies. According to this European strategy, EU countries will allocate 3% of available maritime space to achieve energy goals [17]. The energy balances of each EU member state are largely dependent on its geographical location, energy policy, structure of its energy system, availability of energy resources for primary production, and the structure and development of its economy. As a result, there are significant differences between countries in the use of fossil fuels, renewable energy sources, energy intensity, and CO2 emissions. Due to centuries of industrial development, fossil fuels have significant structural advantages that make them more mature than sustainable alternatives such as wind, solar, and biogas energy. Additionally, fossil fuel resources are still generally sufficient, and the price of non-eco-friendly energy remains much lower than most renewable energy sources [18].

Despite the fact that costs for electricity production using renewable energy infrastructure are decreasing, costs per unit remain higher than in traditional production because costs are spread over a smaller production volume.

The rise in prices for goods, energy, and transportation leads to an increase in production and transportation costs for solar photovoltaic modules, wind turbines, and biofuels worldwide. Since the beginning of 2020, prices for polycrystalline photovoltaic cells have increased by more than four times, steel by 50%, aluminum by 80%, copper by 60%, and transportation fees have increased by six

times. Compared to commodity prices in 2019, investment costs for solar photovoltaic and offshore wind installations are 25% higher. In addition, restrictive trade measures have led to further price increases for solar photovoltaic modules and wind turbines in key markets such as the United States, India, and the European Union [19].

There are four primary mechanisms that governments use to encourage the deployment of renewable energy: preferential tariffs, tax incentives, tradable green certificates, and investment subsidies. The European Union Emissions Trading Scheme (ETS) was introduced in 2005 to address the shortcomings of the market by creating a market for greenhouse gas emissions allowances, thus establishing a price for carbon emissions that reflects the negative externalities associated with electricity generation from fossil fuels, as well as manufacturing and polluting industries such as cement, aluminum, and steel.

However, the generous allocation of pollution certificates has significantly reduced the effective incentive to transition to more environmentally-friendly production in the long run. Carbon prices have more than doubled since the beginning of 2021, reaching a peak of €74.12 per tonne on November 25th after world leaders signed a new agreement aimed at reducing the use of fossil fuels. To support the deployment of renewable energy sources, each member state has implemented a combination of various policy instruments relating to regulatory policy and fiscal incentives, as well as government funding. For example, at the beginning of the 2000s, most European Union countries created a guaranteed purchase price mechanism aimed at promoting the development of renewable energy. While preferential tariffs and bonuses are the main support schemes for the implementation of renewable energy technologies in the electricity sector, it is increasingly recognized that a combination of policy instruments is necessary to promote the carbon transition. Moreover, these instruments may change significantly over time and vary according to different national goals and stages of a country's innovation activity [18].

Under the current structure of competitive electricity markets, renewable energy may still require incentives in the form of subsidies, as low working hours and interruptions mean that it will not receive sufficient revenue at market prices. No method of providing incentives for renewable energy, including cost-based approaches, market-based approaches such as auctions, can guarantee economic efficiency. The uncertain availability of renewable energy imposes costs on network operators and dispatched generators, which are difficult to allocate correctly under a liberalized electricity market model.

The EU's historical policy of promoting renewable energy through incentives has proven effective in ensuring capacity and productivity, but it may have been inefficient in terms of costs and may have provided excessively high profits for investors. Subsidies and incentives were not calibrated to determine what constitutes a "sufficient" rate of return for attracting investments. Additionally, the complexity and opacity in developing renewable energy support schemes increased costs, promoted inefficiency, and may have facilitated abuses.

In addition to direct expenditures on subsidizing renewable energy, its intermittency has led to indirect costs on dispatchable generators, as they were forced to reduce output to accommodate electricity from wind turbines and solar photovoltaic (PV) energy. The impact of unused capacity and the use of capacity as backup for renewable energy sources has called into question the viability of the current structure of liberalized electricity trading markets and has led to new calls for reform of ancillary services, capacity payments, and affordability. The EU's experience in stimulating renewable energy indicates the need to overhaul markets to improve both short-term metrics and ensure the adequacy of long-term investments.

