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Perspective on decarbonization in Ukraine: Selected issues

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Abstract. The aim of this paper is to research Ukraine's path to decarbonization and the European Union's Green Deal "green" *acquis*, to make a successful accession to the European Union. Research methods applied in this paper are two-fold. First layer consists of review and analyse of the respective Ukrainian and EU's legal acts and official documents with desk study on relevant literature and official institutions' documents. Comparative studies are in use to analyse the issue with quantitative method based on secondary statistical data and qualitative method when analysing legal provisions. Second layer consists of descriptive statistical methods including positional and classical measures of population characteristics, as well as methods for determining linear trends and forecasting time series. To assess the accuracy of the forecasts, ex post error measures were used, which are of fundamental importance for evaluating forecast quality. The forecasts were generated for the maximum permissible time horizon, up to the year 2030, a deadline date due to Kyoto Protocol and Paris Agreement and 2035, a date of development Ukraine's fuel and energy due to 2017 Strategy. The outbreak of a military conflict hampered, but not squander the successful pace started in 1990-2022 to reduce GHG emissions in these dates.

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1. INTRODUCTION

Since the Paris Agreement of December 2015 (United Nations 2015), the European Union has been working on a long-term vision strategy that aimed - similarly to its predecessors - at reducing greenhouse gases (GHG) emissions and pollution to reverse negative warming effects, and disastrous climate change scenes observable worldwide. „Nothing can be added to the dramatic findings /…/ about how the limits of the Earth's carrying capacity have already been exceeded, how global resource consumption and global waste volumes will nevertheless continue to increase if nothing is done, and to what extent the resource extraction and processing practices currently in use contribute to climate problems, biodiversity loss and water stress" (MoreTrees, 2020). The problem lies in carbon dioxide (CO_2) excessive emission. Together with other GHG its level have been steadily increasing through the decades. Between 2000 and 2020, the Earth's emissions more than quadrupled from the previous decade. To slow degradation of Nature and warming effect, EU has made a collective effort to put very ambitious goals to its legal sources, *acquis*. The European Green Deal and CBAM are expected and supposed to make EU a carbon-free zone till 2050. All candidate countries to the EU are obliged to fulfil "go green" obligations as a strict requirement to become EU member state. As far as Ukraine is involved as a candidate country, it is also bound by this *acquis*.

The main aim of this paper is to research upon applied methods – comparative legal studies of Ukrainian and EU's official documents and law, analysis of secondary statistical data and descriptive statistical methods including both positional and classical measures together with methods for identifying linear trends and forecasting time series to assess and estimate dispersion between "wishes" and "realities" in Ukraine, a candidate country for the EU membership. Picture that comes out our analysis is dual and contradictory. Legal analysis approach shows that Ukraine is not on the track to fulfil the EU "green" requirements, while statistical approach shows clear possibility to successful reduction of GHG emissions regardless the wartime.

2. LITERATURE REVIEW

2.1. Towards green solutions against carbonization in the EU

In 2011, the European Commission put forward a roadmap for a competitive low-carbon Europe by 2050. The roadmap presented possible action up to 2050 which could enable the EU to deliver greenhouse gas emission reductions in line with the 80 to 95% target agreed internationally in the context of necessary reductions by developed countries as a group. The roadmap outlined milestones towards the target, policy challenges, investment needs and opportunities in different sectors (2050 long-term strategy). According to a Report by the Intergovernmental Panel on Climate Change (IPCC) of October 2018, our planet was warming by 0.2 °C per decade. The increase could reach 2 °C by 2060. Its impacts of climate change will worsen worldwide and affect nature, societies and economies worldwide (European Union 2019). Rio+20 Conference presented "the green economy" as the intersection between environment and economy (Leggett et al., 2012; Mentes, 2023). Due to its assumptions development, industrialization, growth and natural environment protection can go together in "win-win" solutions, which stays in contradiction to previous "either-or" solutions (Mentes, 2023; Loiseau et al., 2020). "The systematic decoupling of rates of change in economic output and the environmental assets used up in that process" is on (Pearce, 1992; Bąk et al., 2020;

