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Economic and Environmental Limitations of Sustainable Energy Transition in Europe

Ekonomiczne i środowiskowe ograniczenia zrównoważonej transformacji energetycznej w Europie

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Abstract

In recent decades, the concept of sustainable development has become increasingly widespread since the United Nations Convention on Climate Change was adopted. However, it is also being overused, imitated, politicized, or even ignored.

This study analyzes the current conditions and long-term consequences of the European energy transition and discusses the limitations and true economic and environmental implications of implementing energy sustainability. The paper is aimed at forming an understanding of the current environmental conditions and challenges associated with the economic, financial, and environmental consequences of introducing renewables in Europe.

Research has revealed that renewables, while cleaner energy sources are not necessarily sustainable as initially suspected. There are various implications and limitations, that is: an initial carbon footprint, land footprint, recycling issues, harmful impacts on wildlife and humans, moreover the efficiency and economic implications when transitioning to a net zero. As a result, it is concluded that the basic principles of the energy transition are to be introduced and considered for it to become indeed sustainable. It is also concluded that when introducing or improving an energy model, it is crucial to consider the country's initial energy and resource base. Nuclear energy should not be disregarded and should considered to be a clean energy source, as well as a safe one, particularly in the context of national security, which is heavily dependent on energy transition.

Key words: energy transition, renewable energy, nuclear energy, sustainability, environmental impact, economic aspects

Streszczenie

W ostatnich dziesięcioleciach koncepcja zrównoważonego rozwoju stała się coraz bardziej powszechna, szczególnie od czasu przyjęcia Konwencji ONZ w sprawie zmian klimatycznych. Jednak jest on również nadużywany, upolityczniany, a nawet ignorowany.
W niniejszym badaniu przeanalizowano obecne warunki i długoterminowe konsekwencje europejskiej transformacji energetycznej oraz omówiono ograniczenia oraz prawdziwe implikacje gospodarcze i środowiskowe wdrożenia zrównoważonego rozwoju energetycznego. Celem artykułu jest zrozumienie obecnych warunków środowiskowych i wyzwań związanych z ekonomicznymi, finansowymi i środowiskowymi konsekwencjami wprowadzenia odnawialnych źródeł energii w Europie.
Badania wykazały, że odnawialne źródła energii, choć czystsze, niekoniecznie są zrównoważone. Istnieją różne implikacje i ograniczenia, tj.: początkowy ślad węglowy, ślad gruntowy, problemy z recyklingiem, szkodliwy wpływ na dziką przyrodę i ludzi, a ponadto problem efektywności i skutków ekonomicznych w przypadku przejścia na zero netto. Należy rozważyć i wprowadzić podstawowe zasady transformacji energetycznej, aby była ona rzeczywiście zrównoważona. Stwierdzono, że wprowadzając lub udoskonalając model energetyczny, należy wziąć pod uwagę wyjściową bazę energetyczno-zasobową danego kraju. Nie powinno się przy tym lekceważyć energetyki jądrowej, którą należy postrzegać jako źródło czystej, a zarazem bezpiecznej energii, szczególnie w kontekście narodowego bezpieczeństwa energetycznego, które jest w dużym stopniu uzależnione od transformacji energetycznej.

Słowa kluczowe: transformacja energetyczna, energia odnawialna, energia jądrowa, zrównoważony rozwój, wpływ na środowisko, aspekty ekonomiczne

1. Introduction

The United Nations Convention on Climate Change has been in place during the last few decades, bringing sustainable development to the forefront. Every year, Earth Overshoot Day counts down on the time left until humanity exceeds the available resources. From this point on, a growing deficit is created. Additionally, the reduction of economic activities caused by the COVID-19 pandemic, such as travel restrictions, border closures, and production cuts, did not significantly improve or stop this trend (Earth, 2021; Kornyliuk et al., 2022). Indeed, the effects of the worldwide lockdowns caused by the COVID-19 Pandemic proved to have an overall positive effect on the environment, but it was not lasting enough to satisfy the temperature target in the long run. Moreover, given this experience, we were able to briefly observe the scale of needed industrial reduction on our path towards a net-zero, and the corresponding economic and social consequences that come with it. Thus, the alternative solutions are indeed crucial.
The ongoing war in Ukraine and the artificially created energy crisis call for immediate action in the net-zero transition. It is necessary not only to ensure the survival of the planet and its ecosystems in the years to come but also to provide the needed energy security and safety for the nations worldwide. As the entire global community is affected by the Russian invasion of Ukraine, the concept of sustainability, especially energy sustainability, is becoming increasingly popular among scholars, politicians and alike. However, do we actually observe any progress in the matter as a result?
Companies and nations are rapidly changing their energy policies to cut ties with oil and gas. This move is driven by the increasing security concerns (Singh et al., 2019). However, the popularity of sustainability as a concept unfortunately leads to its misuse, imitation, exaggeration, politicization, and even neglect. If not implemented properly, this sustainable rush will have consequences.
This research aims to investigate the economic and environmental implications of implementing the energy sustainability. Additionally, it seeks to determine whether any sustainability limitations exist within the net-zero transition. In other words, it is crucial to understand if and how the energy transition is or could be indeed sustainable.

2. Literature Review

The United Nations Convention on Climate Change (United, 1994), adopted in 1992, highlighted the environmental challenge of battling the planet's overheating. It brought to the forefront a new research focus: sustainability as the only rational way of Global development. During the last three decades, science, policy, academia, and even business have been devoted to finding the sustainable solutions to meet the ever-growing economic needs of societies worldwide while protecting the planet's health. But the question is: were they indeed successful?

Throughout its history, Economic theory has been trying to solve an unsolvable problem: finding the ways to form an economic system that will overcome the ever-existing contradiction of economic development. This contradiction is manifested in two dialectically opposite objective economic laws: the law of unlimitedly growing needs and the law of resource scarcity.

Modern technology has enabled humanity to transform nature to its advantages, finding and creating new synthetic resources, rationalizing and optimizing the natural ones, as well as creating the alternative technological processes (Bashynska et al., 2023). However, these new materials and innovations often exacerbate the contradictions mentioned above, forming the basis for the emergence of the new increased needs and their exponential growth, which, in the end, only aggravates the need for existing scarce productive factors.

The use of electric current as a new primary energy source was initially mediated by the Industrial Revolution and its scale effect. Hydropower needed to be more robust to meet actively proliferating societal needs, and steam engines were not feasible due to a lack of coal and the complexity of mining it. Pioneers of the industry saw electricity as a future panacea to solve the energy crisis.

However, introducing electricity is a prerequisite for creating a variety of new goods: from lighting and appliances to supercomputers, nuclear power plants, the Internet, and spacecraft. New industries arose to meet a much more comprehensive range of needs, and this expansion continues today.

The advent of electricity has allowed humanity to reach its current state of development (Iskakova et al., 2017; Sribna et al., 2023). However, it has created the conditions for an even more rapid and sometimes *predatory* use of limited resources. Hence, it has actually reduced the time before the *point of no return* is reached, i.e., the point when humanity consumes more resources than can be reproduced in a year (World, 2016). Progress is often achieved through ruthless exploitation and impoverishment of the environment and a reliance on the *law of the jungle* or *survival of the fittest* (Zgurovsky, 2006).

Capitalism is rarely rational in the environment. It is often only money-driven, leading to *greenwashing* and the *eco-friendliness* imitation (Truth, 2021). Additionally, governments often use climate change as a beneficial tool. They use sustainability as a way to pass *advantageous* laws and establish *advantageous* relationships between political and business elites (Boehmer-Christiansen, 2002).

Additionally, there is an issue of hypertrophy and hyperpolarization when it comes to an understanding the concept of *sustainability*. Literature on this subject has an overwhelming number of works. However, this popularity comes with a price of overuse or misconception.

Some suggest there is an *intimate connection* between renewables and sustainability (Dincer, 2000). Others speculate on whether an energy transition (or return to renewables) will lead to control of Global warming (Abbasi et al., 2011). Still, others praise energy transition as the only suitable choice to overcome the fast-approaching eco-crisis (Reiter & Lindorfer, 2013).

Furthermore, this hypertrophy and hyperpolarisation lead to further disputes, exaggerations and misunderstandings. It, in turn, has led to contradictory opinions (to say the least), such as: sustainable development recognizes the industrial revolution as *unsustainable* (Georgescu-Roegen, 2013); that the frugal use of natural resources will lead to a depletion regardless, thus making sustainable development unattainable (Turner, 1988); that the concept of *sustainability* is *largely unfounded* and so broad, that it is exploited in many areas from economic development to resource management; and that the Brundtland Report (Brundtland, 1987) is more of a *catchphrase for public advertising* mainly promoting well-known strategies for Global development (O'Riordan, 1988).

