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# DECARBONIZATION AS A KEY TO SUSTAINABLE DEVELOPMENT: CHALLENGES AND PROSPECTS OF THE EU AND UKRAINE

## ABSTRACT

Achieving Sustainable Development worldwide largely depends on the implementation of comprehensive energy transformation and decarbonization across all sectors of the economy. It necessitates an analysis of the factors and consequences associated with these efforts. Therefore, this article aims to assess and analyze the factors and barriers influencing greenhouse gas (GHG) emissions reduction and the adoption of decarbonization strategies. Furthermore, it seeks to outline the development prospects of EU countries and Ukraine in the context of energy transformation and the achievement of sustainable development. The research findings highlight a trend of decreasing GHG emissions in both the EU and Ukraine from 2006 to 2022, despite the growing dynamics of GDP. In addition, an increase in the share of renewable energy and a decrease in energy intensity of the GDP of the studied countries have been observed. The energy and transport sectors are identified as the most difficult sectors for decarbonization, and therefore the implementation of hydrogen technologies in them is the most urgent. The interdependence between CO<sub>2</sub> emissions, GDP volume, and energy intensity of GDP in European countries has been proven based on the results of regression analysis for the period of 2012-2022. The obtained dependency allows for predicting emissions in European countries, and the lower the energy intensity, the smaller the carbon footprint will be. The government policy of supporting low-carbon technologies, which manifests itself in the adoption and implementation of environmental legislation, in particular hydrogen strategies, is studied. Climate legislation provides a global framework for economic and social transformations to address global warming and transition away from fossil fuels. From 2022, the war in Ukraine has become a serious challenge for the sustainable development of Europe and affects carbon emissions and climate sustainability. Without achieving peace, it is impossible to achieve sustainable development.

**Keywords:** decarbonization, climate, sustainable development, carbon emissions, energy intensity, energy, hydrogen, environment

**JEL Classification:** F01, H41, L50, O13, Q32

## INTRODUCTION

Everyday life and the functioning of the economy depend on reliable and affordable energy services, such as electricity, heating and cooling, and transport services. Energy provides uninterrupted functioning of all economic sectors and is primarily produced from fossil fuels, which leads to an increase in greenhouse gas (GHG) emissions and is accompanied by changes in the climate system. Reducing overall energy consumption and using renewable energy sources, ensuring the security of supply, competitiveness and accessibility of energy for all citizens, are among the ways in which each country can contribute to the achievement of Sustainable Development Goal 7 "Affordable and clean energy" (SDG 7) and the Sustainable Development Goals 13 "Climate action" (SDG 13).

However, the demand for energy in the world is increasing every year. The increased combustion of fossil fuels to meet this demand has seen GHG emissions soar to more than 50 billion metric tons of carbon dioxide equivalent (GtCO<sub>2</sub>e) annually (Statista, 2022a). Approximately 75% of greenhouse gas emissions, which is the main driver of climate change, are attributed to CO<sub>2</sub>.

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Despite a slight reduction in GHG emissions in 2020 due to the outbreak of the COVID-19 pandemic and stringent quarantine measures, global GHG emissions increased by 3.8% to 54.6 billion metric tons of carbon dioxide equivalent (GtCO<sub>2e</sub>) in 2021, driven by easing of quarantine restrictions and economic recovery. The volume of global GHG emissions in 2021 was 44% compared to 1990 (Liu, 2022; Statista, 2022a).

In 2022 Global carbon dioxide from fossil fuels is estimated to have risen by 0.9 percent and the total level of emissions was 37.5 GtCO<sub>2</sub> (Statista, 2023). This growth was primarily driven by increased coal burning worldwide as countries switched back to this polluting fuel during the energy crisis triggered by the Russia-Ukraine war. Nevertheless, this increase was lower than previously expected due to the growth in the deployment of renewable energy sources and other low-carbon technologies (Statista, 2023).

In order to identify the problems that may arise in the transition to low-carbon technologies with the reduction of GHG emissions, the study should focus on the main industries that are the source of the largest share of emissions in the world.

In 2019, around 34% of net anthropogenic GHG emissions were caused by the energy sector, 24% from industry, 22% from agriculture, forestry and other land use (AFOLU), 15% from transport and 6% from buildings (IPCC, 2022).

The energy sector continued to be the world's largest source of fossil carbon dioxide emissions in 2021, emitting 14.3 GtCO<sub>2</sub>. This represented approximately 38% of global CO<sub>2</sub> emissions that year. At the same time, the energy sector plays an important role in decarbonized energy systems to reduce emissions through electrification and electricity-derived fuels (Bistline & Blanford, 2021). The second largest carbon dioxide emitting sector in 2021 was the transportation sector, which released 7.6 GtCO<sub>2</sub> (Statista, 2022b).

As of 2021, 131 countries have discussed, have announced or have adopted net zero carbon footprint targets covering 72% of global emissions (Höhne et al., 2021). Meeting these targets could reduce the increase in average global temperature to 2.0–2.4 °C by 2100, bringing the Paris Agreement (2015) temperature goal within reach.

However, studies (Fekete et. al. 2021; IEA et. al., 2023; Matthews and Wynes, 2022; UNEP, 2022) show that the world is not on track to reach the Paris Agreement goals and global temperatures can reach 2.8°C by the end of the century instead of the declared limitation of global warming below 2°C, preferably 1.5°. Implementation of the current commitments will make it possible to reduce the temperature by only 2.4-2.6 °C by the end of the century. The world must cut emissions by 45 per cent to avoid global catastrophe (UNEP, 2022). Only urgent general systemic transformation and collective multilateral action towards resource and energy-efficient solutions will help avoid a climate catastrophe.

The insufficient effectiveness of countries' actions on the global climate within the framework of the Paris Climate Agreement was assessed as early as 2016 (Rogelj, et al., 2016) on the basis of Intended Nationally Determined Contributions (INDC), outlining their post-2020 climate action. The INDCs collectively lower GHG emissions compared to where current policies stand, but still imply a median warming of 2.6–3.1 degrees Celsius by 2100.

Considering the scale of the growing climate crisis caused by excessive greenhouse gas emissions, the implementation of decarbonization in all spheres of socio-economic life is crucial to transition towards the use of clean "green" energy and ensure sustainable development across all continents.

Decarbonization is a climate-neutral energy system without coal extraction and combustion; it is the process of reducing carbon dioxide (CO<sub>2</sub>) emissions into the atmosphere. The goal of decarbonization is to achieve a globally low-emission economy and reach climate neutrality by transitioning to renewable energy sources. Decarbonization requires a structural change in energy and entails the removal of carbon from energy production. This is electrification based on clean alternative energies that do not harm the environment.

## LITERATURE REVIEW

The relevance of the decarbonization problem causes a wide presentation of all its aspects in many studies and scientific publications.