UNEP, 2011; UNEP, 2011a; Mukhtarov et al., 2024). Green solutions lead "sustainable development". Their broad goals are introduced in the European Green Deal (Barbier et al. 1989, 2013; Report, 1987; Leggett et al., 2012; Kirchherr et al., 2017). Adopting this document the EU aimed to be climate-friendly and carbon-neutral zone by 2050 - to run an economy with net-zero GHG emissions. This objective is at the heart of the European Green Deal. The Low Carbon Economy Roadmap shows that a transition towards a carbon low economy means reductions in its domestic emissions by 80% by 2050 compared to 1990. The European Union a leader in carbon neutral economy transition together with the European Commission outlined seven main strategic building blocks, among which for example there was a competitive EU industry and the circular economy as a key enabler to reduce GHG emissions, put together with projects on carbon reduction mechanisms and renewable energy resources (European Union, 2014; The roadmap…). Decarbonization is the process of reducing carbon dioxide (CO_2) emissions resulting from human activities, and especially those related to the burning of fossil fuels such as coal, oil, and natural gas. Reduction means transition energy systems, industries, and other sectors of the economy towards low-carbon or carbon-free (when possible) alternatives. Decarbonization can be achieved through many strategies for example by adopting renewable energy sources (wind, solar), and policies like the European Union Emissions Trading Scheme (ETS) (What is the EU…). European Union's decarbonization strategy involves reducing net GHG emissions by at least 55% by 2030 and achieving climate neutrality by 2050, with a proposed 90% reduction target for 2040. Key measures include the "Fit for 55" package, investments in renewable energy and energy efficiency, electrification of industry and transport, enhanced innovation in green technologies, and the promotion of green finance and circular economy principles (European Commission, 2021). The European Green Deal, the most transformative so far EU's strategy, published on 11th December 2019 opened the last phase of the green transformation chapter in the EU in a broad sense as a growth strategy aiming to tackle negative climate changes, maintain biodiversity, combat negatives and achieve a broad set of ambitious goals of building a modern, resource-efficient and competitive economy, environment-friendly with net-zero greenhouse gas emissions by 2050 (*climate neutrality*), and with economic growth decoupled from the use of natural resources (*circular economy*) and create a competitive economy with no net emissions of greenhouse gases in 2050 and growth source is decoupled from resource use (Communication 2019). The European Green Deal poses new obligations for any new EU candidate countries that, since its entry into force, are to fulfil these requirements to complete accession procedures (Communication, 2019; A new Circular Economy, 2020; Dahl, 2021; How can … 2021; European Green Deal; The EU Green Deal 2021; Fetting, 2020; Strategic Perspectives, 2022). By 2030 greenhouse gas emissions should need to be reduced by 40% in the EU to reach its reduction of between 80-95% by 2050 to meet limitation of atmospheric warming to below 2°C (Green Paper, 2013). Following the prescribed path, what level of GHG emissions should be achieved in the EU by 2030? As of 1990, the EU member states' total net GHG emissions were approximately at 4915 Mt CO_2-eq. Reducing that amount by at least 55% means to achieve 2212 Mt CO_2-eq. by 2030. As of 2022 GHG emissions fell about 31% below 1990 levels, and in 2023 another 8%. Projected Total Net Emissions in 2030 in the EU member states forecast a 43% reduction by 2030 according to the European Environment Agency. Additional planned measures, not yet implemented could expand the reduction to 49%. It however falls short of the 55% prescribed target. In the fourth quarter of 2023, EU economy GHG emissions were estimated at 897 Mt CO_2-eq., a 4% decrease compared with the same quarter of 2022, when it was 935 Mt CO_2-eq. In 2023, the EU-27's GHG emissions excluding Land Use, Land-Use Change, and Forestry - LULUCF was estimated at 3.22 Gt CO_2-equivalent, which was a 33.9% reduction compared to 1990 levels. The EU experienced a decrease in its total GHG emissions in 2023 of -7.5% (261 Mt CO_2-eq.) compared with 2022 (European Union, 2024; UNEP, 2024; EU economy emissions in 2021; EU economy greenhouse gas emissions, Q4 2023; EU economy greenhouse gas emissions, Q3 2023; Strategic Dialogue, 2024). Energy-related CO_2 emissions

which is a major component of GHG emissions declined for 2024 by about 2.2%, equivalent to 55 Mt CO_2. Estimates made by CREA reported a 2.9% drop in EU fossil fuel CO_2 emissions in 2024. EU's CO_2 emissions fell 2.9% in 2024 but rose outside the power sector, the most in transportation at about 1.4% (UNEP, 2024; CREA, 2025). Under the EU's Emissions Trading System (ETS) which covers about 45% of the bloc's GHG emissions, ETS CO_2 emissions dropped 5% in 2024, with the power sector leading the reduction at emissions level down 12%. Renewables accounted for almost 50% of electricity production, led by wind and solar, which reached a record share of 28%, for the first time surpassing the combined share from coal and gas (IEA, 2025).

The Carbon Border Adjustment Mechanism (CBAM) is an element of the European Green Deal. It supports decarbonization - eliminate emission of carbon dioxide and greenhouse gases to the atmosphere, and introduce low-carbon economy within green solutions - the achievement of carbon-neutral Europe by 2050, introduces the effective, fair carbon pricing, preventing from shifting industry production that emits carbon from the EU to destinations with less stricter legal provisions on ecology and environment. It assures that carbon price of imported goods is equivalent to the carbon price of domestic production, and that the EU's climate objectives are not weaken. The CBAM mechanisms enter fully into force from 2026 after a transitional phase 2023 – 2025. To ensure that business and operations mitigate negative impacts on natural environment and climate a reduction in business carbon footprint is projected of 15% by 2023, 80% by 2030 to reach finally carbon neutrality by 2050, from a baseline of 2013/14 (Regulation, 2023; Carbon Border Adjustment Mechanism; Annex 7).

Circular economy is the industrial aspect of the European Green Deal (Loiseau et al., 2020; UNEP, 2011a; Kirchherr et al., 2017). The circular economy is based on three principles: 1/ eliminate waste and pollution which means to avoid the single-use products and enhance their maintenance, sharing, reparation etc.; 2/ circulate products and materials at their highest value which means to maintain life cycle of materials in circulation as a product or as a part of a product or raw material. Nothing turns into waste; 3/ regenerate nature which means to focus attention from resource extraction stage to resource regeneration stage, introducing a regenerative model. Reusing, recycling and recovering mean that an economy is restorative, cyclical or regenerative by intention (Przybojewska, 2021; Corvellec et al., 2022; UNIDO, 2024). The circular economy "is not a theory but an emerging approach to industrial production and consumption", a multiplicity, an umbrella concept that creates excitement and enthusiasm as it seemingly provides a new framing able to resolve many problems, for example reconceptualization of "waste" (not treating waste as waste but as a resource to reuse) (Korhonen et al., 2018b; Transforming Our World…). The European Union adopted the European Circular Economy Action Plan (CEAP) in December 2015. With this concept one thing is not however reasonably clear. Renewables are not able to replace non-renewable ones oil, coal, natural gas (Przybojewska, 2021). Solar and wind cannot, on their own, replace coal and gas plants, that produce and supply continual power. To attain continuality with renewables man must learn how to capture and store solar and wind power which to extent seems tricky (Zhao et al., 2015; *Power storage* 2019; Energetyka wiatrowa; Breaking Wind, 2024; Regulation, 2023). Generally, circular economy rules adaptation to national economy sectors mean to make these sectors environmentally friendly with a carbon-neutral footprint. Nevertheless, disadvantage of the EU's "going green" project is that it binds legally only European Union member states, with their share in global environment pollution of only about 8%. Excluded are from the participation the greatest global pollution emitters like the United States, China, Indie and Russia, which does not lead to major progress (Kyoto Protocol, 1997; Kirk, 2023; Nahm, 2023).