One can observe the strict, at least declared one, implementation of the Sustainable Development Goals (SDGs). However, the data must be more conclusive to confirm that the world's economy has become more sustainable.

Some studies have attempted to introduce the critical thinking regarding true energy sustainability. For example, they question whether fast wind turbine deployment has negative environmental consequences (Abbasi et al., 2011) or why is the renewables efficiency insufficient in achieving the 1.5° C goal (Van der Ploeg & Withagen, 2015).

Unfortunately, studies have focused on one renewable energy source, or sector, or goal. Thus, limiting our complex understanding of the true sustainability in terms of renewables, as well as their efficiency limitations. Exploding energy prices in Europe bear the threat of deindustrialization, and the existing price chocs, as well as peculiar political decisions related to renewable energy, do not seem to battle the inflation in the energy sector in the short run (Brandt & Krämer 2022). Additionally, the current political discussion within the energy scope neglects to consider the global constraints of renewable energy resources, namely: by type of renewable source, their geographical distribution, time frame and feasibility (Ellabban et al., 2014; Moriarty & Honnery, 2020).

A key question remains: is the *sustainability* a viable concept? If it can only be forced or enforced, it will always remain imitated, at best. Moreover, are renewable energy sources indeed sustainable?

3. Theoretical Framework

In their previous research, authors have identified the misconceptions regarding the interpretation and implementation of sustainable development, as well as several issues and limitations related to energy sustainability, that is: financial, environmental, and economic concerns (Lukpanova et al., 2022; Yereshko et al., 2022). Hence, the abovementioned results lead us to assume that renewable energy not necessarily implies sustainability, as we are led to believe. Therefore, simply equalizing the renewability and sustainability, while dealing with the energy transition, could potentially lead to serious consequences in the long run. To achieve the true sustainability, energy transition needs to satisfy all the sustainability benchmarks (Kwilinski et al., 2023a). Consequently, in order to better understand the reality behind the energy transition and its associated economic and environmental implications, the research is looking into the reality behind the sustainable energy goals' introduction.

This study highlights the current status of sustainability with a focus on the European energy transition. The empirical evidence of the research is based on the desktop and secondary data analysis that is complemented by expert interviews and case studies from different areas. The complexity of the research requires a qualitative approach. The willingness to answer the questions in greater depth and an open discussion can only be achieved by personal and individual conversations with selected interview partners.

The authors participated in several European projects dedicated to energy-related issues from different business sectors. The empirical results and primary data that result from these projects are presented in the study. The empirical activities were executed between autumn 2019 and spring 2023. Since the field of energy security and transition addresses a quickly developing innovative sector, a large part of the primary research information is confidential; the research has to carefully balance between the scientific novelty and the trade secrets of the investigated companies. Nevertheless, the results are benchmarked and discussed in the context of scientific literature.

This research reveals that, despite policies and impetus, the climate change goals set in 1992 have yet to be met three decades later. Hence, the paper proceeds to analyze the environmental conditions and challenges associated with the economic, financial and environmental consequences of introducing the renewables. Finally, the study investigates the recent experience in the renewables introduction and energy transition. It presents a comprehensive view of energy sustainability, highlighting its main principles when introducing or improving the nation's energy model.

The geographical scope is focused on Europe, or more precisely, several nations with borderline or notable results in the energy transition. To maintain the logic of descent from general to specific, the research presents a broad picture and data on CO2 emissions concerning nations on a global scale according to their income level. The study then compares the significant players in three key economic zones (US, China and Germany). Finally, the research focuses on Europe (or, rather, selected nations), where it is possible to observe and compare several more or less successful energy transition stories and their respective policies.

4. Results

4.1. Climate change on the path to sustainable energy

Since 1992, when the Framework on Climate Change was established, several attempts have been made to create a joint working policy to achieve the sustainability goals outlined in various summits and agreements, namely: Tokyo in 1997 and Copenhagen in 2009, with the Paris-2015 Agreement being the most important. Through the Pact, world economies have adopted a policy that was supposed to be universally accepted and applicable in moving towards net zero emissions.

The idea behind the Paris Agreement, signed by 196 parties, was to reduce global warming to at least 1.5 degrees Celsius below the pre-industrial levels (UNFCCC, 2015). This target is set to be the *red line*, as many countries are threatened by the possibility of not existing if the goal is unmet (The Economist, 2022). Therefore, the UN Environmental Programme Emissions Gap report predicts the volume of greenhouse gas emissions by 2030. The data shows that, with the current policies applied, emissions will be far from the Paris Agreement goal, resulting in a global temperature rise of 2.8 degrees Celsius. However, if nations pledge to reduce emissions, there is a chance of achieving the 2.4-2.6 degrees mark (UNEP, 2022). And still, the abovementioned numbers are far from meeting the Paris goals.

The harsh reality is that the inconvenient truth of keeping 1.5°C alive is *already dead* (Van der Ploeg & Withagen, 2015; The Economist, 2022). Additionally, the World Resources Institute reports that none of the 40 actions for reaching the 1.5°C target are currently on track (Figure 1).

It is worth noting that several key issues concerning the carbon intensity of electricity generation require special attention. These include the carbon intensity of global cement and steel production, the share of global emissions covered by a carbon price of at least \$135/tCO_2e, the deforestation rate and agricultural production GHG emissions

(UNEP, 2022). These benchmarks are of great importance to the global economy. Additionally, the carbon intensity of electricity generation, the share of unabated coal in electricity generation, the diffusion of renewable fuel sources, and the percentage of renewables in energy generation should all be on a timeline track (Boehm et al., 2021).

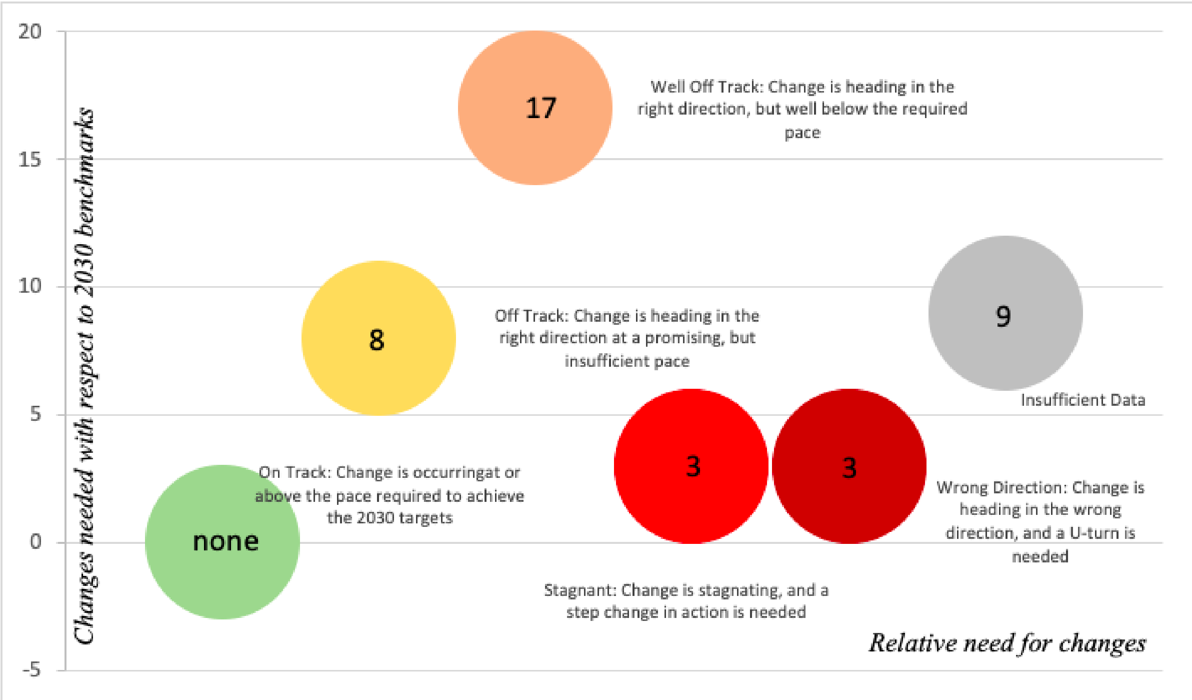


Figure 1. Progress towards 2030 Benchmarks on 40 actions for meeting the 1.5°C target (Boehm et al., 2021)

Recent developments indicate that we are far behind in reaching the 1.5°C target. In fact, the last eight years have been the hottest on record. The trend was only briefly interrupted by the Covid-19 pandemic in 2020. The global average surface temperature rose to +1.18 °C compared to the pre-industrial baseline, and greenhouse gas emissions were the highest they have ever been (Fountain & Rojanasakul, 2023).