The research was conducted on the basis of international reports (CCPI, 2023; Eurostat, 2023; Hydrogen Council, 2023; IEA & IFC, 2023; IEA et. al., 2023; UNEP, 2022; UN Ukraine, 2020); Ukraine's reports (KSE. 2023; State Energy Efficiency Agency, 2020; Ministry of Environmental Protection and Natural Resources of Ukraine, 2023; Ministry of Finance, 2023); statistical information worldwide (Statista, 2022a; Statista, 2022b; Statista, 2023; World Bank, 2023; World Economics, 2022; Yearbook, 2023); statistical information of EU (Eurostat, 2023a; 2023b); conference materials "Ukraine Green Recovery Conference" (European Commission, 2023), The international ecological forum "United for Nature. Agenda for

Ukraine" (Ministry of Environmental Protection and Natural Resources of Ukraine, 2024), The Ukraine Recovery Conference 2023 (Ukraine Recovery Conference, 2023); normative regulatory documents (IEA, 2023; UNFCCC, 2015); scientific publications of foreign and Ukrainian scientists.

The theoretical foundations of decarbonization are explored in Peñasco et al. (2021), where the authors assessed the impact of regulatory, economic and financial instruments on environmental, technological and innovation outcomes, and as a result, developed an online interactive Decarbonization Policy Evaluation Tool. The global carbon budget during 2010-2021 is estimated in the Global Carbon Project (2021). Cole et al. (2023) examined the cost of decarbonization based on five types of metrics and concluded that the health benefits outweigh the costs of decarbonization.

Decarbonization in various sectors of the economy has also been studied extensively, particularly in the energy sector by Sepulveda et. al. (2018); Bistline et. al, (2021); automotive industry - Poschmann et. al. (2023); Gunnarsdóttir et. al. (2023), steel production - Rossetto D. (2023a; 2023b), cement and concrete industry - Griffiths et. al. (2023). Decarbonization is also relevant for logistics. In particular, the directions to reduce emissions across all sectors and parts of the supply chain were considered by Gulev et al. (2021); BVL, (2022), and industrial logistics and the main directions of emission reduction - Miklautsch and Woschank (2023).

The financial aspects of decarbonization, including investments by developed and developing countries, as well as the impact of foreign direct investments, have been discussed in the works of Sarkodie & Strezov (2019) and Yan et. al (2023), and also in the reports of the European Commission services and Environment Information and Observation Network (Eionet), Tracking SDG 7: The Energy Progress Report (2023).

Regional aspects of decarbonization are presented in the works of Farnsworth & Gencher (2023); Yan et. al. (2023); Miklautsch and Woschank (2023); Gunnarsdóttir et. al, (2023); Rossetto (2023b).

Analysis of scientific research has led to the conclusion that the issue of decarbonization is quite extensive. However, despite the multifaceted nature of the research, there are still many unanswered questions. In this study, from an economic perspective, we will analyze and compare the current state of greenhouse gas emissions in the European Union and Ukraine, identify the main obstacles, risks, and challenges for decarbonization, and attempt to forecast further directions of development for European countries and Ukraine towards a climate-neutral economy and the achievement of sustainable development.

## AIMS AND OBJECTIVES

The main aim of the article is to investigate the impact of contemporary challenges on greenhouse gas emissions reduction and decarbonization efforts in the EU and Ukraine; to determine the interdependence between carbon emissions and GDP volume along with its energy intensity, and to outline the prospects for further decarbonization of the economies of EU countries and Ukraine in the context of ensuring energy transformation and achieving climate stability.

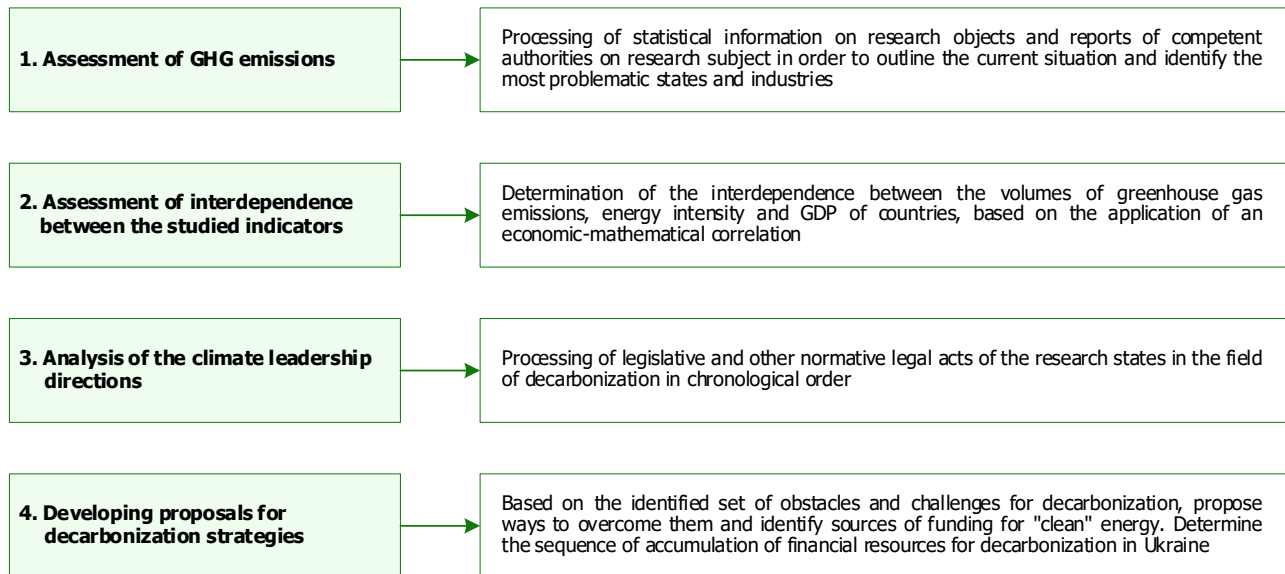
The achievement of the stated goal involves the execution of the following tasks:

- assessment of greenhouse gas emissions in the EU and Ukraine;
- analyzing GDP and Energy Intensity in the EU countries and Ukraine;
- evaluation of the interdependence between the studied indicators;
- examination of climate leadership strategies;
- formulating recommendations for decarbonization strategies.

## METHODS

The study of the current state of decarbonization in the EU and Ukraine requires a continuous approach and processing of the latest analytical and statistical information, in particular reports/ratings from leading international and European environmental organizations and institutions.

The research methodology is based on the following algorithm, which determines the main research stages and includes a number of scientific methods (Figure 1).



**Figure 1. The sequence of scientific research.**

Thus, investigating the state and problems of decarbonization in European countries and Ukraine involves the following sequential stages:

1. Assessment of greenhouse gas emissions is a key stage of the research that enables understanding the scale of the problem and determining the pace at which countries worldwide are moving towards climate neutrality. Methods used include synthesis and analysis, statistical-analytical methods, comparison, and systematization.
2. Assessment of the interdependence between the examined indicators - based on the use of methods such as economic-mathematical correlation, graphical method, and regression analysis, we establish the relationship between the main analyzed indicators to determine the mutual influence.
3. Analysis of the climate leadership directions - based on the exploratory and analytical method of research, analyze the effectiveness of the adopted regulatory acts at both national and regional levels that influence the achievement of climate neutrality.
4. Developing proposals for decarbonization strategies - this is a final, summarizing stage of the research, based on the results of previous investigations. At this stage, we will propose schemes for mobilizing financial resources to reduce greenhouse gas emissions, attract financial investments for green energy development, and create innovative energy-efficient technologies.