The experience of the EU in promoting renewable energy has also revealed shortcomings in achieving national goals. Europe has promoted the integration of energy markets to rationalize capacities and ensure that flows correspond to prices, but the fragmented design of incentives for renewable energy at the country level has led to inefficiencies and suboptimal investment models compared to what could have been achieved through incentives throughout the EU. It is clear that there is an opportunity to learn from the EU experience to develop new policies that balance the needs for economic efficiency of renewable energy sources.

Decisions regarding the type of renewable energy production, stimulating specific solutions, or allowing market forces to direct capital have also formed the choice of support schemes. In France, tariffs and surcharges for renewable energy were adapted to specific locations, sizes, technologies, and uses. When choosing schemes, policies also weighed restrictions on the size and number of projects.

Currently, most jobs in the energy sector in the EU are related to traditional energy sources such as oil, gas, coal, and nuclear power. However, clean energy technologies are becoming a dynamic area for investment and employment, leading to new jobs in related sectors such as construction and manufacturing.

Some sectors and regions in the EU will need time to transition to new renewable energy sources and to transfer skills where possible. This is already happening in coal regions in the EU. The European Commission has initiatives to help and support a fair transition for coal regions, both in the EU and in the Western Balkans and Ukraine, on their path to decarbonization.

Thanks to the EU's long-term goal of climate neutrality and reducing dependence on imported fuels, the renewable energy sector in the EU will inevitably develop much faster than initially planned. In 2020, the turnover of the renewable energy sector in EU-27 countries amounted to approximately 163 billion euros, which represents a gross increase of around 13.7 billion euros compared to 2019 (+9.2%) [16].

Therefore, the EU must continue its efforts to ensure leadership in the fight against global warming, but it will face various obstacles. In the context of huge state debts and high levels of uncertainty in energy prices caused by the COVID-19 pandemic, the development of energy transition and renewable energy sources may be at risk in the short term. Mobilizing both public and private investments will be important for achieving climate change goals.

On the other hand, the COVID-19 crisis has highlighted the need for a shift in production systems, which could accelerate the decentralization of national energy systems and thus promote the development of local renewable energy sources. Additionally, the EU must prevent the negative impact of its environmental policy on firms' competitiveness and the energy vulnerability of low-income households.

Overall, the use of renewable energy sources has many significant benefits for the EU, including reducing greenhouse gas emissions, diversifying energy sources, and reducing dependence on fossil fuel markets (particularly oil and gas). The growth of the renewable energy market can also stimulate employment in the EU by creating jobs in new "green" technologies.

The high share of fossil fuels in the energy balance is a burden not only in terms of greenhouse gas emissions, but also in terms of supply security. With limited and depleted resources, the EU has extremely high dependency rates: 95% for oil (relatively stable) and 85% for gas (increased by 15% over the past decade). Recent crises (COVID-19, sharp increases in gas and electricity prices in 2021, Russian-Ukrainian war in 2022) are a harsh reminder that long-term climate goals cannot be achieved without parallel solutions to energy security and affordability issues. In 2019, prior to the COVID-19 crisis, oil was the most consumed energy source in the EU, accounting for one third of the total energy consumption, followed by gas (24% of total consumption).

Globally, similar shares can be observed for oil and gas consumption. The main difference comes from the lower dependence on coal in the EU (13% share in the EU compared to 27% worldwide) with the gradual phase-out of coal since 2015. This is balanced by a higher share of nuclear energy in the EU compared to the rest of the world (14% versus 5%).

Transportation, specifically road transport, accounts for 70% and 60% of final oil consumption in the EU. The pandemic had a profound impact on the transportation sector due to lockdowns and remote work, which somewhat reduced freight transport and aviation by implementing strict preventive measures. In 2021, the overall demand for oil in the EU recovered by 5% (after an 8% drop in 2020) mainly due to the economic recovery (GDP grew by 5.3% in 2021 compared to a 5.9% decline in 2020) [20] (Figure 4)?

The Ukrainian crisis has exacerbated the explosion of natural gas prices and added a supply security crisis. Of the more than 150 billion cubic meters, Russian imports account for nearly 40% of

the total annual natural gas imports, which is roughly equivalent to the gas consumption in the EU energy sector. Uncertainty regarding the role of natural gas in the EU energy system has increased, as natural gas was labeled a transitional fuel in the EU taxonomy in early February, and shortly after, the European Commission presented options for reducing dependence on Russian imports and natural gas in general in its REPowerEU plan.