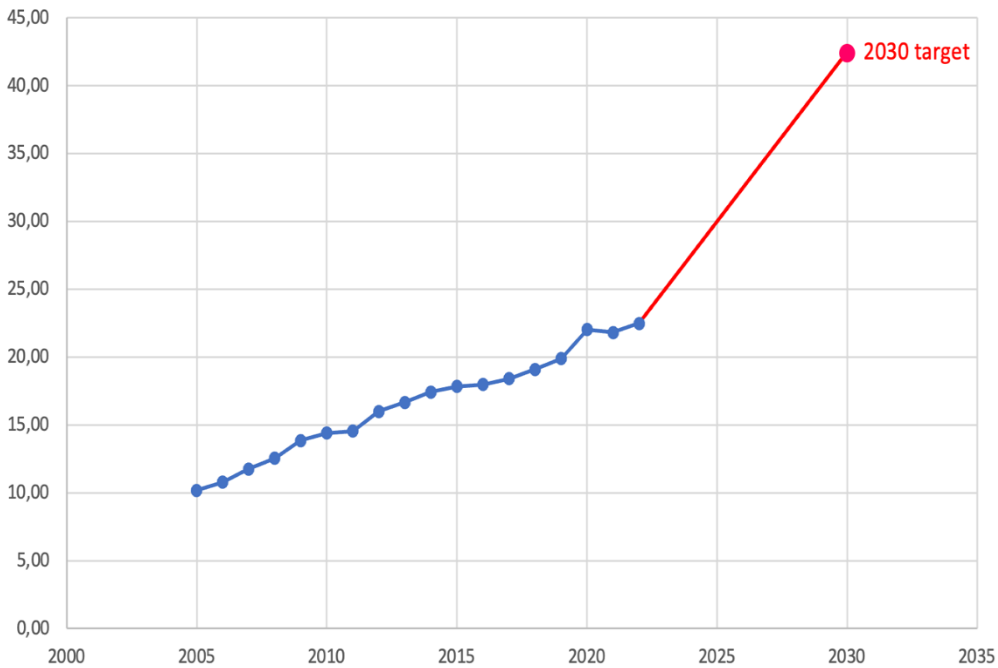


Figure 2. Progress towards 2030 Goal, set within the Renewable Energy Directive, source: built using data from the European Environment Agency (2023)

To keep up with the Brundtland goals and as a response to the energy crisis, EU nations adopted the Renewable Energy Directive, according to which, the renewables share in total energy supply is to increase to 42,5% by 2030. European Environment Agency (EEA) is reporting a slow, slightly staggering progress towards the EU-27 2030th goal (Fig. 2), with the main accent not so on the actual increase of the renewables share, but also on the reduction of non-renewable energy sources use due to growing energy prices. In 2022, we can observe a slight increase of approx. 0,67%, compared to the previous year, but according to EEA, this increase results from both the above-mentioned processes (European Environment Agency, 2023). Nevertheless, no matter the nature of factors facilitating its growth, the share of renewable energy sources is expected to increase continuously, and high energy prices can play a significant role in the future *renewable revolution*.

4.2. Sustainability in numbers: Economic reality wise

Charging toward net zero is essential, fashionable, and crucial for achieving the 2ºC benchmark. To do this, *the world has to cut 45% of emissions to avoid the Global catastrophe* (UNEP, 2022). It comes with a cost, in any case. According to modeling from the IPCC Report on the Mitigation of Climate Change, meeting the 2ºC benchmark could shrink economic growth by at least 0.6 % (Intergovernmental, 2015). It is lower than the global economy's predicted (at the time of publication in 2015) 2% annual growth, but could still be significant in the current economic climate. In 2018, substantial decarbonization of the European economy was deemed cost-effective (Kwilinski et al., 2023c; Mattauch et al., 2018). However, public investment in renewables started decreasing in 2017 (IRENA, 2020).

As energy is and was the key to economic development, there is a widespread belief that CO_2 emissions levels are linked to economic growth (Koval et al, 2021; Ritchie et al., 2020; Rui et al., 2020; Tymoshenko et al., 2023). This correlation can be demonstrated by comparing developed and underdeveloped nations' greenhouse gas emissions rates (Figure 3).

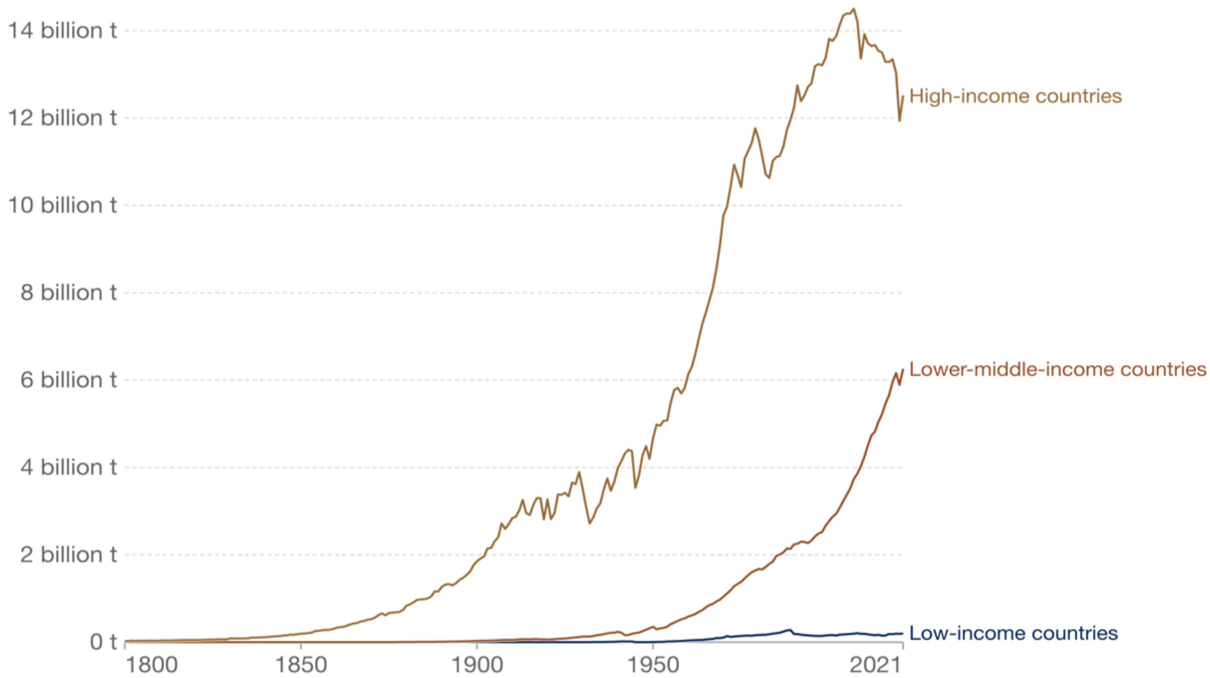


Figure 3. Annual CO_2 emissions based on countries' income level, source: built using visualization instruments and data from (Eurostat, 2022; IRENA, 2022)

CO_2 emissions can only be correlated with specific indicators of economic growth, with results varying dramatically between regions (Shpak et al., 2022a; Shpak et al., 2022b). There is no clear correlation between economic growth and CO_2 emissions (International, 2020). However, the most influential economic sectors are not very emissions-intensive (Table 1).

Table 2 and Figure 4 demonstrate that Sweden's economy produces the least emissions among those observed. We believe, that is being achieved combining the renewables and nuclear power, that ensures stability, safety and cleanliness. However, the development of the renewable energy sources is hindered by the need to improve the wind energy regulation in various countries and to find the available areas to place the engineering solutions, taking into account the environmental state of the region (International, 2020).