Considering that the European Union (as a whole and the leading countries within it) and Ukraine are the main objects of this study, the material processing and conclusion drawing will be based on methods of comparison, generalization, and forecasting trends in the further development of decarbonization in national economies.

## RESULTS

### *Evaluation, analysis and relationship of indicators*

In 2020, the European Union united 27 member countries. Every country strives to increase its GDP, which leads to the use of more resources and requires more energy. It is as a result of the production of goods and services that carbon is released into the atmosphere, which causes the greenhouse effect. The high energy intensity of production causes a greater volume of carbon emissions. Therefore, the volume of GDP of the countries, the level of energy intensity of GDP, the volume of carbon emissions, the share of renewable energy, etc. will be analyzed (Table 1).

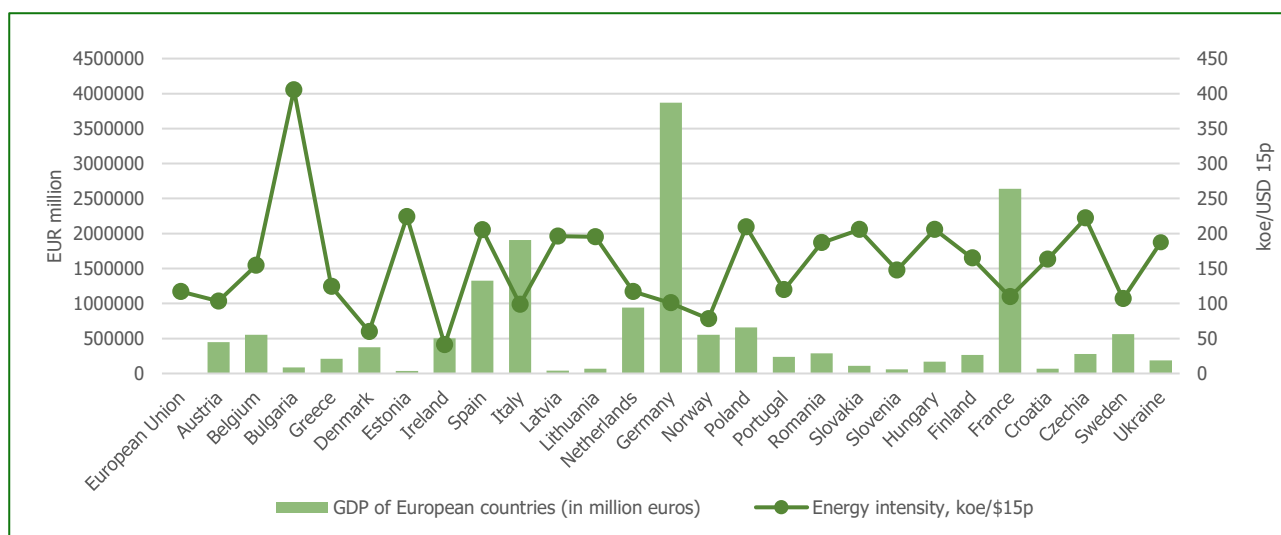
**Table 1. The main indicators of the impact on the environment and climate neutrality (EU and Ukraine in 2022).** (Sources: compiled based on data from the World Economics, 2022; Eurostat, 2023a; Yearbook, 2023)

Countries	GDP, million	Energy intensity, koe/ USD15p	Carbon Emission, Total MtCO <sub>2</sub> e*	Share of renewable energy in gross final energy consumption by sector	CO <sub>2</sub> intensity, kCO <sub>2</sub> / USD15p
European Union	EUR 16 641 000	107.4	3514	23.03	0.134
Ukraine	USD 160 500	156.21	119	16.59	0.352

In 2022, the countries with the largest GDP in the EU were Germany, France, Italy and Spain. The share of the GDP of these countries in the overall European indicator was 24.19%, 16.49%, 11.93% and 8.29%, respectively.

Despite the significant volume of production, among the mentioned countries, Bulgaria took the leading position in terms of energy intensity in the EU – 394.95 koe/USD15p; Estonia – 238.55 koe/USD15p; Czechia-212.22 koe/USD15p; and Poland -189.71 koe USD15p (Eurostat, 2023a).

The GDP of Ukraine in 2022 amounted to USD 160 500 million, which was nearly 1.0 % of the GDP of the EU. The energy intensity of Ukraine's production amounted to 156.21 koe USD15p, which was slightly higher than the average European indicator (Figure 2).

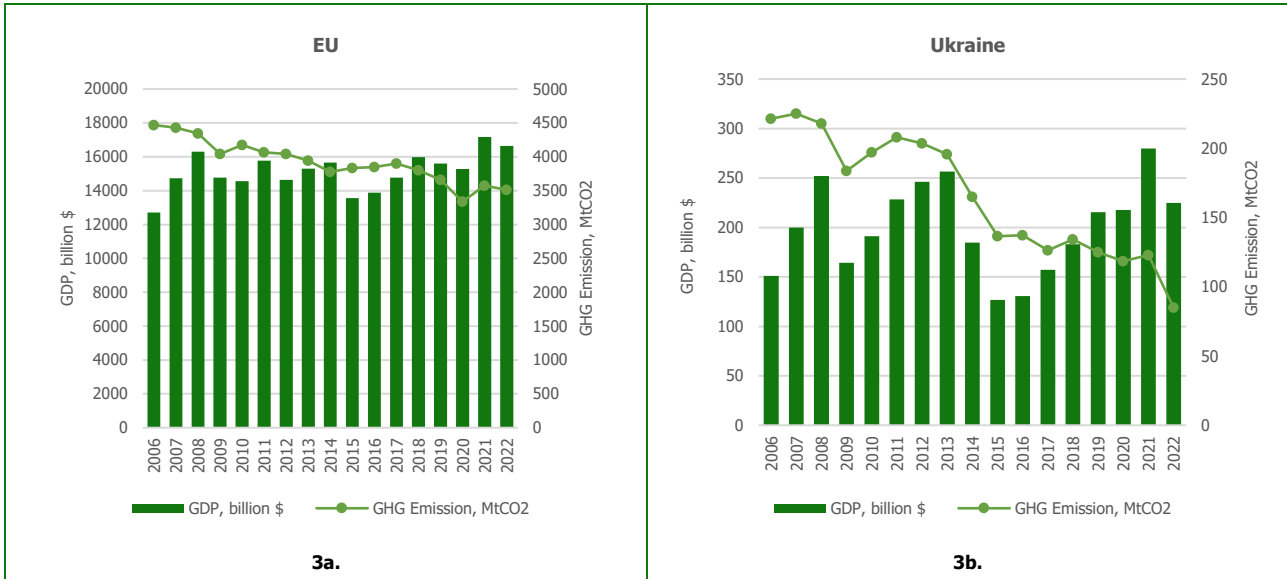


**Figure 2. GDP and Energy Intensity in the EU countries and in Ukraine in 2022.** (Source: compiled based on data from the World Bank, 2023; Eurostat 2023a)

One of the most effective ways to achieve decarbonization goals is to improve energy efficiency through the use of energy-saving or "green" technologies that reduce energy consumption. Therefore, countries that demonstrate high energy intensity (Figure 2) compared to the volume of GDP (Bulgaria, Czechia, Estonia, Poland, Slovakia, Spain, etc.) (Eurostat, 2023a) should make efforts in all spheres of socio-economic life to move towards climate neutrality and achieving the climate SDGs, focusing on the energy transformation measures presented in the Emissions Gap Report 2022: The Closing Window (UNEP, 2022) and on the energy efficiency policy proposed in Tracking SDG7 and in The Energy Progress Report 2023 (IEA et. al., 2023).