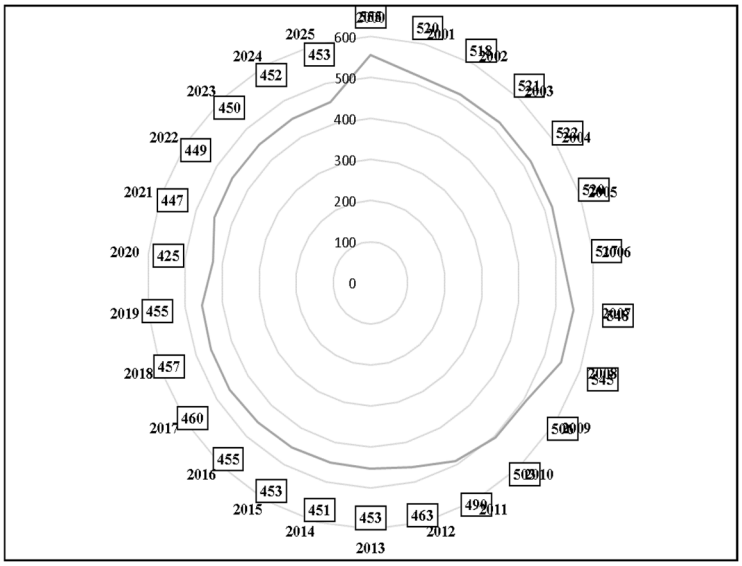

Figure 4: Oil consumption in EU countries from 2019 to 2021 and forecast of oil consumption in the EU for the years 2022-2025, in million tons of oil equivalent [20].

The main challenges associated with natural gas, stemming from the recent crisis and the energy transition, lie in the EU's energy sector. Gas-fired power plants, which account for about 20% of electricity generation, play a key role in the electricity structure and offer flexibility for grid balancing. This is a dispatch technology with relatively high short-term marginal costs. The main factors affecting natural gas power generation in the short term depend on the overall balance of electricity demand/supply and relative competitiveness with other dispatch technologies.

Recent crises have impacted several factors, leading to a decrease in natural gas-based electricity production in both 2020 and 2021. In 2020, this decline was a direct result of the pandemic, which affected the global economy and demand for electricity. In 2021, it was mainly due to a shift towards coal-based electricity production as gas-fired power plants became less competitive with the sharp rise in natural gas prices, despite a weaker wind power capacity and economic recovery. The Ukrainian crisis has intensified the pressure on natural gas prices, and future gas prices suggest that this situation may persist beyond 2024 [20].

The energy crisis calls for a coordinated, inclusive, and harmonized global energy management to ensure fully functioning global markets and accessible energy during the "green transition for all." In 2008, when oil prices were very high, the EU convened an international conference of suppliers and buyers. Increased international coordination will not automatically lead to lower gas prices, but collective action by the world can help calm speculative markets [21].

Decarbonizing economies is a key task for the EU and humanity. This will be the defining challenge of the 21st century, the key or the turning point for the future of humanity. Globally, the main challenge will be to provide enough energy for the entire population, which currently consumes very limited or no energy while combating climate change. In 2019, 759 million people still lived without electricity. This delicate process must be precisely tuned to avoid short-term shocks with brutal price increases that could derail the entire energy transition in the EU. Foreign and security policy can also contribute to achieving long- and short-term goals.

The EU began 2022 with the Russian-Ukrainian war, which greatly affected energy markets. Oil prices are reaching record highs, and overall, the surge in energy prices that began in 2021 is a key

factor pushing inflation to unprecedented levels in the last decade. The consequences for economic activity and purchasing power will limit or dampen the growth of oil demand in 2022. From a supply security perspective, the Ukrainian crisis and dependence on Russian oil imports have limited impact (especially compared to gas) on the EU due to the liquid and global nature of the oil market.

The war in Ukraine in 2022 has prompted many countries to rely more on fossil fuels in the short term, while promising to phase them out more quickly in the future. Currently, the energy crisis, global wave of droughts, steep price increases, supply chain disruptions, and concerns about an economic downturn threaten to delay long-term commitments to transition to lower-emissions energy sourcesНачало формы

Supporters of green energy argue that the war in Ukraine and high fuel prices could help accelerate the transition on the continent by forcing a painful abandonment of oil and gas and changing consumer habits that might otherwise remain entrenched [22]. The "green transition" package includes measures that directly relate to oil consumption and automotive transport, such as developing a new emissions trading system for buildings and automotive transport, developing infrastructure for alternative fuels, and banning cars and vans with internal combustion engines by 2035. Recent crises underscore the need for the EU to reduce its dependence on fossil fuel imports, and among the measures taken to combat high energy prices and dependence on Russian oil and gas, only some have a direct positive impact on the energy transition [23].