Table 1. Contribution to value added (%) compared to the share of CO_2 emissions (%) in the US, China and Germany (1995-2009), source: adapted from (International, 2020)

Sector	US		Germany		China	
	Value added	CO_2 emissions	Value added	CO_2 emissions	Value added	CO_2 emissions
IT, Research & Development	**13.40**	**2.50**	**13.60**	**1.90**	3.70	0.40
Real Estate Activities	11.90	0.20	12.20	1.10	5.40	0.10
Public Admin & Defence	12.60	6.10	6.00	0.90	3.70	0.40
Health & Social Work	7.40	2.10	7.80	1.00	1.70	0.40
Wholesale & Commission Trade	5.60	0.70	4.60	1.00	6.90	0.10
Agriculture, Forestry & Fishing	1.00	1.20	0.90	1.10	**10.20**	**1.90**

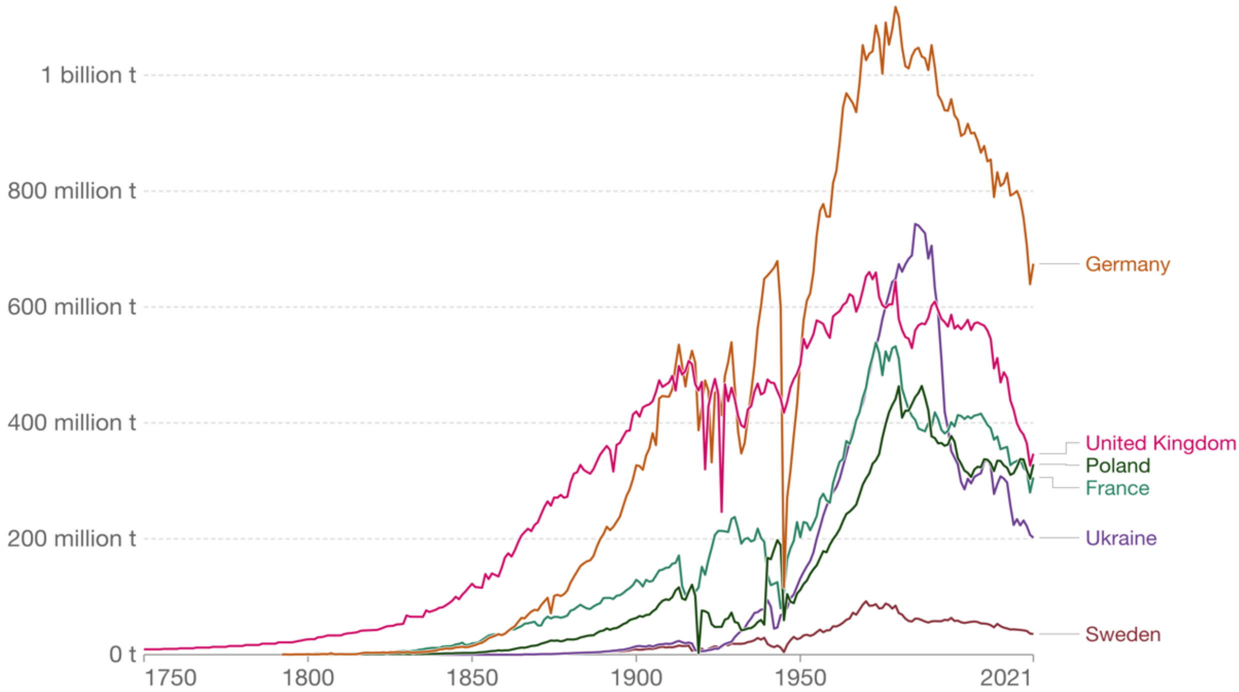


Figure 4. Annual CO_2 emissions based on countries' income level, source: built using visualization instruments and data from (Ritchie, 2020)

Table 2. Energy profiles of selected economies of the European region, source: built based on data from (Eurostat, 2022; IRENA, 2022)

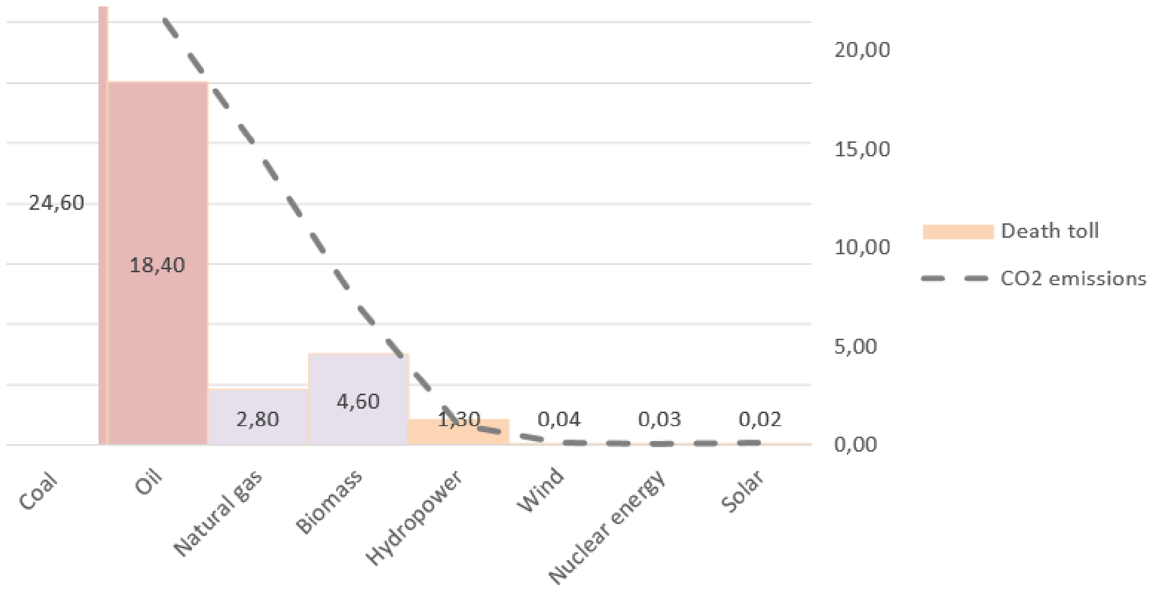
Economy	Total energy supply, TJ*	Renewables, %	Main energy source	Main renewable energy source
Germany	12 337 629	15	gas, 34%	bioenergy, 59%
France	10 153 250	11	nuclear, 42%	bioenergy, 60%
United Kingdom	7 177 048	13	gas, 39%, oil, 35%	bioenergy, 63%
Ukraine	3 725 839	4	coal, 30%, gas, 26% nuclear 24%	bioenergy, 63%
Poland	4 330 350	10	coal, 45%	bioenergy, 82%
Sweden	2 056 261	39	renewables, 39% nuclear, 35%	bioenergy, 58%

* last available data as of 2019.

4.3. Environmental issues

When it comes to clean and safe energy sources, there are several ways to classify them, including the renewable sources (Kurbatova et al., 2023; Kwilinski et al., 2023b; Nitsenko et al., 2018; Ostapenko et al., 2020; Prokopenko et al., 2017; Prokopenko et al., 2021; Sembiyeva et al., 2021). The primary considerations include air pollution, death toll related to accidents, and CO_2 emissions (Dudek et al., 2023; Prokopenko et al., 2021; Rui et al., 2020; Trypolska et al., 2022). Solar, wind and nuclear energies are the safest and cleanest options, with nuclear being the most emission-free (Figure 5).

Figure 5. Energy sources rated according to safety and cleanliness (Ritchie et al., 2020; Eurostat, 2020)



As evidence accumulates, the sustainability of renewable energy is not entirely clear, despite the positive impact of replacing the fossil energy sources with the renewable ones, since the insufficient level of technological development in this area does not allow for meeting the conditions for sustainable development (Kurbatova, & Sidortsov, 2022; Kurbatova, 2018; Mikhno et al., 2022; Shkola et al., 2021; Wang & Huang, 2021):

- *Carbon Footprint of Renewable Energy.* Renewable energy is not to be presumably considered a *net-zero*, as it almost always has a hidden carbon footprint associated with its initial production and deployment (de Chalendar & Benson, 2019; Pehl et al., 2017). It is well-established that current renewable energy generation is relatively inefficient in terms of volumes and, more importantly, stability. It is due to its reliance on unpredictable weather conditions and the intensity of renewable sources. It is, therefore, impossible to predict the exact efficacy and to influence it other than through developing the new technologies. The same applies to energy storage. Unused energy must either be used in the present or must be stored, which comes with its own *carbon price* or carbon footprint due to production, utilization, and disposal of batteries.
- *Relative caducity conditions recycling.* Due to the short lifespans of wind turbines (up to 25 years), recycling is difficult due to their structural features and not all their components could be effectively processed. It increases the amount of plastic waste and counteracts the initial positive climate impact. Technology for recycling the carbon fibre-reinforced plastic (CFRP) to cement-based materials is still being developed, and more information is needed on its potential environmental effects (Akbar & Liew, 2020). The potential hazardous impact also depends on the scale of the system and the technology used to manufacture the device, i.e., either photovoltaic solar cells (PV) or solar thermal plants (CSP) (Desai & Nelson, 2017). The latter adds another aspect of their potential negative environmental impact, as they require large amounts of water for cooling. Depending on their cooling technology, CSPs use up to 2500 liters of water per megawatt-hour of energy, thus posing another environmental threat.
- *Energy landscape.* The volume of energy consumption is rising, increasing the land use for setting up the renewable energy plants. It has a direct impact on the region's landscape. The difficulty arises due to the requirement for more land to install wind farms. Solar energy has a higher density than wind power, with estimates of 35-146 kWh/m2a or 4-17 Watts per square meter (Denholm & Margolis, 2008). It is anticipated that the nuclear power will remain the least land-intensive by 2030.
- *Wildlife and humans.* Windmills, both coastal and shore-based, have a significant impact on the habitats of animals. Studies have found that marine species, such as fish, shellfish, and mammals, are affected by wind farms (Gohlke et al., 2008). People, living near these farms are subjected to up to 45 dB of noise, which can cause stress, insomnia, and health problems. Hydro-energy plants have a vast impact on migratory fish due to their dams. Additionally, they result in flooded lands, altered river beds, and permanently changed landscapes. Moreover, in case if dam collapses, the environmental catastrophe is inevitable. Solar plants also leave a noticeable land footprint and use a large amount of water, which can alter the habitats of mammals and humans (Moore, 2019).