However, it is worth noting that in 2022 all EU countries showed a positive trend in increasing the share of renewable energy (Eurostat, 2023b), which is in line with the goals of the Green Deal. Norway remained the leader, with its share of renewable energy in gross final energy consumption increasing to 75.82%. However, countries with the highest CO<sub>2</sub> emissions also increased their share of renewable energy by 1-1.5% on average: Germany 19.39% (2021) - 20.79% (2022); Poland 15.61% (2021) - 16.87% (2022); France 19.20% (2021) - 20.25% (2022). Only a slight decrease was observed in Italy - 19.15% (2021) - 19.00% (2022).

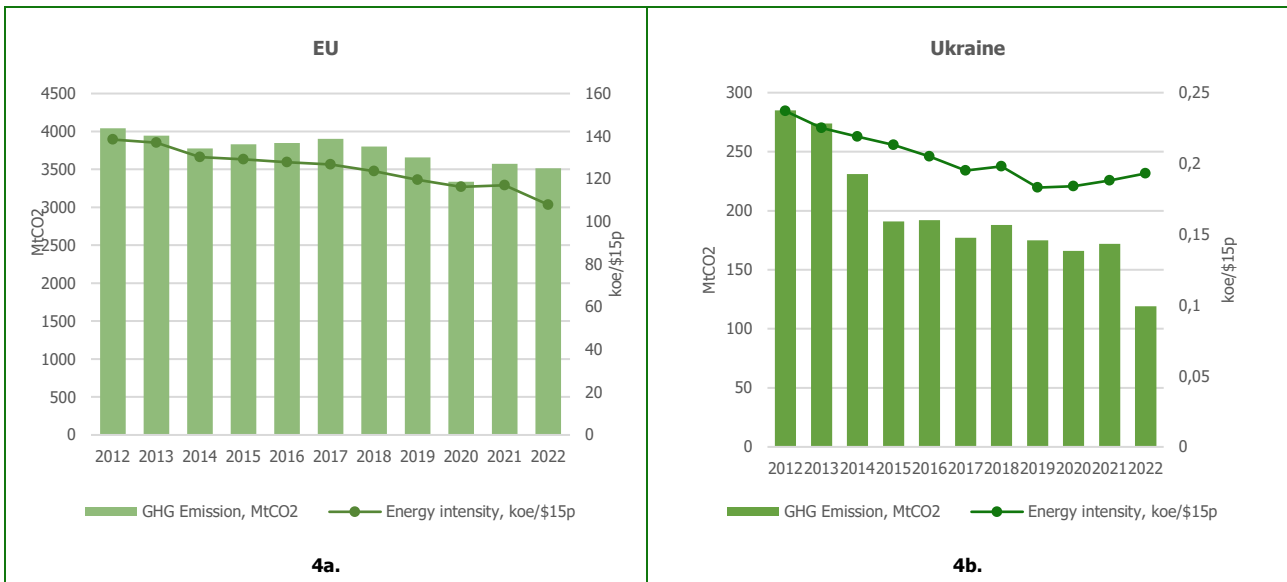
According to the Yearbook (2023), total CO<sub>2</sub> emissions from fuel combustion in Europe in 2021 were 3 514 MtCO<sub>2</sub>, and in Ukraine - 119 MtCO<sub>2</sub>. It is worth noting the downward trend of greenhouse gas emissions in both Europe and Ukraine during 2006-2022 along with the growing GDP dynamics. This indicates the intensification of energy-saving measures and the gradual decarbonization of GDP (Figures 3a, 3b).



**Figure 3. GDP and GHG Emission of the European Union (3a) and Ukraine (3b) in 2006-2022, USD billion, MtCO2.** (Source: compiled based on data from the Yearbook, 2023; World Bank, 2023)

During 2006-2022, GHG emissions in the EU decreased by 1.27 times (Yearbook, 2023), while GDP grew and increased by 1.3 times (World Bank, 2023). In Ukraine, the downward trend of GHG emission has a greater slope amplitude than in the EU. This indicates the significant efforts of the Ukrainian government in decarbonization and achieving climate neutrality: over 17 years, GHG emissions have decreased by 2.6 times (Yearbook, 2023).

In order to establish interdependence, we will study the dynamics of energy intensity of GDP and greenhouse gas emissions in the European Union and in Ukraine in 2012-2022 (Figure 4).



**Figure 4. Dynamics of energy intensity of GDP and greenhouse gas emissions in the European Union (4a) and in Ukraine (4b) in 2012-2022, MtCO2.** (Source: compiled based on data from the Yearbook, 2023; Eurostat 2023a)

The data trends depicted in Figure 4 demonstrate a decrease in all indicators both in the EU and Ukraine from 2012 to 2021, highlighting a direct correlation between GHG emissions and energy intensity of production. That is, the amount of GHG emissions is the result of energy consumption in the country, and the higher the energy efficiency of the GDP, the less emissions will be generated. Sarkodie and Strezov (2019) hold a similar opinion in the study and indicate a strong positive effect of energy consumption on CO2 emissions. Thus, in 2012-2022, the EU demonstrated a movement towards achieving climate sustainability. In Ukraine, starting from 2022, other factors began to act in order to reduce greenhouse gas emissions - a sharp reduction in industrial capacity associated with military aggression on the territory of the state.

The interdependence between CO2 emissions, GDP volume, and energy intensity of GDP in European countries has been proven based on the results of regression analysis for the period of 2012-2022. The coefficient of determination of the linear model obtained is  $R^2 = 0.785$ , which confirms a significant positive correlation between the investigated factors with a probability of 0.95. In other words, the coefficients of the model are statistically significant. The regression gives the following model of interdependence between the indicators:

$$GHG \text{ Emission} = \frac{913,44}{\beta_1} - \frac{0,0046}{\beta_2} GDP + \frac{23,14}{\beta_3} \text{ Energy intensity}$$

where: *GDP* - in USD billion, *Energy intensity* - in koe/USD15p.

The obtained dependency allows for predicting emissions in European countries, and the lower the energy intensity, the smaller the carbon footprint will be. Currently, Europe's energy intensity is already 42% lower than the world average.