3. METHODOLOGY

This paper focuses on decarbonization prospects for Ukraine to "go green" and access the EU in the field of *acquis* referring to the European Green Deal. Methodology we based on the linear trend estimated by using the ordinary least squares (OLS) method. This approach is based on fitting a straight line to the empirical values of a time series in such a way that the sum of squared deviations between the observed values and the theoretical values of the model is minimized. The general form of the linear trend equation can be expressed as (Shah et al., 2024; Kolambe, 2024):

$$y_t = \alpha + \beta t + \varepsilon_t \quad (1)$$

where:

- y_t denotes the value of the variable y at time t,
- α is the intercept,
- β represents the slope coefficient, indicating the average change in the variable per unit of time,
- ε_t is the random error term.

The parameters α, β are estimated by minimizing the objective function:

$$min \sum_{t=1}^{n} (y_t - \alpha - \beta_t)^2. \quad (2)$$

The obtained linear trend reflects the long-term direction of changes in the analyzed phenomenon, smoothing out short-term fluctuations and allowing for the extrapolation of values into future periods. This makes the OLS method a fundamental tool for both descriptive analyses and forecasting within time series research (Harefa et al., 2023). Based on the obtained functions, forecasts were determined and their quality was assessed based on ex post errors (Rublikova et al., 2018; Dittmann, 2010). Absolute forecast error at t (q_t) moment/interval is a difference between actual (yt) and anticipated (y_t^*) value over forecasted period t:

$$q_t = y_t - y_t^* \quad (3)$$

Mean ex post forecasts error (mean error, ME) calculated for n + 1, ..., T moments/intervals is calculated from the following equation:

$$q = \frac{1}{T-n} \sum_{t=n+1}^{T} (y_t - y_t^*) \quad (4)$$

where: n – number of the last known observation of the forecasted variable, T – number of the last known moment/interval, for which the forecast was verified.

In the case of unbiased forecasts, the error value should equal 0; however, in practical application, a value approaching 0 is considered satisfactory.

Root mean square error is defined as the measure of the differences between values that are predicted by a model and values that are actually observed. Here, N is the number of observations:

$$RMSE = \sqrt{\frac{1}{m} \sum_{t=1}^{m} (y_t - y_t^*)^2} \quad (5)$$

The above methodological approach we completed with comparative studies referred to legal documents and strategies research and studies. The scope was legal acts on the EU's green solutions and

Ukraine's legal provisions that are in force, but do not work in practice due to military conflict. Additionally literature and international organizations (institutions, foundations and think-tanks) documents were desk studied.

Limitations: Given the latest official data on Ukraine's inventory available for 2022 – *Ukraine's Greenhouse Gas Inventory 1990-2022, Kyiv 2024* – the Authors are under pressure by scarcity of data, but are keenly determined to highlight the issue presented in this paper the most precisely.

4. EMPIRICAL RESULTS AND DISCUSSION

4.1. Perspective on green solutions in Ukraine

Ukraine has been reducing emissions during the past 30 years, primarily due to the decline of heavy industry in the 1990s and economic transformation in the 2000s. The country was the world's sixth largest GHG emitter (only fuel combustion) in 1990, but in 2020, it was outside the 30 largest GHG emitters. In 2024 Ukraine adopted a climate law, which set the goal of reaching climate neutrality (net zero emissions) by 2050. In 2020, GHG emissions in Ukraine amounted to 9% of total EU emissions. Since that date and due to warfare GHG emissions level drastically picked up (Diachuk et al., 2025). Ukrainian Strategy under the law of 18th August 2017, "Безпека, енергоефективність, конкурентоспроможність"[1] outlined strategic guidelines for the development of Ukraine's fuel and energy complex up to the year 2035. Ukraine is one of the largest producer of hydrocarbon – a major contributor to global warming effect and contamination of soil. 2035 seems to the Authors a hardly real date to optimize and innovate of energy sector infrastructure with additional contribution to emissions due to unsolved military conflict. It can paradoxically serve as a "booster" of progress, an opportunity to rebuild its power system on new rules "build it back better". The 2017 Strategy sets the goal of environmental protection through the main directions of energy efficiency improvement of the economy that are for example: 1/ raising awareness to the need of energy saving; 2/ reduction of energy consumption of households, commercial and communal sectors; 3/ completeness and transparency of accounting for all forms of energy and energy resources; 4/ reduction of energy consumption in the systems of transportation and distribution of electric and thermal energy by technical, technological modernization and conceptual revision of power supply schemes, taking into account the achievements in the field of decentralized energy supply, in particular through the use of renewable energy sources (RES) and energy management; 5/ optimization of the central heating system by switching to individual heating in the regions and at sites where it is economically feasible (Kabinet Ministriv Ukrainy, 2017; Iakovenko et al., 2024). 2035 achievements are expected to path the way to achieve zero emissions in the energy sector by 2050 and climate neutrality of the entire economy no later than by 2060.