4.4. Spatial and technical issues

The literature review reveals a large number of studies about the global potential of renewable energy resources, together with their geographical distribution and their development prospective (Oakleaf et al., 2019; Redko et al., 2023). The common key conclusion for all of these studies is, that geographical locations, suitable for potential green energy production and the actual points of energy demand are not congruent, i.e., the needed green energy has to be stored and transported between the sources and the consumers. The second baseline point of the existing studies highlights that the estimated future global energy demand can be covered only by photovoltaic (PV) when deciding on only one renewable energy resource alone. All other renewable energy resources comprising wind energy, hydroelectric, biomass can only contribute locally to energy generation.

This situation spurs the discussion about the storage of energy and its and transportation posing the important questions about logistics, costs and corresponding investments into the infrastructure. Only the reflection on the issue of PV-based electrical production reveals that the most favorable places for PV-electricity generation are close to the equator, whereas the main production and industry centers are located rather in Nordic areas where the sun power is reduced. The related infrastructural question on the energy transportation or even more pressing one, on the Power-to-X (i.e. the conversion of renewable energy into eco-products like ammonia, hydrogen or synthetic fuels) directly at the site of the green energy production goes far beyond techno-economic issues (Gerlitz et al., 2022; Prause et al., 2023).

These techno-economic topics also represent important impact factors for the success of the energy transition and its acceptance by the politicians and general public. Recent discussions and political events on the agenda of the European Union highlight the notions of high energy prices and fears of deindustrialization related to energy transition having the potential to destabilize the political systems inside Europe. As pressing concerns bring into power the extreme far-right or far-left political forces all over the region. Moreover, we observe the increase of conflicts related to EU energy policy and green transition regimentations between the EU member states.

5. Discussion

The energy crisis impacted the global economy severely, causing a 3.3% decline in the GDP and further devaluing the value-added due to the rising inflation caused by food and gas shortages resulting from military conflicts (Samandari et al., 2022). It has forced economies worldwide to re-evaluate and re-establish their energy security systems (McDonald et al., 2009). War-related shortages could complicate and slow the energy transition down and not only in the short run, especially given the scale of the current crises. However, as evidenced by the performance indicators of nations already aiming for true sustainability, an already established and well-thought-out strategy could facilitate a faster recovery and ensure future rapid development and security (Jankauskas et al., 2014; Saik et al., 2021).

A peculiar German approach to the energy transition has led to the struggles in ensuring the energy security and a limited ability to act according to present circumstances. It has resulted in the economy underdelivering in value-added, as GDP is expected to be 1.7% lower than the previous year (Person, 2022). There are already talks in place, that Germany is becoming a *sick man of Europe* once again, referring to nation's previous struggles in the late 1990's.

In contrast, France has been more flexible, despite energy prices rising to 160%. It is due to their wise decision to keep nuclear power plants running, thus ensuring the various energy sources.

However, nations that are heavily dependent on the gas face an energy crisis. Although the war in Ukraine has been a tragic development, it has enlightened the importance of the energy transition and could potentially result in a significant push for the industry. It could even be a turning point in accelerating the progress in the medium run (Moore, 2019; McDonald et al., 2009).

Ongoing political processes inside the European Union reveal a decreasing acceptance of the green issues with the EU population, as well as within the EU government. The rise to power of the extreme political parties promoting *green-sceptical* programs in the last European elections in Italy, Spain, Germany, as well as Central Eastern European states, is to a certain extent related to the high energy and investment costs for the green industries, at the same time reducing the individual mobility, leisure options and individual freedom (Olaniyi et al., 2022). Besides that, growing conflicts between EU governments about the high investment costs for net-zero transitions or even threats of deindustrialization e.g. in the areas of the metal industry of car manufacturing endanger the energy transition process.

Based on that analysis, we are looking at the energy transition implementation, as well as its implications and limitations. It leads to the conclusion that baseline principles of energy sustainability have to be formulated to achieve the true energy transition without sustainability limitations or negative environmental impact. The authors suggest the following principles:

- Holistic: treating a nation's energy system as an integral part of its national security, recognizing that any changes or shifts could become potential threats.

- Precedence of energy independence: analyzing the German and French experiences of transitioning to a net zero, it is clear that frugality today can jeopardize energy and economic security shortly.
- Equilibration precedence: when building or improving the energy system for a net zero transition, the outcomes, efficiency limitations and energy diversity for a balanced system should be considered.
- Consistency: an updated or new energy system should be designed to achieve true sustainability, considering SDGs and avoiding greenwashing and imitation.
- Social and political balancing: The energy transition process has a positive perspective only in case of the social and political acceptance of the stakeholders. The steps for the energy transition have to be adapted to the social and political situation of the population and the economy. If energy transition is considered as an elitist project that is only affordable by the rich layer of the society and is linked to risks or losses of poorer people then the success of the green transition might be endangered (Chupryna et al., 2022).

The above principles do not contradict the theoretical baselines of constructing and updating energy systems. Instead, they are the core requirements to ensure true sustainability. This list of conditions can be extended under the initial parameters of any particular energy system and the peculiarities of the relevant economy.

To address the problems described above as well as the ongoing energy crisis, the European Commission introduced the REPowerEU Plan in May 2022. The programme aims to secure the EU's citizens and businesses from energy shortages, as well as accelerate net-zero transition and covers, namely, safe energy, clean energy, and energy diversity. According to the European Commission (2022), to date, the results are as follows: reduced dependence on fossil fuels (80% of pipeline gas was cut in under eight months), reduced energy consumption within the EU (20% reduction in energy demand), and rapid deployment of renewables (39% of electricity in the EU in 2022 came from renewable sources). Moreover, to secure affordable energy and supply, EU nations are introducing common gas procurement as well as gas and oil price caps. With the REPowerEU launch, European companies are able to negotiate energy prices directly with suppliers, which is aimed at safeguarding businesses in the midst of energy market disruptions. The future steps towards REPowerEU implementation, among others, include legislative and regulatory measures to ensure a holistic approach across EU member states (described by us as one of the main principles of true energy transition), boosting industrial decarbonization, and a modern regulatory framework for hydrogen acceleration.

Every crisis has the potential to cause the system to collapse or evolve. The war in Ukraine will act as a catalyst for the global energy transition. This highlights the significance of a secure energy system and energy independence for a nation's security.

A survey conducted by the European Investment Bank suggests that the majority of Europeans (80%) recognize the importance of energy transition and the need to reduce energy consumption (84%) (EIB, 2022). However, the energy transition can be successful only when its social and political acceptance by the population and political stakeholders is safeguarded. In case of an unbalanced political approaches together with social risks and threats for large parts of the society, there is a chance that the energy transition process might fail (Beutelbacher, 2023).

The ruination of Ukraine's energy infrastructure presents an opportunity for the country to leap forward in its energy development. The Ukrainian energy sector can sustain industry and households even during the invasion (Ukrinform, 2022). It is mainly due to the advantageous use of nuclear and hydropower plants, which were previously underutilized under inadequate gas treaties. A timely separation from the former Soviet energy system, which linked Ukrainian energy infrastructure to those of Belarus and Russia, also aided energy security.