However, this econometric interdependence cannot be applied to Ukraine due to the military aggression of the Russian Federation on the territory of Ukraine, which leads to a destructive impact on the entire economic system of the country, prompting a 20% reduction in GDP in 2022 (Ministry of Finance, 2023) and, consequently, greenhouse gas emissions.

Based on previous estimates, throughout 2022, total GHG emissions in Ukraine could have decreased by approximately 60-80 million tons of CO2 equivalent, of which 28 million tons of CO2 equivalent were in the energy sector (Ministry of Environmental Protection and Natural Resources of Ukraine, 2023). Meanwhile, according to other studies (Bielousova, 2023), approximately 33 million tons of CO2 were released into the atmosphere as a result of the military actions. The main sources of emissions during the period of hostilities were:

- fires – 23.8 million tons of CO2;
- combat actions – 8.9 million tons of CO2;
- displacement of internally displaced persons and refugees – 1.4 million tons of CO2.

Ukraine's green energy sector also suffered significant damage, as 85% of wind farms and 50% of solar power plants were destroyed.

Russia's war against Ukraine is causing irreparable damage to the environment and accelerating climate change through increased greenhouse gas emissions. There can be no effective climate policy without peace and sustainable development.

Thus, prior to the full-scale invasion of Ukraine by Russia, the Ukrainian government demonstrated its commitment to European and global environmental values, particularly in achieving the SDGs and reducing GHG emissions. However, the war initiated by Russia on February 24, 2022, completely disrupted all efforts and acted as a powerful destructive force majeure, the consequences of which are impossible to predict even today. The war in Ukraine inflicts irreparable damage to the environment and accelerates climate change through increased greenhouse gas emissions. Without achieving a reduction in greenhouse gas emissions in Ukraine, as the largest country in Europe, it is impossible to achieve carbon neutrality on the continent. Effective climate policy cannot exist without peace and sustainable development.

### *Climate Policy of the EU and Ukraine*

Continued support for low-carbon technologies needs to be combined with government policies directed at phasing out the use of fossil fuels. The global basis for economic and social transformations in the direction of overcoming global warming through the reduction of greenhouse gas emissions was laid in the Paris Agreement (2015) - a legally binding international treaty on climate change.

Peters et. al. (2020) research found that larger and more comprehensive policy portfolios are conducive to emission reductions. And Peñasco's et. al. (2021). study substantiated that regulatory instrument are generally associated with positive climate impacts on environmental, technological and innovation outcomes.

There are more than 1,800 laws on climate change in the world. A total of 131 countries have been discussing, have announced or have adopted net zero targets, covering 72% of global emissions (Höhne et al., 2021). Eskander and Fankhauser (2020) argue that each new law reduces annual carbon dioxide (CO2) emissions per unit of gross domestic product by 0.78% nationally in the short term (during the first three years) and by 1.79% in the long term (beyond three years). Such political measures, according to Rogelj et al. (2016), can significantly reduce the projected warming as compared to currently implemented policies (2.9–3.2°C) or pledges submitted to the Paris Agreement (2.4–2.9°C). Höhne et al. (2021) share the same opinion. In 2016, current climate laws were associated with an annual reduction in global CO2 emissions

of 5.9 GtCO<sub>2</sub> (Eskander and Fankhauser, 2020). At the same time, countries with fast-increasing emissions have significantly fewer policies overall but policies are especially missing in energy-demand sectors, such as building and transport (Nascimento and Höhne, 2023).

Thus, expanding the implementation of climate policy is desirable to slow down future emissions. However, despite a collective increase in current policy, in force, countries can still expand legislative framework to use the full breadth of mitigation options available.

The main regulatory documents of the EU countries and Ukraine, which form the legislative basis of climate policy, are presented in Table 2.

**Table 2. Main climatic regulatory documents of the EU and Ukraine.** (Source: compiled based on data from the IEA, 2023)

Countries	Name of the documents	Year
European Union	Directive 2003/87/EC dated 13.10.2003 Regarding the establishment of a scheme to reduce greenhouse gas emissions by trading within the Community	2003
	The European Climate Change	2000
	Paris Climate Agreement	2015
	The European Green Deal	2020
	EU Strategy for Energy System Integration	2019
	EU Hydrogen Strategy	2020
	"Fit for 55"	2021
<b>in particular</b>		
Italy	Italian hydrogen strategy	2020
	Budget Law 2007 - Energy efficiency provisions	2007
United Kingdom	Energy Act	2008
	UK hydrogen strategy	2022
Ireland	Low Carbon Homes Programme	2008
Hungary	National Energy Conservation Programme 2008 (NEP 2008)	2008
France	Retailer Sustainable Commerce Agreement	2008
	The French Green Hydrogen Plan 2020-2030	2020
Germany	Renewable Energies Heat Act	2009
	The National Hydrogen Strategy	2022
Poland	Polish Energy Policy until 2030	2009
	"My Electricity" Programme	2019
	Energy Plus Priority Programme	2019
	Polish Geothermal Energy Plus Programme	2019
	Energy Law	2021
National Recovery Plan	2022	
Croatia	EU Cohesion policy: Energy-efficiency heating system	2021
Lithuania	Economic Recovery and Resilience "New Generation Lithuania" / Green Transformation / Sustainable Electricity	2021
	National Recovery and Resilience Plan / M2C2: Renewable energy, hydrogen, grid and sustainable mobility	2021
Czech Republic	National recovery plan / 2. Physical infrastructure and Green Transition / Transition to cleaner energy sources	2021
Slovenia	Recovery and Resilience Plan / 1. Green transition / Renewable energy sources and energy efficiency in the economy	2021
Portugal	Recovery and resilience plan / CTD / Hydrogen and renewables/ Potentiation of renewable electricity in the Madeira Archipelago	2021
Spain	Environmental Fund program - Sustainable Buildings	2020
	Spanish Strategy on Climate Change and Clean Energy 2007-2012-2020	
	Recovery, transformation and resilience plan / Modernisation of public administration (IV)	2021
	Spain 2050 strategy: circular and carbon-neutral economy	2021
Finland	Sustainable growth agenda / Pillar 1/ 1- The framework of the energy system	2021
Ukraine	"On Alternative Energy Sources" Law of Ukraine	2003
	Ukrainian hydrogen strategy (project)	2021
	On the responsible consumption of natural resources (project)	2021

As we can see, a large number of climate documents were adopted in the period of 2007-2008 and earlier, we believe that the starting point for the actuation of GHG emissions reduction and decarbonization of all public life's spheres was The Paris Agreement (UNFCCC, 2015).

The conducted research showed that the transition to a green hydrogen economy was enshrined in the EU Hydrogen Strategy – an important part of the European Green Deal (2020) on achieving climate neutrality by 2050 and greening the economy. Currently, many countries, including world leaders such as Italy, the United Kingdom, Germany, and France, present their own national hydrogen strategies within the European concept.

At the end of 2021, the "Ukrainian Hydrogen Council" together with the Institute of Renewable Energy of the NAS developed and presented the project Hydrogen Strategy of Ukraine (Institute of Renewable Energy, 2021).