At the same time, most member states have introduced short-term measures to protect consumers from the direct impact of rising prices. In the case of oil and gas, this can be seen as direct support or subsidies for fossil fuels, which could delay the transition to alternative fuels.

Reducing energy consumption and improving energy efficiency are recognized priorities of the green economy in line with European and global requirements for sustainable development. However, there are ongoing discussions regarding the identification of factors that contribute to changes in energy consumption (energy conservation), which are also prerequisites for recognizing the composition of instruments in the approach to measuring their effectiveness. Identifying relevant factors that influence energy consumption is strategically important for regions and sectors [24].

Based on current research among individual consumers, the following factors can be identified as affecting energy consumption: economic and financial conditions, socio-demographic conditions, physical characteristics of housing, location of the apartment, environmental and climatic conditions, as well as fees for energy use.

In May 2022, the European Commission proposed to increase its already ambitious target for the use of renewable energy sources from 40% to 45% of the electricity balance block by 2030. This includes plans to more than double the solar capacity of the block by 2025 [25].

To achieve all of this, Europe needs to roughly double the current level of investment in renewable energy to around €66 billion per year. This, in turn, requires European governments to implement measures such as streamlining the permit processes for renewable energy sources and encouraging the market for clean energy contracts.

European governments must also promote energy-saving measures and abandon their attempts to shield consumers and businesses from higher energy costs. Between September 2021 and May, European countries allocated at least €187 billion to such subsidies.

Governments can leverage the momentum of competitive solar and wind energy, but they must also significantly increase their political focus on dispatchable renewable electricity and the use of renewable energy in buildings, industry, and transport. Governments should also consider the possibility of directing much larger expenditures towards renewable energy sources to revive the economy, as well as implement policies and rules that will foster greater mobilization of private capital.

Therefore, the EU has decided to take the initiative in the current energy transition, aiming to become the first climate-neutral continent by 2050. This is expected to significantly transform European society and the economy. For many years, the EU has set important climate and energy targets, reinforcing its firm political commitment to combat greenhouse gas emissions and overcome the consequences of climate change. The biggest risk to the EU's environmental ambitions lies in

whether public support for the "green" economy will decline due to its impact on citizens' bills. In contrast, the European Commission has announced that special funds will be allocated to support the most vulnerable segments of the population in this green transition [26, 27].

The European Union's climate agenda faced significant obstacles in 2022. In this policy area, as in many others, the full-scale invasion of Ukraine by Russia on February 24, 2022, changed everything for Europeans.

Some EU member countries believe that transitioning to clean and renewable energy sources will not lower energy prices quickly enough. That's why Austria, Germany, Greece, the Netherlands, Poland, and the Czech Republic have recently extended the service life of their coal-fired power plants. Member states are also turning their long-term attention back to infrastructure, which they once considered a transitional source of energy during Russia's war against Ukraine. Germany is exploring the possibility of building liquefied natural gas (LNG) import terminals to replace Russian gas pipelines, while France and Spain have resumed negotiations on the construction of the Midi-Catalonia gas pipeline. Bulgaria and Greece have also confirmed plans to build a gas pipeline. Currently, France plans to build 14 new nuclear power plants by 2050. EU governments are trying to deepen their relationships with gas suppliers other than Russia, from Algeria to Qatar [28].

5. Discussion

The energy crisis caused by the war in Ukraine is likely to accelerate the transition to more environmentally friendly fuels in the medium term, according to the head of the International Renewable Energy Agency (IRENA). Greater use of renewable sources can help improve the environment and ensure energy independence.

The short-term use of fossil fuels may increase to ensure stable energy supply, but the risks to energy security highlighted by Russia's invasion of Ukraine will contribute to a global shift away from polluting fuels. Germany is delaying the planned closure of some coal-fired power plants, while the UK is turning to old coal power units as a "last resort" in case other sources cannot provide enough electricity during the coming winter [23].