4.1.1. Greenhouse gases (GHG) emissions

According to the Kyoto Protocol and the Paris Agreement, Ukraine defined its pace to reduce greenhouse gas emissions by 65% between 1990 and 2030, which is a deadline date. Currently, only in 2024 alone GHG emissions caused by armed conflict and warfare were estimated to increase by 30%. This was 55 Mt CO_2 -eq. The total emission for 2024 in Ukraine was estimated at 230 Mt CO_2-eq. It was the equivalent of the annual collective emissions of Austria, Hungary, Czech Republic and Slovakia. Realities may hamper to meet the date 2030 as armed conflict makes home environment extremely unfavourable for

[1] "Security, energy efficiency, competitiveness".

sustainable development and "going green" progress (Ukraine's Greenhouse Gas Inventory 1990-2022; Climate Damage; de Klerk, 2023). Nevertheless, the picture drawn for a period 1990-2022 shows since 1990 GHG emissions level has been decreasing in general, with significant drop in the beginning of the timeline, but at standstill since 2015 (Table 1, Figure 1). Figure 1 additionally shows timeline expanded to 2030, a deadline date.

Table 1

GHG emissions in Ukraine in 1990-2022 (Mt CO_2-eq.)

Gas /Year	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022
Total*	915.5	532.9	408.3	435.8	396.0	328.4	348.8	325.8	351.7	344.9	309.3	327.9	223.2

***** including LULUCF and indirect CO_2

Source: https://countryeconomy.com/energy-and-environment/co2-emissions/ukraine?utm_source=chatgpt.com

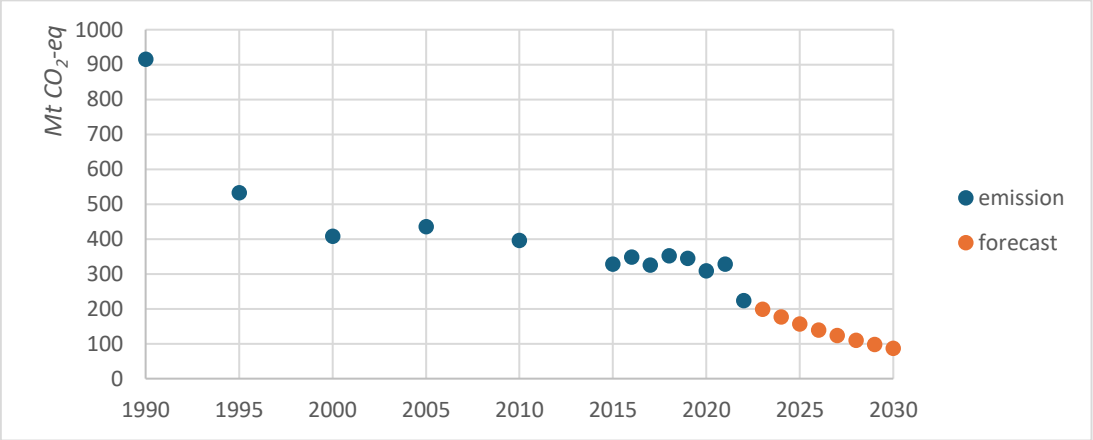

Figure 1. GHG emissions in Ukraine with a forecast in a period 1990-2030 (Mt CO_2-eq.)

***** including LULUCF and indirect CO_2

Source: https://countryeconomy.com/energy-and-environment/co2-emissions/ukraine?utm_source=chatgpt.com

Between 1990-2022, annual average changes were at the level of 0.889. Assumption that the level of GHG emissions in the following years 2023-2028 will reflect that similarity is currently false. As we mentioned due to wartime activity only in a single year 2024 GHG emissions increased by 30%, which accounted for 55 Mt CO_2 -eq. If the similarity annual average changes rate from 1990-2022 period continued GHG emission in Ukraine in 2028 it should touch the level of 110 Mt CO_2-eq. It would be over eightfold decrease compared to a base year 1990. The largest greenhouse gases (GHG) emitter in 2021 and 2022 was the Energy sector (including among others: energy industries, transportation, manufacturing and construction) of the Ukrainian economy (Table 2) (Environmental Security; Iakovenko et al., 2024; Vasylieva et al., 2025; Ukraine's Greenhouse Gas Inventory 1990-2021; 2023 Annex I).

Table 2

Structure of GHG emissions in traditional economic sectors in Ukraine in 2021 and 2022

Sector of Economy	Share in emission (%)	
	2021	2022
Energy	64	72**
IPPU*	18	9
Agriculture	14	13.3
Waste	4	6.1

* Industrial Processes and Product Use

** without LULUCF

Source: Ukraine's Greenhouse Gas Inventory 1990-2021; Ukraine's Greenhouse Gas Inventory 1990-2022.

Generally it has been the highest energy consuming sector, a core of major economies and its GHG emissions score is usually the highest. The European Union for comparison is not an exception in this case (Table 3).

Table 3

GHG emissions by sector of economy in Ukraine and in the EU in 2021 and 2022

Emmission per sector of economy (Mt CO_2-eq.)				
Sector	Ukraine		EU-27	
	2021	2022	2021	2022
Energy	210	170.3	2663	2603.8*
IPPU	58	21.6	318	291.8
Agriculture	47	31.8	378	365.7
Waste	12	14.6	109	109

* excluding LULUCF

Source: Ukraine's Greenhouse Gas Inventory 1990-2021; Iakovenko, Zachmann 2024; Ukraine's Greenhouse Gas Inventory 1990-2022; European overview of GHG emissions. GHG emissions in the EU-27 in 2022.