At the legislative level, the policy of "green" reconstruction of Ukraine is proposed by the draft law "On responsible consumption of natural resources", which is designed to harmonize the legislation of Ukraine and the EU. In addition, Ukraine is talking about the implementation of the European Green Course, the main goal of which is a climate-neutral Europe by 2050.

If Ukraine is moving towards the European Union, it should align itself with its reference points and directives. However, European legislation needs to be analyzed and adapted to ensure its effective implementation in Ukraine without causing harm.

### *Problems and prospects of decarbonization in the EU and Ukraine*

The whole world is facing the climate problem and is now engaging in decarbonization, and each country determines its own ways to achieve global goals. The energy transition to renewable energy sources relies on the commitment of international organizations, countries and individuals to define and follow the steps to move in the common direction of emissions mitigation (Enerdata, 2023). Such a shared direction of energy transformation should be defined for all European countries, including Ukraine, despite the ongoing military aggression on its territory.

The most significant measures taken by EU countries to accelerate decarbonization and achieve climate neutrality are outlined in the legislative package "Fit for 55," which includes the development of the European Union Emission Trading Scheme (EU ETS). EU ETS is a carbon market based on a cap-and-trade system for emissions in energy-intensive industries and the electricity production sector. It is the primary tool used by the EU to combat emission reductions and aims to reduce emissions in relevant sectors by 62% by 2030 compared to 2005. The package introduces the following changes:

- inclusion of maritime emissions in the EU ETS, with all emissions allowances becoming payable from 2026;
- phasing out of the free allocation of emissions allowances for aviation, with 100% of aviation emissions allowances to be sold via auction from 2026;
- implementation of the global Carbon Offsetting Scheme for International Aviation (CORSIA) through the EU ETS. CORSIA is a global scheme adopted by the International Civil Aviation Organization (ICAO) in 2018 to offset CO<sub>2</sub> emissions from international aviation;
- increased funding from the Modernization Fund through the auctioning of an additional 2.5% of the emissions allowances cap and the Innovation Fund, which will receive funds from the sale of an additional 20 million allowances resulting from the expansion of the EU ETS to include maritime activities;
- strengthening the Market Stability Reserve (MSR) by extending the period after 2023 with an elevated level of annual allowances (24% of the total volume, up to a maximum of 400 million allowances) directed to the MSR. The MSR is a reserve where a certain percentage of emissions allowances are annually placed to be released into the market (European Council, 2022).

In the European Union, there is a clear and well-developed strategy for reducing carbon emissions, which will gradually ensure EU policy alignment with climate targets and provide a coordinated and balanced foundation for achieving EU climate goals.

However, despite the outlined decarbonization roadmap, Europe's reliance on fossil energy resources remains high, posing a challenging problem that is difficult to overcome in the near future. For instance, Europe imports around 400 billion cubic meters of gas per year, including 175-200 billion cubic meters from Russia (equivalent to 370 GW of electricity), making it challenging to replace these supplies with alternatives and reduce gas consumption. Approximately 40% of natural gas consumption is attributed to residential needs. This situation is further exacerbated by bureaucratic delays in implementing green energy projects, regional disputes among regulatory bodies, and significant local opposition to the construction of energy facilities, along with insufficient funding, among other factors (The Economist, 2022).

Thus, on one hand, the issue of energy resource deficits remains unresolved in Europe, raising concerns about meeting the industrial and domestic demands for natural gas and coal. On the other hand, the inability to replace the consumption of fossil fuels with renewable energy sources will limit the reduction of greenhouse gas emissions by this volume. Although efforts to decarbonize sectors that produce the highest CO<sub>2</sub> emissions will help achieve the desired climate neutrality and set climate SDGs.

Implementation of initiatives to achieve climate neutrality requires significant financial resources, which can only be realized through collective efforts.

According to the research on Sustainable Development in Europe (Eurostat, 2023b), the contribution of the European Commission, the European Investment Bank, and EU member states to international climate-related financial commitments amounted to USD 100 billion from 2014-2021. This figure serves as a measure of the overall amount spent on climate financing in accordance with the United Nations Framework Convention on Climate Change (UNFCCC). International financial commitments are also aimed at ensuring and supporting enhanced actions by developing countries to promote low-emission development and climate resilience, as envisioned by the Paris Agreement (2015) and the Scaling Up Private Finance for Clean Energy in Emerging and Developing Economies report by the International Energy Agency and International Finance Corporation (IEA & IFC, 2023). As highlighted in studies (Sarkodie and Strezov, 2019; Yan Chen et al., 2023), it is often recognized that the financial sectors in developing countries are insufficiently developed to finance climate-related initiatives.

But according to Tracking SDG 7: The Energy Progress Report (IEA et. al., 2023), the volume of public international financial flows to developing countries in support of clean energy research and development and renewable energy production (together referred to as renewables throughout this chapter) decreased in 2020 and 2021. In 2021, these flows totalled USD 10.8 billion, down 11.4 per cent from 2020. This level matched the investment levels of 2012, the lowest investment levels recorded over the last 10 years.

Thus, the actual barriers to CO<sub>2</sub> emissions reduction and comprehensive decarbonization in European countries are primarily the significant dependence of the economic system on natural gas and coal, the consumption of which cannot be significantly reduced in the near future, as well as the insufficient volume of international financial flows to developing countries for financing energy transformation.

Ukraine, as a European state, shares European values and has been striving to achieve them in order to become a member of the EU. As evidenced by the conducted research, Ukraine made significant efforts to reduce CO<sub>2</sub> emissions before the full-scale invasion by the Russian Federation and the onset of hostilities, which decreased by a factor of 1.98 from 2006 to 2021 (Yearbook, 2023). Moreover, Ukraine has also made progress in reducing the energy intensity of its industry, which decreased by a factor of 3.54 during the same period (Yearbook, 2023), as well as increasing the share of renewable energy in various sectors, reaching 16.1% in 2021 (Yearbook, 2022). However, the war has negated all these achievements and inflicted significant (and sometimes irreversible) damage to the country's economy, energy sector, and environment. As of the end of October 2023, the total amount of such damages to Ukraine's energy infrastructure amounted to USD 10.3 billion (including USD 2 billion for the destruction of the Kakhovka HPP), with 50% of solar and wind energy stations being destroyed (KSE, 2023). The total amount of damage caused to the infrastructure of Ukraine due to the war as of January 2024 is USD 155 billion (KSE, 2024). The war has proven to be an unforeseen, force majeure, and extremely destructive factor, the consequences of which Ukraine will continue to overcome for a long time.

However, despite the ongoing hostilities in Ukraine, the countries of the whole world, and especially the USA, EU countries, and Great Britain, extremely support the state both at the front and in economic recovery. In particular, the recovery of Ukraine was discussed at the international conference The Ukraine Recovery Conference 2023 in London on 21-22 June 2023 (Ukraine Recovery Conference, 2023), where Great Britain announced the provision of 62 million pounds to the Green Innovation Fund, and the United States provided USD 120 million for energy restoration. The provided funds are crucial for decarbonizing Ukraine's economy and implementing energy efficiency measures.