Ukraine should aim for a fast transition to renewables, taking advantage of its geography. The current energy crisis creates an opportunity for the renewables industry, as fossil fuels endanger the environment and global safety and security. With its heavily bureaucratic machinery, even Germany is speeding up the energy transition to solve wind energy problems. However, one poorly working transition strategy is being replaced with another questionable one, as the government has decided to switch back to coal to replace lacking and expensive gas. It allows us to comprehend the true sustainability (or lack of it) behind the energy transition policies in various nations in Europe and worldwide.

The ongoing war in Ukraine has made it more challenging to achieve the sustainability goal of reducing greenhouse gas emissions to meet climate targets. It calls for a rapid and comprehensive energy transition (Sala et al., 2023). Some countries are now considering energy independence as a matter of national security, potentially leading to a nuclear revival. Both scientific and legislative progress is facilitating this.

The European Parliament has recently classified investments in nuclear energy as meeting Sustainable Development Goals. It could enhance energy security for many European countries which rely heavily on nuclear power plants for energy production, such as Ukraine and Slovenia, which has the cleanest energy profile.

Germany needs help with its energy transition, and nuclear energy could provide a solution. Nuclear power is considered one of the safest and cleanest energy sources, alongside wind and solar. The recent nuclear fusion breakthrough also promises a carbonless and endless energy source, powerful enough to *change the future of humanity* (Pelley, 2023).

6. Conclusion

The tight interconnection, high dependence, and strong influence of the global energy system on the global security system are confirmed. There was also concluded that this correlation remains valid at the level of national energy and national security systems.
Research has revealed that renewables, while cleaner energy sources, are not necessarily sustainable as initially suspected. There are various implications and limitations, namely: an initial carbon footprint, land footprint, recycling issues, and harmful impacts on wildlife and humans. Additionally, when considering a net-zero transition, there are various efficiency and economic implications.
The analysis of annual CO_2 emissions demonstrated that in countries with emissions levels over 400 million tons annually, the level of renewable energy share ranged from 10-15%. The most efficient energy transition is structured around a perfect balance and diversity of clean energy sources, including nuclear power. Furthermore, the cleanest energy sources, namely: wind, solar and nuclear power, are also the safest.
When updating or constructing a nation's energy system, it is essential to adhere to core principles. These include:
- Holistic: Treat the energy system of a nation as a crucial part of an interconnected national security system. Any shift or change should be considered for its potential threat.
- Precedence of energy independence: Phantom frugality today can threaten energy and economic security in the short term.
- Equilibration precedence (energy diversity and balance in energy sources): When building or improving the energy system to achieve the net-zero transition.
- Consistency (long-run sustainability): An updated or new energy system should be constructed to achieve true sustainability. It should consider not only political SDGs but also their true essence.
- Social and political balancing: The energy transition process will be successful only if the society accepts and backs the development. This requires a balanced distribution of social risks among all stakeholders. Moreover, it has to be linked to a transparent feasibility concept. Future developments should consider constructing a theoretical model of a truly sustainable energy system. It should take into account the corresponding economic, environmental, and efficiency limitations. The new or improved system should be balanced according to given predispositions and resource base. Additionally, energy diversity is critical in constructing a well-balanced energy system. Nuclear energy should not be disregarded and is to be considered a clean and safe energy source.

References

1. ABBASI T., PREMALATHA M., ABBASI S.A., 2011, The Return to Renewables: Will It Help in Global Warming Control?, *Renew. Sustain. Energy Rev.*, 15: 891–894, https://doi.org/10.1016/j.rser.2010.09.048.
2. AKBAR A., LIEW K. M., 2020, Assessing recycling potential of carbon fiber reinforced plastic waste in production of eco-efficient cement-based materials, *Journal of Cleaner Production*, 274: 123001, https://doi.org/10.1016/j.jclepro.2020.123001.
3. AMELANG S., APPUNN K., KYLLMANN C., WEHRMANN B., WETTENGEL J., 2022, War in Ukraine: Tracking the impacts on German Energy and Climate Policy, *Clean Energy Wire*, https://www.cleanenergywire.org/news/ukraine-war-tracking-impacts-german-energy-and-climate-policy (2.11.2022).
4. BASHYNSKA I., MUKHAMEJANULY S., MALYNOVSKA Y., BORTNIKOVA M., SAIENSUS M., MALYNOVSKYY Y., 2023, Assessing the Outcomes of Digital Transformation Smartization Projects in Industrial Enterprises: A Model for Enabling Sustainability, *Sustainability*, 15: 14075, https://doi.org/10.3390/su151914075.
5. BEUTELBACHER S., 2023, Europas Traum von der Klimaneutralität droht zu platzen, *Die Welt*, Berlin, https://www.msn.com/de-de/finanzen/top-stories/europas-traum-von-der-klimaneutralit%C3%A4t-droht-zu-platzen/ar-AA1d1ni4?ocid=msedgntp (30.06.2023)
6. BOEHM S., LEBLING K., LEVIN K., FEKETE H., WAITE R., GEIGES A., NILSSON A., WILSON R., THWAITES J., JAEGER J., PLECHATY D., 2021, We're not on track for 1.5 degrees C. what will it take?, *World Resources Institute*, https://www.wri.org/insights/climate-action-progress-indicators-2030-2050-targets (27.12.2022).
7. BOEHMER-CHRISTIANSEN S., 2002, The geopolitics of sustainable development: bureaucracies and politicians in search of the holy grail, *Geoforum*, 33(3): 351-365, https://linkinghub.elsevier.com/retrieve/pii/S0016718502000180.
8. BRANDT A., KRÄMER H., 2022, Droht der deutschen Wirtschaft eine Deindustrialisierung?, *Wirtschaftsdienst*, 102(12): 917, https://doi.org/10.1007/s10273-022-3336-8.
9. BRUNDTLAND G. H., 1987, *Our common future*, Oxford University Press, New York.
10. CHUPRYNA I., TORMOSOV R., ABZHANOVA D., RYZHAKOV D., GONCHAR V., PLYS N., 2022, Scientific and Methodological Approaches to Risk Management of Clean Energy Projects Implemented in