Of all GHG emissions in Ukraine in 2021 carbon dioxide (CO_2) remained the largest emitted gas. The largest emitter was Energy sector (Table 4).

Table 4

Carbon dioxide emissions in traditional economy sectors in Ukraine in 2021 and 2022

Sector of Economy	Carbon dioxide 16mission (Mt)	
	2021	2022
Energy	159.74	125.34
IPPU	50	17.16
Agriculture	42,5*	2.75[2]
Waste	-	-

* in 2019. *Source:* Ukraine's Greenhouse Gas Inventory 1990-2021; Ukraine's Greenhouse Gas Inventory 1990-2022; Trypolska et al., 2022.

[2] Only 2.75 Mt of emitted carbon dioxide in Agriculture sector seems not realistic level even considering significant reduction in agricultural activity, reduction in livestock, reduction area of harvest and fertilizers during warfare. Broader picture of carbon dioxide emission by economy sector in Ukraine in a period 2014-2023 shows quite shallow levels of carbon dioxide emission in Agricultural sector, so it might be the correct value. (https://greendealukraina.org/gd-tracker/figure-of-the-week/2024/co2-emissions-in-ukraine?utm_source=chatgpt.com).

Data on GHG emissions of individual gas measured in Ukraine and compared with data of the EU-27 shows a size of tremendous green gap between Ukraine and the EU, a perfect carbonization of economy of the former (Table 5).

Table 5

The share of GHG emissions in Ukraine and in the EU in 2021 and 2022

Emmission per gas (%)				
Gas (total)	Ukraine		EU-27	
	2021	2022	2021	2022
Carbon dioxide, CO_2	65.6	57.2	79.1	74.0
Methane, CH_4	21	29.7	12.8	18.0
Nitrous dioxide, N_2O	12.8	12.0	5.7	5.0

Source: Ukraine's Greenhouse Gas Inventory 1990-2021; Iakovenko et al., 2024; Ukraine's Greenhouse Gas Inventory 1990-2022; Annual European Union greenhouse gas inventory 1990-2022 and inventory document 2024; Greenhouse Gas Emission Footprint.

2022 alone marked in Ukraine with 57.2% while the EU-27 average 74.0%. Greenhouse gases levels in Ukraine in percentage formulation show higher levels in comparison with the EU 27 member states. Carbon dioxide level is frightening as nearly reach the EU-27 level. Overall picture of the dynamics of total greenhouse gas emissions in Ukraine in a period 1990-2020 is presented in Table 6.

Table 6

Dynamics of total greenhouse gas emissions in Ukraine in a period 1990-2022 (Mt CO_2-eq.)

Gas / Year	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022
CO_2 emissions with net CO_2 from LULUCF	659.3	344.6	252.6	295.5	273.5	228.0	240.2	220.8	239.1	227.3	191.2	205.4	127.7
CH_4 emissions with CH_4 from LULUCF	208.0	158.7	135.3	117.8	97.3	71.1	76.4	74.0	78.2	81.1	83.1	82.6	66.3
N_2O emissions with N_2O from LULUCF	48.1	29.4	20.3	22.1	24.4	28.4	31.1	29.9	32.8	34.6	32.9	37.6	26.8

Source: Ukraine's Greenhouse Gas Inventory 1990-2022.

GHG emission in a period 1990-2022 shows consistent effort to reduce its levels (also Table 1). Carbon dioxide emission was reduced by almost 80%, methane by 69% and nitrous dioxide by 45%. Breaking moment on this timeline was 2021/2022 when the respective emission decreased by impressive 38%, 20% and 29% (Figure 2). To keep this trend was missed for good when the military conflict broke out in late February 2022 (Euractiv, 2025).