The Government of Ukraine is already working towards the future by mobilizing funds for energy restoration, improving the energy efficiency of the economy, and establishing a Green Innovation Fund. An energy-inefficient economy is a priority for Ukraine's recovery and was discussed at the "Green Recovery of Ukraine" conference in Vilnius, Lithuania, from November 28 to December 1, 2023 "Ukraine Green Recovery Conference" (European Commission, 2023), and at the international ecological forum "United for Nature. Agenda for Ukraine" held in Kyiv on January 31, 2024 (Ministry of Environmental Protection and Natural Resources of Ukraine, 2024). The new economy of Ukraine will align with sustainable development, be decarbonized, and energy-efficient, and contribute to achieving the goals of climate neutrality for the European continent.

In the future, the European Union considers Ukraine as the main exporter of energy hydrogen to the leading "hydrogen" countries of the European Union, planning to invest at least EUR 40 billion in hydrogen energy by 2030 (Hydrogen Council, 2023). Therefore, the Ukrainian government should use this advantage to attract investments and import the latest technologies from the EU, Japan and other "hydrogen" countries to build factories for the production of "green" hydrogen in order to become one of the world's leading exporters of fuel for all types of hydrogen transport in the coming years. Already today, the Ukrainian authorities should emphasize the prospect of using hydrogen technologies and adjust the Concept of hydrogen energy in Ukraine.

Currently, hydrogen is becoming the main pillar of the energy transition in the transportation sector. The European Union is actively involved in developing the ecosystem of its countries in terms of automobiles. This includes not only charging stations but also investing around 60 billion in the development of hydrogen energy and infrastructure (IEA & IFC, 2023).

The development of hydrogen transportation is also important for Ukraine and appears to be quite realistic. The main reason is the reduction of GHG emissions, almost a quarter of which are produced by automobiles. In addition, transitioning to alternative energy sources will reduce dependence on oil and gasoline-exporting countries.

Rebuilding the energy sector of post-war Ukraine should be done in accordance with European standards. The new energy system should be sustainable and decarbonized, meeting the requirements of Ukraine's energy and economic security, as well as aligning with the country's economic structure and development needs during the recovery process. The energy efficiency of the new energy sector should encompass all stages, from extraction of energy resources, their production, generation, transportation, and distribution, to utilization, aiming to achieve European climate neutrality goals. These components should be supported by appropriate normative and legal regulations and institutional mechanisms for policy implementation.

We believe that the main principles guiding Ukraine's post-war energy transformation towards decarbonization should include:

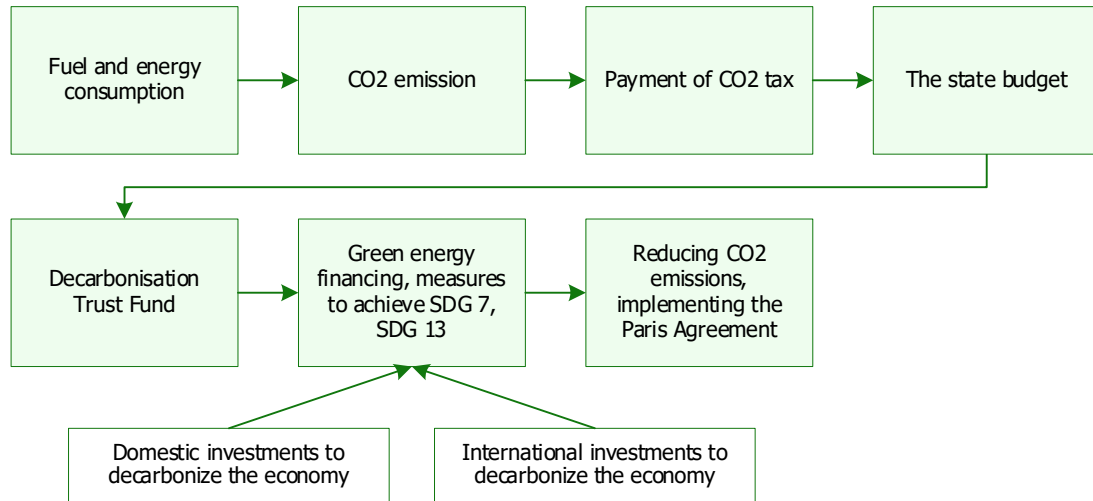
- transition to renewable energy sources, with a priority on hydrogen technologies;
- energy efficiency across all sectors of the national economy;
- energy self-sufficiency based on intensive development of domestic resources and technological base, with wide utilization of low-carbon sources;
- responsible environmental stewardship.

The mobilization of financial resources, including budgetary, international, and investment, plays a crucial role in decarbonizing Ukraine's economy and implementing energy efficiency measures. Particularly, international assistance is presently required by Ukraine for the realization of two directions: the immediate restoration of damaged energy infrastructure and the strategic goal of ensuring access to affordable, reliable, sustainable, and modern energy sources. In this context, it is essential that environmental funds are allocated with a clear and targeted purpose.

Unfortunately, direct budget financing for eco-modernization is lacking in Ukraine. Therefore, it is essential to actively develop funds that will accumulate domestic and foreign investments for the implementation of measures to stimulate energy efficiency in the national economy. However, Ukraine needs assistance to achieve victory and reconstruction. Every country in the world must understand that war is costly. Every civilized country must make its contribution. Without this, sustainable peace and development are impossible. Each day of war moves the civilized world further away from achieving the civilized goals of sustainable development.

Ukraine should also leverage European experience in taxing CO<sub>2</sub> emissions, which is an important tool for incentivizing investments in green logistics. Subsequently, the tax should be increased to the average European level of 6 EUR 0-80 per ton (Public report of the State Energy Efficiency Agency in Ukraine. Results of 2020), which will accelerate the trend towards emissions-free technology adoption.

The proposed funding directions for decarbonization in Ukraine are presented in Figure 5.



**Figure 5. Sources of financing decarbonization in Ukraine.**

## DISCUSSION

The results obtained during the study of the prerequisites, challenges, and further prospects of decarbonization in the EU countries and in Ukraine prompt scientific discussion along several lines.

First of all, attention should be drawn to the research by scientists (Rogelj, et al., 2016) and the findings of the Tracking SDG7. The Energy Progress Report 2023 (IEA et al., 2023) regarding the failure to meet the requirements of the Paris Agreement and the inadequate progress of the world towards reducing greenhouse gas emissions.

In our opinion, the analysis conducted in the article provides grounds to argue that Europe is implementing sufficient measures to reduce CO<sub>2</sub> emissions, transform the economy towards renewable energy sources, and achieve climate neutrality on the continent. Although global CO<sub>2</sub> emissions increased by +2.5% to a record level in 2023, surpassing the 2019 level, aggregate CO<sub>2</sub> emissions in Europe decreased by -2%, including a decrease of -1.8% in the EU (Yearbook, 2023). In fact, Europe is the only continent moving towards reducing its carbon footprint and achieving climate neutrality. Therefore, in studies of global progress towards reducing greenhouse gas emissions and reducing global temperatures, it is important to highlight the achievements of each continent.