Ukraine on the Terms of Public-Private Partnership, *Proceedings of the 2022 International Conference on Smart Information Systems and Technologies (SIST); IEEE*: 1-8, https://doi.org/10.1109/SIST54437.2022.9945809.
11. DE CHALENDAR J. A., BENSON S. M., 2019, Why 100% renewable energy is not enough, *Joule*, 3(6): 1389-1393, https://doi.org/10.1016/j.joule.2019.05.002.
12. DENHOLM P., MARGOLIS R. M., 2008, Land-use requirements and the per-capita solar footprint for photovoltaic generation in the United States, *Energy Policy*, 36(9): 3531-3543, https://doi.org/10.1016/j.enpol.2008.05.035.
13. DESAI J., NELSON M., 2017, Are we headed for a solar waste crisis. *Environmental Progress*, http://environmentalprogress.org/big-news/2017/6/21/are-we-headed-for-a-solar-waste-crisis (2.12.2022).
14. DINCER I., 2000, Renewable Energy and Sustainable Development: A Crucial Review, *Renew. Sustain. Energy Rev*., 4: 157–175, https://doi.org/10.1016/s1364-0321(99)00011-8.
15. DUDEK M., BASHYNSKA I., FILYPPOVA S., YERMAK S., CICHOŃ D., 2023, Methodology for assessment of inclusive social responsibility of the energy industry enterprises, *Journal of Cleaner Production*, 394: 136317, https://doi.org/10.1016/j.jclepro.2023.136317.
16. EARTH OVERSHOOT DAY, 2021, July 12, *Past earth overshoot days – move the date of earth overshoot day*, https://www.overshootday.org/newsroom/past-earth-overshoot-days/ (17.02.2022).
17. EIB, 2022, *2022-2023 EIB climate survey, part 1 of 2: Majority of Europeans say the war in Ukraine and high energy prices should accelerate the green transition*, https://www.eib.org/en/surveys/climate-survey/5th-climate-survey/eu-usa-china (2.11.2022).
18. ELLABBAN O., ABU-RUB H., BLAABJERG F., 2014, Renewable energy resources: Current status, future prospects and their enabling technology, *Renewable and Sustainable Energy Reviews*, 39: 748-764, https://doi.org10.1016/j.rser.2014.07.113.
19. EUROPEAN COMISSION, 2022, *REPowerEU*, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en (30.12.2023).
20. EUROPEAN ENVIRONMENTAL AGENCY, 2023, *Share of energy consumption from renewable sources in Europe*, https://www.eea.europa.eu/en/analysis/indicators/share-of-energy-consumption-from-renewable-resources.
21. EUROSTAT, 2020, *Renewable energy statistics. Statistics Explained*, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics (17.02.2022).
22. EUROSTAT, 2022, *Shares (Renewables) – Energy – Eurostat*, https://ec.europa.eu/eurostat/web/energy/data/shares (27.02.2023)
23. FOUNTAIN H., ROJANASAKUL M., 2023, The last 8 years were the hottest on record, *The New York Times*, https://www.nytimes.com/interactive/2023/climate/earth-hottest-years.html?utm_campaign=likeshopme&utm_medium=instagram&utm_source=dash+hudson&utm_content=ig-nytimes (27.09.2023).
24. GEORGESCU-ROEGEN N., 2013, *The entropy law and the economic process*, Harvard University Press.
25. GERLITZ L., MILDENSTREY E., PRAUSE G., 2022, Ammonia as Clean Shipping Fuel for the Baltic Sea Region, *Transport and Telecommunication Journal*, 23 (1): 102−112, https://doi.org/10.2478/ttj-2022-0010.
26. GOHLKE J. M., HRYNKOW S. H., PORTIER CH. J., 2008, Health, Economy, and Environment: Sustainable Energy Choices for a Nation, *Environmental Health Perspectives*, 116(6): A236-A237, https://doi.org/10.1289/ehp.11602.
27. IPPC (Intergovernmental Panel on Climate Change), 2015, *Climate Change 2014: Mitigation of Climate Change*, Working group III contribution to the IPCC Fifth Assessment Report, Cambridge University Press.
28. IEA *(International Energy Agency)*, 2020, *Germany 2020 – Energy Policy Review*, https://www.iea.org/reports/germany-2020 (17.02.2022).
29. IRENA, 2022, *Statistical Profiles*, https://www.irena.org/Data/Energy-Profiles (27.12.2022).
30. IRENA, 2020, *International renewable energy agency*. *Renewable Energy Target Setting*, Abu Dhabi, UAE. https://www.irena.org/ (2.09.2021).
31. ISKAKOVA D., KIRDASINOVA K.A., SEMBIYEVA L., MAKYSH S., KAZBEKOV G. SABIROVA R., UMARBEKOVA A., 2017, Innovative approaches to electric power industry management, *International Journal of Economic Perspectives*, 11(2): 418–428, https://doi.org/10.1016/j.gloei.2021.01.006.
32. JANKAUSKAS V., RUDZKIS P., KANOPKA A., 2014, Risk factors for stakeholders in renewable energy investments. Energetika, 60(2): 113–124, https://doi.org/10.6001/energetika.v60i2.2935.
33. KOVAL V., SRIBNA Y., KACZMARZEWSKI S., SHAPOVALOVA A., STUPNYTSKYI V., 2021, Regulatory policy of renewable energy sources in the European national economies, *Polityka Energetyczna – Energy Policy Journal*, 24(3): 61-78, https://doi.org/10.33223/epj/141990.
34. KORNYLIUK A., IVASHCHENKO A., POLISHCHUK Y., TERESHCHENKO O., ONIKIIENKO S., 2022, Government early policy responses on COVID-19 challenges in Central and Eastern Europe: SME support, *Acta Innovations*, 2022(42): 50–58, https://10.32933/ActaInnovations.42.4.

35. KURBATOVA T., SIDORTSOV R., 2022, Trash to Hryvnias: The economics of electricity generation from landfill gas in Ukraine, *International Journal of Sustainable Energy Planning and Management*, 33: 53-64, https://doi.org/10.5278/ijsepm.6707.
36. KURBATOVA T., 2018, Economic benefits for producers of biogas from cattle manure within energy co-operatives in Ukraine, *International Journal of Sustainable Energy Planning and Management*, 18: 69–80, https://doi.org/10.5278/ijsepm.2018.18.5.
37. KURBATOVA T., SOTNYK I., PROKOPENKO O., BASHYNSKA I., PYSMENNA U., 2023, Improving the Feed-in Tariff Policy for Renewable Energy Promotion in Ukraine's Households, *Energies*, 16: 6773,https://doi.org/10.3390/en16196773.
38. KWILINSKI A., LYULYOV O., PIMONENKO T., 2023a, Environmental Sustainability within Attaining Sustainable Development Goals: The Role of Digitalization and the Transport Sector, *Sustainability*, 15(14): 11282, https://doi.org/10.3390/su151411282.
39. KWILINSKI A., LYULYOV O., PIMONENKO T., 2023b, Greenfield Investment as a Catalyst of Green Economic Growth, *Energies*, 16: 2372, https://doi.org/10.3390/en16052372.
40. KWILINSKI A., LYULYOV O., PIMONENKO T., 2023c, The Effects of Urbanisation on Green Growth within Sustainable Development Goals, *Land*, 12: 511, https://doi.org/10.3390/land12020511.
41. LUKPANOVA Z., JUMABEKOVA A., MUKUSHEV A., MATAIBAYEVA G., KADRINOV M., BAIMAGAMBETOVA Z., 2022, Environmental Concerns Associated with the Development of the Agro-Industrial Complex and Analysis of Its Financing, *Journal of Environmental Management and Tourism*, 13(5): 1396–1406, https://doi.org/10.14505/jemt.v13.5(61).15.
42. MASYK M., BURYK Z., RADCHENKO O., SAIENKO V., DZIURAKH Y., 2023, Criteria for governance' institutional effectiveness and quality in the context of sustainable development tasks, *International Journal for Quality Research*, 17(2): 501-514, https://10.24874/IJQR17.02-13.
43. MATTAUCH L., RADEBACH A., SIEGMEIER J., SULIKOVA S., 2018, Shrink emissions, not the economy, *Our World in Data*, https://ourworldindata.org/shrink-emissions-not-the-economy (27.12.2022).
44. MCDONALD R. I., FARGIONE J., KIESECKER J., MILLER W. M., POWELL J., 2009, Energy sprawl or energy efficiency: climate policy impacts on natural habitat for the United States of America, *PloS one*, 4(8): e6802, https://doi.org/10.1371/journal.pone.0006802.
45. MIKHNO I., REDKVA O., UDOVYCHENKO V., TSIMOSHYNSKA O., KOVAL V., KOPACZ M., 2022, Sustainable energy supply management in the mechanical-engineering industry, *Polityka Energetyczna – Energy Policy Journal*, 25(4): 39-54, https://doi.org/10.33223/epj/156627.
46. MOORE A., 2019, Renewable energy poses challenge for wildlife conservation, *College of Natural Resources News*, https://cnr.ncsu.edu/news/2019/11/renewable-energy-poses-challenge-for-wildlife-conservation/ (17.02.2022).
47. MORIARTY P., HONNERY D., 2020, Feasibility of a 100% Global Renewable Energy System, *Energies*, 13: 5543, https://doi.org/10.3390/en13215543.
48. NITSENKO V., MARDANI A., STREIMIKIS J., SHKRABAK I., KLOPOV I., NOVOMLYNETS O., PODOLSKA O., 2018, Criteria for Evaluation of Efficiency of Energy Transformation Based on Renewable Energy Sources, *Montenegrin Journal of Economics*, 14(4): 237-247, https://doi.org/10.14254/1800-5845/2018.14-4.17.
49. O'RIORDAN T., 1988, The politics of sustainability, *Sustainable environmental management*, Belhaven Press, London: 48-54.
50. OAKLEAF J. R., KENNEDY C. M., BARUCH-MORDO S., GERBER J. S., WEST P. C., JOHNSON J. A., KIESECKER J., 2019, Mapping global development potential for renewable energy, fossil fuels, mining and agriculture sectors, *Sci Data*, 6: 101, https://doi.org/10.1038/s41597-019-0084-8.
51. OLANIYI E. O., PRAUSE G., GERASIMOVA V., INKINEN T., 2022, Clean Cruise Shipping: Experience from the BSR, *Sustainability*, 14 (9): 5002, https://doi.org/10.3390/su14095002.
52. OSTAPENKO O., OLCZAK P., KOVAL V., HREN L., MATUSZEWSKA D., POSTUPNA O., 2022, Application of Geoinformation Systems for Assessment of Effective Integration of Renewable Energy Technologies in the Energy Sector of Ukraine, *Applied Sciences*, 12(2): 592, https://doi.org/10.3390/app12020592.
53. PEHL M., ARVESEN A., HUMPENÖDER F., POPP A., HERTWICH E. G., LUDERER G., 2017, Understanding future emissions from low-carbon power systems by integration of life-cycle assessment and integrated energy modelling, *Nature Energy*, 2(12): 939-945, https://doi.org/10.1038/s41560-017-0032-9.
54. PELLEY S., 2023, Inside the nuclear fusion breakthrough that could be a step to unlimited clean energy in the distant future, *CBS News*, https://www.cbsnews.com/news/nuclear-fusion-60-minutes-2023-01-1 (25.01.2023).
55. PERSON, 2022, *German economy to lose $265 billion in added value due to war, high energy prices, study says*, https://www.reuters.com/markets/europe/german-economy-lose-265-bln-added-value-due-war-high-energy-prices-study-2022-08-09/ (4.10.2023).