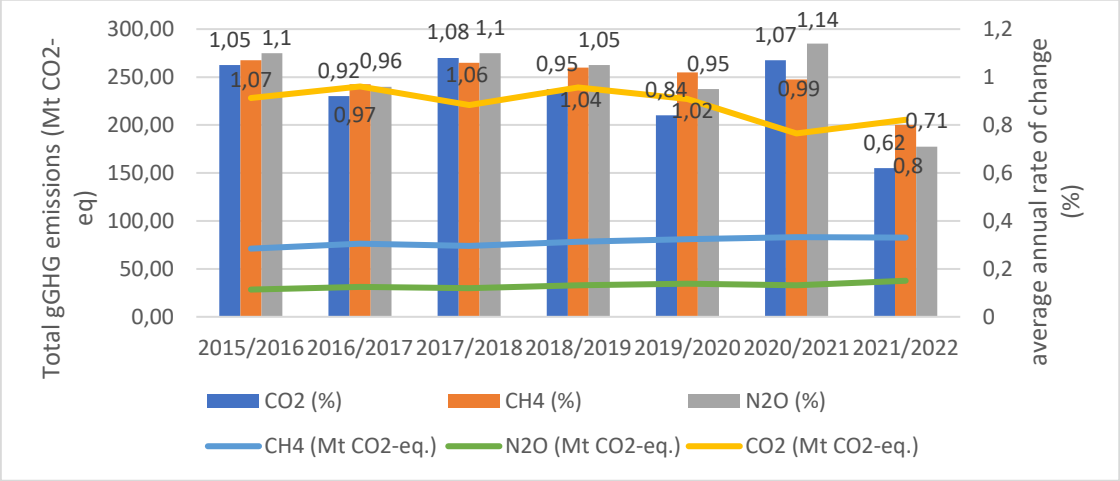

Figure 2. Annual average changes and GHG emission in Ukraine in 2015-2022

Source: Ukraine's Greenhouse Gas Inventory 1990-2022

As the armed conflict horizon is still open, it is difficult to define and strictly project a specific value of annual GHG emission in the following years towards 2030 or 2035. We presented therefore three scenarios to examine if 2030 and 2035 binding dates are real in terms of reducing GHG emissions by 65%. First scenario is optimistic with our assumption of GHG emissions between 2025-2035 around the half of the 2024 emission, that is 55x 50% ≈ 25 Mt CO_2-eq. annually. Second scenario assumes that in a period 2025-2035 the level of emissions will be steady, invariable fixed at the 2024 level – 55 Mt CO_2-eq. annually. Our third scenario, a pessimistic one assumes the severe intensification of armed activities due to unsolved result after three years of conflict. Annual GHG emissions for the period 2025-2030 in third scenario would be around 80 Mt CO_2-eq. annually. We also present neutral scene, as if a military conflict did not break out (Table 7).

Table 7

The level of GHG emissions for 2030 and 2035 in three scenarios in 2025-2035

Year	Scenario: no military conflict	Optimistic scenario: annually 25 Mt CO_2-eq.	Invariable scenario: annually 55 Mt CO_2-eq.	Pessimistic scenario: annually 80 Mt CO_2-eq.
2025	156,8	181,8	211,8	236,8
2026	139,4	164,4	194,4	219,4
2027	124	149	179	204
2028	110,2	135,2	165,2	190,2
2029	98	123	153	178
2030	**87,1**	**112,1**	**142,1**	**167,1**
2031	77,4	102,4	132,4	157,4
2032	68,8	93,8	123,8	148,8
2033	61,2	86,2	116,2	141,2
2034	54,4	79,4	109,4	134,4
2035	**73,4**	**98,4**	**128,4**	**153,4**

Source: Authors own calculations.

First column presents forecasts of GHG emission based on trend function describing general regularity of examined variable in time. We calculated the values projected using the rate of change (reduction of GHG emission) standard for a period 1990-2020 (Table 1). To enhance the reliability and probability of the

results obtained and meet actual dynamics of examined variables and phenomena we adjusted and tested our estimates and projected values by average annual rate of changes observed in analysis period. This approach enabled to obtain more compatible and consistent results with historic rate of changes and reduced overestimation and underestimation that could occur resulting from the trend estimation alone. These scenarios account for GHG emissions level resulting from wartime activities throughout the 2025–2035 period as well as those generated during the post-conflict reconstruction process. This approach enables our analysis of the impact of varying emission growth levels on the examined variables, as well as an assessment of the short- and medium-term economic and environmental effects.

The base year 1990 GHG emission level in Ukraine was 915.5 Mt CO_2-eq. including LULUCF and indirect CO_2 (Table 1). If 65% of this value is around 595, the level of GHG emissions for 2030 should therefore be around 320.5 Mt CO_2-eq. All three scenarios project possibility to obtain this level by 2030 and 2035 both binding dates.

4.1.2. Carbon border adjustment mechanism initiative

The EU Carbon Border Adjustment Mechanism (CBAM) Initiative introduced by the European Union to prevent warming effect and encourage decarbonization by reducing carbon footprint is regulated by the EU Regulation 2023/956 of the European Parliament and of the Council of 10th May 2023 establishing a Carbon Border Adjustment Mechanism. CBAM imposes reporting obligations on importers of goods operating in the EU customs territory whose production puts at risk of carbon leakage. It will cover at first the categories of industrial activity with the highest risk on natural environment in case of pollution and emissions of gases: iron, steel, cement, aluminium, fertilisers, electricity, and hydrogen. It encourages in point 14 of the Regulation third countries' producers to use technologies that reduce greenhouse gases emissions and point 16 emphasis that the Regulation should apply to goods imported into the customs territory of the Union from third countries. If the word "should" does not clearly enough represents "obligation" the further provision of point 26 does not leave any doubts that CBAM creates "obligations" and not only "optional possibilities". Point 26 of the Regulation states that Member States have the power to impose penalties for infringements of this Regulation and ensure that such penalties are enforced (Regulation 2023). CBAM would hamper heavy industry areas, such as Eastern part of Ukraine, a coalfield and metallurgy area of Donets Coal Basin production for export to the EU, the main trading partner for Ukraine. The share of Ukrainian import to the EU in case of products covered by CBAM was estimated at 17%. Economic interests of the EU industry and producers may lobby to force the EU authorities to limit some Regulation provisions and obligations for the sake of both trading parties. CBAM regulations offer exemptions, if the country complies with a set of requirements. In specific circumstances cases which a military conflict is considered Ukraine may enjoy special treatment in the application of CBAM. Ukraine does not meet all the criteria for granting the exemption. There has been a lack of the market coupling requirement or the requirement for the roadmap to achieve climate neutrality by 2050 and introduction of the domestic ETS by 2030. One of the exemptions is the *force majeure* derogation for countries facing extraordinary economic conditions due to factors beyond their control. A military conflict in a country increasing the risk of economic crises once again may be considered as such force majeure. In such cases country's CBAM application will be determined separately by the Commission. Upon this provisions Ukraine can get a delay in official adjustment schedule in accession procedure, arguing that the ongoing military conflict and its obvious economic repercussions hinder full CBAM compliance. The country or territory seeking exemption must fulfil all conditions specified in paragraph 7 of Annex III and submit two progress reports to the European Commission. Based on these submissions, the European Commission will evaluate whether the country continues to meet the required exemption conditions. Further, this delay