Another point of discussion is the proposed econometric interdependence in the article.

The relationship between CO<sub>2</sub> emissions and energy dependency on GDP in European countries has already been studied in the works of scientists (González-Álvarez M., Montañés A., 2023; Sarkodie S. A., Strezov V., 2019; Onofrei M., Vatamanu A.F., Cigu E., 2022). The scholars have concluded that the relationship between economic growth, energy consumption, and carbon emissions is not stable. We concur with the research findings; however, the stability of the development of EU countries over the past 10 years allows us to derive a mathematical relationship between these indicators based on econometric calculations using Eurostat data from 2012 to 2022 (Eurostat, 2022a; 2023a).

At the same time, we note that the econometric dependency developed by us cannot be used to forecast CO<sub>2</sub> emissions in Ukraine - during any crisis, including a military one, forecasts and models do not hold true.

Considering the significant share of transportation in the overall volume of greenhouse gas emissions worldwide, we agree with the opinions of scientists (Roy A., Pramanik S., 2024; Moriarty P., Honnery D., 2019) on the necessity of intensifying the transition of vehicles to hydrogen fuel cells. This will facilitate the departure from excessive use of fossil fuel resources and reduce more than a quarter of CO<sub>2</sub> emissions.

## CONCLUSIONS

The research allowed for a comprehensive examination of the problems and prospects of decarbonization in the EU and Ukraine. The necessity of decarbonization and energy transformation is driven by the negative impact of significant GHG emissions, which leads to climate change, including global warming. Decarbonizing the economy is an ambitious and promising global goal, the implementation of which will help achieve energy efficiency and climate neutrality.

The EU countries and Ukraine have made significant efforts to reduce CO<sub>2</sub> emissions, as evidenced by the analysis of indicators from 2006 to 2022. The study revealed a decrease in the energy intensity of GDP and an increase in the share of energy from renewable sources, indicating a direct correlation between energy efficiency and greenhouse gas emissions in the EU countries.

The relationship between CO<sub>2</sub> emissions, GDP, and energy intensity has been proven through regression analysis and econometric modelling. The obtained dependency allows for predicting emissions in European countries, and the lower the energy intensity, the smaller the carbon footprint will be.

The state policy aimed at gradually phasing out the use of fossil fuels as a direction of climate leadership is crucial for achieving sustainable climate development. EU countries and Ukraine have adopted and are implementing national strategies to reduce GHG emissions and transition to hydrogen technologies in the future. This is a significant step towards decarbonization, which is already being implemented today.

It has been identified that the main challenges on the path to decarbonizing the economies of European countries and achieving climate neutrality are the dependence on fossil fuels and the impossibility of completely transitioning the energy system to renewable energy sources in the short term. Decarbonizing the transportation sector, which traditionally relies on carbon-based fuels, also presents a significant problem.

Since 2022, the war in Ukraine has become a major challenge for European society, causing an energy crisis in Europe and resulting in a 23% increase in CO<sub>2</sub> emissions in Ukraine compared to 2021. The war has disrupted the interdependence between GDP and carbon emissions, as well as caused significant damage to Ukraine's energy infrastructure, which amounted to USD 10.3 billion as of June 2023.

Overcoming the challenges of decarbonization is a key task for achieving climate neutrality in Europe and ensuring a sustainable future for the next generations. Therefore, it is necessary to develop state/international/global mechanisms for financing climate neutrality to address the issue of insufficient financial resources for the greening of the economy, especially in developing countries. Additionally, funding is required for the energy transition of Ukraine based on the principles of climate neutrality.

To accelerate the decarbonization process, the Ukrainian government should attract investments and import cutting-edge hydrogen technologies for the construction of plants producing "green" hydrogen, aiming to become a major exporter of energy hydrogen to leading "hydrogen" countries in the EU in the future. Furthermore, the main principles guiding Ukraine's post-war energy transformation towards decarbonization should include transition to renewable energy sources, with a priority on hydrogen technologies; energy efficiency across all sectors of the national economy; energy self-sufficiency based on intensive development of the domestic resource and technological base, with wide utilization of low-carbon sources, and responsible environmental stewardship.

Therefore, it is essential to actively develop funds that will accumulate domestic and foreign investments for the implementation of measures to stimulate energy efficiency in the national economy

To further advance decarbonization in the EU and Ukraine, future research should focus on identifying innovative technological solutions, exploring policy instruments to incentivize sustainable practices, and assessing the socio-economic impacts of decarbonization initiatives. Collaborative efforts between governments, industry stakeholders, and civil society are essential to drive forward the energy transformation agenda and meet the temperature goals outlined in the Paris Agreement.

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## ADDITIONAL INFORMATION

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*The Authors declare that there is no conflict of interest.*

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## ДЕКАРБОНІЗАЦІЯ ЯК ЗАПОРУКА СТАЛОГО РОЗВИТКУ: ВИКЛИКИ Й ПЕРСПЕКТИВИ ЄС ТА УКРАЇНИ

Досягнення сталого розвитку в усьому світі значною мірою залежить від упровадження комплексної енергетичної трансформації та декарбонізації в усіх секторах економіки. Це потребує аналізу чинників і наслідків, пов'язаних із цими зусиллями. Тому це дослідження має на меті оцінити й проаналізувати чинники та бар'єри, що впливають на скорочення викидів парникових газів (ПГ) і впровадження стратегій декарбонізації. Окрім того, стаття окреслює перспективи розвитку країн ЄС та України в контексті енергетичної трансформації й досягнення сталого розвитку. Результати дослідження підкреслюють тенденцію до зменшення викидів парникових газів і в ЄС, і в Україні з 2006 по 2022 рік, незважаючи на зростання динаміки ВВП. Крім того, спостерігається збільшення частки відновлюваної енергетики та зниження енергоємності ВВП досліджуваних країн. Енергетика й транспорт визначені як найскладніші для декарбонізації сектори, а тому впровадження водневих технологій у них є найбільш актуальним. За результатами регресійного аналізу за період 2012-2022 рр. доведено взаємозалежність між викидами CO<sub>2</sub>, обсягом ВВП та енергоємністю ВВП в країнах Європи. Отримана залежність дозволяє спрогнозувати викиди в європейських країнах,

і чим менша енергоємність, тим менший буде вуглецевий слід. Досліджено державну політику підтримки низьковуглецевих технологій, яка виявляється в ухваленні та реалізації екологічного законодавства, зокрема водневих стратегій. Законодавство щодо клімату забезпечує глобальну основу для економічних і соціальних перетворень із метою подолання глобального потепління та переходу від викопного палива. З 2022 року війна в Україні стала серйозним викликом для сталого розвитку Європи та впливає на викиди вуглецю й стійкість клімату. Без досягнення миру неможливо досягти сталого розвитку.

**Ключові слова:** декарбонізація, клімат, сталий розвиток, викиди вуглецю, енергоємність, енергія, водень, навколишнє середовище

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