56. PRAUSE G., OLANIYI E. O., GERSTLBERGER W., 2023, Ammonia Production as Alternative Energy for the Baltic Sea Region, *Energies*, 16 (4): 1831, https://10.3390/ en16041831.
57. PROKOPENKO O., CEBULA J., CHAYEN S., PIMONENKO T., 2017, Wind energy in Israel, Poland and Ukraine: Features and opportunities, *International Journal of Ecology and Development*, 32(1): 98-107, http://www.ceser.in/ceserp/index.php/ijed/article/view/4772 (20.02.2021).
58. PROKOPENKO O., CHECHEL A., SOTNYK I., OMELYANENKO V., KURBATOVA T., NYCH T., 2021, Improving state support schemes for the sustainable development of renewable energy in Ukraine, *Polityka Energetyczna*, 24(1): 85-100, https://doi.org/10.33223/epj/134144.
59. REDKO K., BORYCHENKO O., CHERNIAVSKYI A., SAIENKO V., DUDNIKOV S., 2023, Comparative analysis of innovative development strategies of fuel and energy complex of Ukraine and the EU countries: international experience, *International Journal of Energy Economics and Policy*, 13(2): 301-308, https://10.32479/ijeep.14035.
60. REITER G., LINDORFER J., 2015, Global Warming Potential of Hydrogen and Methane Production from Renewable Electricity via Power-to-Gas Technology, *Int. J. Life Cycle Assess*, 20: 477–489, https://doi.org/10.1007/s11367-015-0848-0.
61. RITCHIE H., 2020, What are the safest and cleanest sources of energy?, *Our World in Data*, https://ourworldindata.org/safest-sources-of-energy (27.12.2022).
62. RITCHIE H., ROSER M., ROSADO P., 2020, CO_2 emissions, *Our World in Data*, https://ourworldindata.org/co2-emissions (2.06.2022).
63. RUI LI, JIANG H., SOTNYK I., KUBATKO O., ISMAIL ALMASHAQBEH, Y.A., 2020, The CO_2 emissions drivers of post-communist economies in Eastern Europe and Central Asia, *Atmosphere*, 11(9): 1019, https://doi.org/10.3390/atmos11091019.
64. SAIK P., DYCHKOVSKYI R., LOZYNSKYI V., FALSHTYNSKYI V., CABANA E. C., HRYTSENKO L., 2021, Chemistry of the Gasification of Carbonaceous Raw Material, *Materials Science Forum*, 1045: 67–78, https://doi.org/10.4028/www.scientific.net/msf.1045.67.
65. SALA D., BASHYNSKA I., PAVLOVA O., PAVLOV K., CHORNA N., ROMANYUK R., 2023, Investment and Innovation Activity of Renewable Energy Sources in the Electric Power Industry in the South-Eastern Region of Ukraine, *Energies*, 16: 2363, https://doi.org/10.3390/en16052363.
66. SAMANDARI H., PINNER D., BOWCOTT H., WHITE O., 2022, The net-zero transition in the wake of the war in Ukraine: A detour, a derailment, or a different path?, *McKinsey Company*, https://www.mckinsey.com/business-functions/sustainability/our-insights/the-net-zero-transition-in-the-wake-of-the-war-in-ukraine-a-detour-a-derailment-or-a-different-path (29.08.2022).
67. SEMBIYEVA L., SERIKOVA M., SATYMBEKOVA K., TULEGENOVA Z., NURMAGANBETOVA B., ZHAGYPAROVA A., 2021, Tax audit in innovative development of the energy sector of the economy: Global trends, *Journal of Water and Land Development*, 48(1-3): 70–80.
68. SHKOLA V., PROKOPENKO O., STOYKA A., NERSESOV V., SAPIŃSKI A., 2021, Green Project Assessment within the Advanced Innovative Development Concept, *Estudios de Economia Aplicada*, 39(5), https://doi.org/10.25115/eea.v39i5.5135.
69. SHPAK N., OHINOK S., KULYNIAK I., SROKA W., ANDRONICEANU A., 2022a, Macroeconomic Indicators and CO2 Emissions in the EU Region, *Amfiteatru Economic*, 24(61): 817-830, https://www.amfiteatrueconomic.ro/Home_Ro.aspx.
70. SHPAK N., OHINOK S., KULYNIAK I., SROKA W., FEDUN Y., GINEVIČIUS R., CYGLER J., 2022b, CO2 Emissions and Macroeconomic Indicators: Analysis of the Most Polluted Regions in the World, *Energies*, 15(8): 2928, https://doi.org/10.3390/en15082928.
71. SINGH H. V., BOCCA R., GOMEZ P., DAHLKE S., BAZILIAN M., 2019, The energy transitions index: An analytic framework for understanding the evolving global energy system, *Energy Strategy Reviews*, 26: 100382, https://doi.org/10.1016/j.esr.2019.100382.
72. SRIBNA Y., SKAKOVSKA S., PANIUK T., HRYTSIUK I., 2023, The Economics of Technology Transfer in The Environmental Safety of Enterprises for the Energy Transition, *Economics Ecology Socium*, 7: 84-96, https://doi.org/10.31520/2616-7107/2023.7.1-8.
73. THE ECONOMIST, 2022, T*he world is going to miss the totemic 1.5°C climate target,* https://www.economist.com/interactive/briefing/2022/11/05/the-world-is-going-to-miss-the-totemic-1-5c-climate-target (23.08.2023)
74. TRUTH IN ADVERTISING, 2021, *November 22, Earth day 2021: Companies accused of Greenwashing,* https://www.truthinadvertising.org/six-companies-accused-greenwashing/ (17.02.2022).
75. TRYPOLSKA G., KURBATOVA T., PROKOPENKO O., HOWANIEC H., KLAPKIV Y., 2022, Wind and Solar Power Plant End-of-Life Equipment: Prospects for Management in Ukraine, *Energies*, 15(5): 1662, https://doi.org/10.3390/en15051662.
76. TURNER R. K., 1988, *Sustainability, resource conservation and pollution control: an overview,* Belhaven Press, London.

77. YMOSHENKO M., SAIENKO V., SERBOV M., SHASHYNA M., SLAVKOVA, O., 2023, The impact of industry 4.0 on modelling energy scenarios of the developing economies, *Financial and credit activity-problems of theory and practice*, 1(48): 336-350, https://doi.org/10.55643/fcaptp.1.48.2023.3941.
78. UKRINFORM, 2022, *Ukrenergo awaits decision to raise electricity exports to Europe*, https://www.ukrinform.net/rubric-economy/3556868-ukrenergo-awaits-decision-to-raise-electricity-exports-to-europe.html (4.10.2023).
79. UNEP, 2022, *Emissions gap report 2022*, https://www.unep.org/resources/emissions-gap-report-2022 (27.12.2022).
80. UNFCCC, 2015, *The Paris Agreement*, https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement (27.12.2022).
81. UNITED NATIONS, 1994, *What is the United Nations Framework Convention on Climate Change?* https://unfccc.int/process-and-meetings/what-is-the-united-nations-framework-convention-on-climate-change (27.12.2022).
82. VAN DER PLOEG F., WITHAGEN C., 2015, Global Warming and the Green Paradox: A Review of Adverse Effects of Climate Policies, *Rev. Environ. Econ. Pol.*, 9: 285–303, https://doi.org/10.1093/reep/rev008.
83. WANG J. B., HUANG L., 2021, A Game-Theoretic Analytical Approach for Fostering Energy-Saving Innovation in the Electric Vehicle Supply Chain, *SAGE Open*, 11(2): 21582440211021581.
84. WWF *(World Wide Fund)*, 2016, *Living Planet Report 2016*, https://admin.zsl.org/sites/default/files/media/2016-10/LPR_2016_Full%20Report.pdf (27.12.2022).
85. YERESHKO J., KOVAL V., NESENENKO P., KOVBASENKO S., GUI H., TAMOŠIŪNIENĖ R., 2022, Theory meets reality: Investigating the financial, economic and environmental aspects of sustainability, *12th International Scientific Conference Business and Management 2022*, https://doi.org/10.3846/bm.2022.908.
86. ZGUROVSKY M., 2006, Ukraine in global dimensions of sustainable development, *Dzerkalo tyzhnya*, 19(598): 14.