(postpone completion date) would require the approval from all EU Member States. The accession procedures of new members include environmental and climate targets. Failure to meet them may complicate Ukraine's EU accession. The bitter irony in this context comes out of fact that frightening 68% of Ukraine's coal-generating capacity damaged by the military conflict the Government of Ukraine would consider as phasing out coal from its power sector by 2035 easier than if it worked (Clean Energy; Chepeliev et al., 2025). Approved by Resolution of the Cabinet of Ministers of Ukraine dated March 3, 2021 No. 179 National Economic Strategy for the period until 2030 [3] – assumes total decarbonization (декарбонізація), a net zero goal within green transformation and green deal course (зелений курс) till 2060 (Kabinet Ministriv Ukrainy, 2021). The latest legal development however makes a step forward in the issue. In June 2023, Ukraine presented the Energy Strategy through 2050. It projected to decarbonize Ukraine's energy sector by 2050 (Clean Energy). Estimates concerning decarbonization investments in Ukraine towards Green Deal point at 102 billion euro to 2030 (Kabinet Ministriv Ukrainy, 2021a). This sum undoubtedly will have to be multiplied as the military conflict is on. For the same reason decarbonization process is today vague. Also, as was already mentioned above, legal obstruction to follow through required provisions in wartime has been critical. A very important component of CBAM compliance – the establishment of Monitoring, Reporting, and Verification (MRV) systems that enables to account for GHG emissions is not functioning in Ukraine as intended which raises a serious drawback in country's participation in CBAM. There existed a lack of complete data on carbon emissions, which in case of CBAM is important to justify elements of the Ukrainian ETS (Chepeliev et al., 2025).

4.1.3. Renewable energy resources

Conducive, friendly environment for successful decarbonization process and contribution to environmental sustainability and meeting targets of the Paris Agreement are provided by renewable energy resources, 603628 sq.km Ukraine is abundant with and of enormous potential. This in case of wind energy is around 180 GW, while for solar energy it's around 39 GW. A total capacity of 219 GW would vastly exceed the generation capacity of 59 GW Ukraine had at the start of the military conflict. Considering 272 GW of wind capacity in EU-27, the Ukrainian wind capacity looks stunning (SolarPower Europe, 2023; Wind energy, 2023). Solar energy estimated around 39 GW easily outperforms solar market output in the EU, guaranteeing a convenient background for supporting the EU green transformation to carbon-free energy (Table 8).

Table 8

Solar market output in the selected EU countries in 2023

2023 Solar market output (GW)	EU Country:									
	Germany	Spain	Italy	Poland	Netherlands	France	Austria	Belgium	Greece	Hungary
	14.3	8.2	5.2	4.8	4.5	3.2	2.2	1.7	1.6	1.6

Source: SolarPower Europe 2023.

Onshore wind in Ukraine could reach 320 GW and solar 70 GW by 2030. The World Bank estimates pointed the country's offshore wind potential at 183 GW of fixed turbines and 68 GW of floating turbines. These kind of turbines need unfortunately to be situated in the waters of annexed Crimea, the region of unknown political future today. Ukraine could meet its total electricity demand from only 1% of all sites suitable for solar and wind installations, but this will require reliable local power systems integrating

[3] The Ukrainian National Economic Strategy of 3rd March 2021.

distributed renewables with ecological and secure electricity microgrids, including advanced monitoring and forecasting solutions (Wojciechowski et al, 2025; Tomczyk et al., 2025). Adding biomass, biofuels, biogas and hydro resources, Ukraine's technical renewables potential could be 415 GW, excluding offshore wind (Ukraina; Energy Monitor).

4.1.4. Circular economy

The Circular Economy and decarbonization are both systems-level transformation towards resource efficiency, innovation in industry and shifts in business models to mitigate climate changes. It represents a significant milestone idea advancing Ukraine's efforts and accelerating its path to integration with the EU. In 2023 the Government of Ukraine initiated the development of a National Circular Economy Strategy and Action Plan with the EU support. Sustainability principles, resource efficiency, and climate neutrality, in line with the European Green Deal's vision of a competitive, climate-neutral economy by 2050 were aimed at transformation of Ukraine's economy (Civita, 2025). In 2021, over 90% of Ukrainian household waste was disposed of at landfill sites, only 7% was recycled, and 1.7% burned. Out of the 6000 operational landfills, 824 did not meet environmental standards, 371 required renovation, 230 were overcrowded. Ukraine was the only European country without extended producer responsibility. As the Project highlights only 3% of municipal solid waste was recycled, while 94% was landfilled across over 167.000 hectares. Post-war demolition waste exceeded 12 million tons, yet there is no proper infrastructure for its recycling. Mechanisms for hazardous waste disposal, including electronics and batteries, remain underdeveloped (Lindskog, 2023; Civita, 2025; Circular Economy, 2025). The Law of Ukraine on 'National waste management" of June 2022 regulating the relations in connection to the management of waste generated in Ukraine, transported through the territory of Ukraine, exported abroad and imported into Ukraine for the purpose of recovery or recycling. In 2019, The National Waste Management Plan until 2030 was adopted to identify tasks and practical measures designed to enable Ukraine to switch to a new model of waste management by 2030. The Law is modelled after the EU directives and is in line with the EU membership requirements. It will be in effect on July 9th 2023 which does not change much to influence during wartime reality (UNIDO, 2024). On September 20th 2023 a new regulation on waste management in Ukraine was adopted (DLF, 2023). The Law was however only on paper. The implementation process was significantly delayed. It was planned to reduce the use of primary raw materials to 80% by 2023, and to 20% by 2030. Up to 100 waste collection centers should be established for further repair and reuse by 2030. In 2030, their number should increase to 250. According to the law, 8% of household waste should be sent for reuse by 2023 and 10% from 2024 to 2030. As for 2020 only about 5% of waste was recycled in Ukraine (Shpak et al., 2020). Nevertheless, statistics from various sectors, particularly Textiles and Electronics, revealed alarmingly low rates of reuse in Ukraine. According to UNIDO analysis the circular economy is in early stage of development in Ukraine (UNIDO, 2024). No one should doubt today that such official strategies and plans for Ukraine like Circular Economy Development Strategy until 2035 or the Operational Plan for 2025–2027 would be operational only after the military conflict ends.