Energy security issues in Europe have also led to renewed interest in African gas reserves. Italy has signed new agreements with Algeria and Angola to increase exports, while the EU and other member countries have turned their attention to Egypt and Nigeria.

African countries are seeking external investments to quickly fill gaps in infrastructure for natural gas exports and protect themselves from price instability.

This could create short-term opportunities, despite Europe's efforts to quickly end foreign investments in fossil fuels, and may lead to African countries being reluctant to fully embrace more environmentally friendly alternatives. However, the EU's long-term response remains clean energy both at home and abroad.

For African economies, this rhetoric alone is far from a viable alternative to the development of their fossil fuel reserves and reinforces the notion that the transitional period in Europe hinders rather than supports Africa's economic development.

To earn trust in its climate and energy diplomacy, the EU will need to reinforce its narrative of a just transition by linking its investments in green energy to ambitions for the development and industrialization of African countries and societies [14].

However, in the medium to long term, the crisis in Ukraine will accelerate the energy transition, as governments finally realize that choosing renewable energy sources is beneficial not only for the environment, job creation, and GDP, but also for ensuring higher energy independence.

The global energy crisis has led to a renewed interest in nuclear energy. Governments in Europe and Asia are extending the lifespan of their aging nuclear power plants, restarting reactors, and dusting off plans to revive projects that were postponed after the Fukushima nuclear crisis in 2011 in Japan.

European countries are starting to implement policies to support the adoption of renewable energy sources, followed by certain investments. For example, Germany has passed a law on

renewable energy that sets higher targets for wind power and improves permits, according to the industry group WindEurope.

The European Investment Bank, the EU's lending arm, has announced a 550 million euro loan, equivalent to $561 million, to Spanish utility company Iberdrola SA to finance wind and solar projects in Spain over the next 18 months. The European Commission is providing 118 million euros to help finance Enel's solar panel factory in southern Italy. SolarPower Europe, the continent's main solar energy trade group, has stated that installations will exceed the group's most colorful forecasts this year.

However, much more money and action is needed to move away from fossil fuels at a pace that will keep emissions - and global warming - under control. Implementing these steps would have been difficult even without recent economic and energy shocks.

Throughout 2021 and January 2022, EU member countries fiercely debated whether the EU should adopt nuclear energy and gas as part of its goal to achieve net-zero carbon emissions by 2050. The European Commission proposed a compromise classification that would include nuclear energy and gas in the EU's transitional energy balance, but this did not resolve the dispute. The Commission's proposal to include nuclear energy in the mix prompted threats of legal challenge from Austria and Luxembourg, as well as criticism from Spain, Portugal, and parts of the German government. Meanwhile, climate policy experts in many member countries condemned the inclusion of gas.

The rapid transition to renewable energy sources will depend on Europe's ability to extract or import materials necessary for clean energy technology, such as copper, lithium, and cobalt. And this is happening at a time when supply chains are facing increasing demand for renewable energy worldwide.

It has been found that achieving the EU's emissions reduction goal by 2050 will require approximately 35% more copper and aluminum than is currently consumed, and approximately 45% more silicon - a key component of solar panels. At the same time, demand for lithium could increase 35-fold, to over 800,000 tonnes, and rare earth elements will be needed up to 26 times more. Demand for cobalt and nickel could increase by 330% and 100%, respectively. These materials are necessary for the production of electric vehicles, batteries, wind turbines, and solar panels - all of which are crucial for achieving Europe's ambitious emission reduction targets.

The EU's energy strategy outlines ways to avoid future trade dependence by encouraging new extraction and processing within Europe, as well as recycling of metal waste and scrap. The strategy also mentions the potential for strategic raw material partnerships and trade agreements with countries in Africa and Latin America.

The European Commission has recommended measures to expedite the complex procedures for obtaining permits and designated "green zones" for renewable energy sources with lower environmental risks. According to a study by KU Leuven, local processing of metals used in cars and wind turbines could provide Europe with up to 75% of its demand for clean metals, but this will only happen after 2040. Beyond this point, Europe's future growth will depend on its ability to invest in recycling operations and prevent the export of scrap metal to other countries. The shortage of skilled labor is another problem, as installers across Europe and in many foreign markets report difficulties in finding qualified workers for construction and installation projects.

Meanwhile, while the EU is intensifying its ambitions, some member states have increased their targets for renewable energy. Germany now plans to meet 100% of its electricity needs from renewable sources by 2035, five years earlier than initially planned. The Netherlands, on the other hand, plans to double its offshore wind energy to almost 22 GW by 2030.

The European Green Deal plays an important role in addressing some of the consequences of the war in Ukraine. This can contribute to an integrated response that takes into account the global problems caused by simultaneous geopolitical, medical, and socio-ecological crises in both the short and long term. The impact of the war on food security, energy security, industrial supply chains, and environmental protection should be considered, paying proper attention to immediate threats and with the aim of accelerating the emerging transformation towards sustainability to avoid exacerbating future disruptions.

To achieve this, three approaches are necessary: ensuring policy coherence across sectors and institutions, developing relevant social protection measures, and fostering international cooperation.

6. Conclusions

The main priority for any national economy is to increase its level of ecological and energy security. However, a paradoxical phenomenon may arise, whereby a high level of ecological security is achieved based on national priorities, but the concept of sustainable economic development, which requires the harmonization of the ecological, economic (energy), and social components of sustainable development, is undermined. This leads to negative ecological, economic, and social consequences. Therefore, the question arises at the present stage of achieving a level of ecological security that would correspond to the principles of sustainable economic development. To simultaneously address the issue of energy security and the climate crisis, which is crucial for ecological security, the energy transition needs to be accelerated worldwide. Within the EU, production of renewable energy sources can be increased, gradually phasing out the use of fossil fuels, and increasing energy efficiency in all sectors and industries. The EU also has the potential to create strong international partnerships to help other interested countries in their own energy transitions and support them in becoming key trading partners in renewable energy.

Global supply chains, especially industrial supply chains, have been disrupted by war and related sanctions. Ukraine, Russia, and Belarus supply a significant portion of key global raw materials such as neon, nickel, aluminum, and palladium, as well as essential goods such as iron products and fertilizers. Rising energy prices and the unavailability of transportation routes have further exacerbated the disruptions. As companies relocate their production and seek new suppliers, the EU should strive to incentivize low-carbon options, encourage innovation and material efficiency, and support developing countries in building their own green industries.

Over the past three decades, the European Union (EU) has been rethinking the energy sector in Europe. Transnational policies aimed at liberalization, integration, energy efficiency, renewable energy sources, carbon pricing, and energy security have led to significant progress in creating a safer, more integrated, and environmentally friendly energy supply.

Energy production and use account for over 75% of the EU's greenhouse gas emissions. Therefore, decarbonizing the energy system is crucial for achieving the EU's long-term goal of becoming climate-neutral by 2050.

Renewable energy sources represent a vital foundation for global efforts to reduce and ultimately phase out fossil fuels, increasing national resilience to the volatility of fossil fuel prices. Energy from renewable sources is essential to "cleanse" the EU's energy system. At the same time, increasing the share of renewable energy sources in the energy balance will also benefit citizens by creating new jobs in various sectors, fostering dialogue between communities, and creating opportunities for more equitable and inclusive standards in the energy sector.

High coal and fossil gas prices in 2021 and 2022 further undermined the competitiveness of fossil fuels, making solar and wind energy even more attractive. Due to the unprecedented rise in fossil gas prices in Europe, new fossil gas production in Europe will become increasingly unprofitable over the entire service life.

The war of Russia against Ukraine, while devastating in terms of its humanitarian and economic consequences, may have a "positive" collateral impact on the European Green Deal. This would not be the first time that an international crisis has had positive side effects for the planet: the COVID-19 pandemic also led to a global 7% reduction in greenhouse gas emissions in 2020 as the virus spread.

The war in Ukraine has not only caused a humanitarian tragedy but also delivered a significant shock to the efforts towards achieving zero greenhouse gas emissions. However, for leaders in the public and private sectors who wish to take the necessary bold steps, a new logic of energy security and economics promises to make this a turning point in using the opportunity to overcome the unfolding global climate crisis.

The increasing frequency and severity of cyber attacks on the energy sector pose a significant risk to the environment, potentially resulting in ecological disasters. Proactive measures, collaboration, and investment in cybersecurity are crucial to mitigating these threats and ensuring the resilience of the energy infrastructure.

Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

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