5. CONCLUSION

In this paper we showed that the prospects for decarbonization in Ukraine, reducing the share of carbon dioxide (CO_2) in GHG emission as well as other GHG components may seem vague. The country has never been "green" however the reduction of GHG emissions rate of change in 1990-2022 was optimistic and impressive. The military conflict disrupted this pace. Levels of emission rose continually as a result of burning fuels from diesel generators in use as the military conflict since 24th February 2022 deteriorated electricity infrastructure - over 80% of Ukraine's conventional power plant capacity has been

occupied and , destroyed (Ukraine's Greenhouse Gas Inventory 1990-2021; Nies et al., 2024; Meissner et al., 2024). The area of forests burned in wildfires military conflict was 25 times larger in 2022 than in 2021 (Dibrova et al., 2022). Compared to 2021, the total area of forest fires in Ukraine increased 100 times, with most fires happening in the South and East of Ukraine. The forest and green area shrank while exceeding carbon dioxide emission levels were additionally released to the atmosphere by the military equipment. In the period of 24th February to 31st December 2022, at least 33 Mt CO_2-eq. were recorded – from hostilities – about 8.9 million tons, from the movement of internally displaced persons – about 1 million tons and from fires – more than 23.4 million tons (UNDP, 2023; Brown et al., 2023). Latest estimates showed around 36% of total GHG emissions in 2022 coming from military equipment fuel, ammunition production, fortifications, etc., which was around 82.1 Mt CO_2-eq. Forest fires contributed to emission around 49 Mt CO_2-eq. in total over three years. It was 16.9 Mt CO_2-eq. only in 2024 alone. Combined estimates for a period February 2022 – February 2024 placed total emissions at approximately 175 Mt CO_2-eq. stemming directly from the conflict and reconstruction efforts. These emissions were divided: 1/ 29% from direct warfare activities (military fuel use, ammunition), 2/ 33% from reconstruction efforts, particularly due to carbon-intensive cement and steel, 3/ 38% from fires, airspace rerouting, and related factors. 175 Mt CO_2-eq. in 24 months was the equivalent of the annual use of 90 million cars. In March 2023, Ukraine was one of the countries most affected by air pollution in Europe (UNDP, 2022; Bun et al., 2024; de Klerk et al., 2023; Liu et al., 2024; Frost, 2024). Enhanced destruction of energy infrastructure, lead to a 16% increase in emissions (energy-related). Emissions from the energy sector were 1.1 Mt CO_2 -eq. in 2022–2023, and rose to 2.1 Mt CO_2-eq. in 2024. By 2024, cumulative military conflict related emissions rose to about 230 Mt CO_2 eq. marking a 30% increase compared to earlier years (Міністерство захисту). Only 2024 alone contributed to 55 Mt CO_2-eq. of GHG emission. A three year of conflict GHG emission was estimated at 230 Mt CO_2-eq. (The Guardian February 2025). Additionally to 'popular' warming effect gas, carbon dioxide emission, the military activity is responsible for releasing more environmentally danger gas than CO_2 – sulphur hexafluoride (SF_6) when energetic and high voltage stations are attacked (Brussels, 2022). Released to the atmosphere 40 tonnes of sulphur hexafluoride is corresponding with a million tonnes of carbon dioxide.

Nevertheless, our three scenarios projected GHG emission level reduction based on the rate of change standard for 1990-2022 in a period 2025-2035, regardless wartime show clear possibility to obtain the projected binding levels of 65% GHG emission reduction in 2030 and 2035 respectively due to the Paris Agreement and the Strategy of August 2017 "Безпека, енергоефективність, конкурентоспроможність". Of course, after the military conflict ends it may be hardly possible to sketch daily reality by statistical approach. Some research estimate 48.7 Mt CO_2-eq – amount of emissions of GHG "required" to conduct the process of reconstruction the country (Dervos et al., 2000; Briefing, 2022; Clean Energy). As a result of the military conflict about 90% of wind power capacity and 50% of solar energy capacity have been taken offline. More than 500 water infrastructure facilities, including hydroelectric dams, have been destroyed. Considering the above, the planned end to coal-fired power generation by the year 2035 may not succeed in that date (Brown et al., 2023; Science Business, 2024; Ukraine). Legal analysis show pessimism contrary to statistical approach. Ukraine is not even on the track to meet any of the EU green solutions put to its respective *acquis*. Green requirements would need a prolonged timeline to be met, but the success depends on how a wartime would develop in coming years. Green *acquis* together with CBAM provisions and requirements would be probably adopted with reasonable limitations and exemptions after numerous multi-staged negotiation rounds and only after the military conflict ends. It is the inevitable cost of the gap between the developed EU and reviving Ukraine, not possible to catch up in a few years, even by eager participant

and efficient legal division in government of Ukraine (Kobyłka et al., 2022; Rimini et al., 2023; Europejska stal; Keim et al., 2024; Trade Beyond).

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