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The Role of LULUCF Monitoring in the National Inventory System for Reaching Climate Neutrality Goals

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SUMMARY

The LULUCF sector in the greenhouse gas inventory structure is of particular interest due to its dual capacity to both produce and absorb greenhouse gases (GHG). This study conducts a comparative analysis of the actual and forecasted potential of the LULUCF sector in the overall structure of GHG emissions for European countries and Ukraine. It was found that from 1990 to 2010, the LULUCF sector showed a trend toward GHG absorption, whereas from 2011 to 2021, it became a net source of emissions. According to official data from Ukraine's NIR, LULUCF sector values ranged from -31.4 $MtCO_2e$ in 1990 to 14.2 $MtCO_2e$ in 2021, with a peak of 24.9 $MtCO_2e$ in 2018. This imbalance is directly linked to agro-technological approaches in agriculture and losses in the Forest Land use category. Over the past 10 years, a decreasing trend in GHG absorption has been observed for EU countries as well. Using predictive and comparative data analysis methods, the potential for GHG emissions/absorption by the LULUCF sector in Ukraine over the next decade was calculated. Based on the current data set, there is a high likelihood that the LULUCF sector will tend toward producing GHG emissions in the near future. However, the implementation of effective institutional approaches could improve these prospects. The potential of the LULUCF sector could play a more significant role in the overall architecture of national climate policy, especially considering Ukraine's substantial agricultural potential.

Introduction

The world emits around 50 billion tonnes of greenhouse gases each year measured in carbon dioxide equivalents (CO_2eq). A greenhouse gas inventory is the primary institutional tool for evaluating a country's economic activity and its internal carbon footprint. Under the Enhanced Transparency Framework, parties to the Paris Agreement are required to submit Biennial Transparency Reports (BTR) every two years, including a National Inventory Report (NIR) on anthropogenic emissions from sources and removals by GHG sinks. For Ukraine, GHG emissions are distributed among the following Intergovernmental Panel on Climate Change (IPCC) sectors: Energy excluding LULUCF – 64%; Industrial Processes and Product Use (IPPU) – 18%; Agriculture – 14%; and Waste – 4% (Ukraine's greenhouse gas inventory 1990-2021, 2023). From an environmental standpoint, the "Land Use, Land-Use Change, and Forestry" (LULUCF) component is of particular interest. This sector in the greenhouse gas inventory includes both emissions and removals of GHGs resulting from direct anthropogenic land use, land-use changes, and forestry activities. The land-use sector encompasses the management of cropland, grassland, wetlands, forests, settlements, and land-use changes, including afforestation (tree planting), deforestation, and peatland drainage. The central concept is that agricultural land management practices can lead to either GHG emissions or absorption related to both biomass and soils. Given that agricultural and forest lands cover more than three-quarters of the EU's territory, the land-use sector is promising in terms of carbon sequestration and emission reduction potential (Greenhouse gas emissions from LULUCF in Europe, 2024).

Method and Theory

There are three greenhouse gases relevant for the LULUCF sector: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). CO_2 equivalent is a common unit that allows these different gases to be added up based on their warming potential. Following the IPCC 5th Assessment report and as agreed for the Paris agreement, 1 tonne CH_4 = 28 tonne CO_2 equivalent, 1 tonne N_2O = 265 tonne CO_2 equivalent and 1 tonne CO_2 = 1 tonne CO_2 equivalent (Greenhouse gas emissions from LULUCF in Europe, 2024). However, the main challenges for sustainable approaches in the LULUCF sector lie in the potential reversibility and variability of carbon stocks. The process of CO_2 absorption by vegetation and soil can be disrupted by human activities, natural processes, and climate change. Such impacts include an increase in the frequency and severity of wildfires, as well as a higher rate of forest disease and pest infestations. It is also important to consider that Ukraine, compared to European countries, has a relatively low percentage of forested land in its landscape: 15.9% currently, with an optimal potential of 20%. During the full-scale invasion, nearly 30% of Ukrainian forests suffered varying degrees of damage. According to Eurostat, the average forest cover for EU countries is 39%.

Examples

Trends for Ukraine: In June 2022, the European Commission and European Council officially approved Ukraine's EU candidate status. A significant challenge for Ukraine on its EU membership path is aligning its environmental component, including climate policy and green transition potential, with EU standards. At the initial stage, the European Commission's assessment of Ukraine's alignment with EU environmental and climate criteria scored a "one," the lowest rating among all sectors. In November 2023, the European Commission recognized Ukraine's "certain level of readiness" in environmental and climate sectors. The report noted, however, that "Ukraine needs to do more to consistently mainstream climate considerations in all dimensions of public policy in a whole-of-government approach". Ukraine's climate policy is defined by several international and domestic documents, including the Paris Agreement, the Low Carbon Development Strategy of Ukraine until 2050, the Covenant of Mayors, and the European Green Deal. In June 2022, Ukraine joined the EU LIFE program for climate and environment. On October 8, 2024, the Verkhovna Rada of Ukraine passed Draft Climate Law No. 11310, "On the Basic Principles of State Climate Policy," which

establishes Ukraine's climate governance framework and commits to a 65% reduction in GHG emissions by 2030 (from 1990 levels) and to climate neutrality by 2050. Based on 1990 and 2021 data, Ukraine's average GHG emissions trend, including the LULUCF sector, shows a 62.53% reduction, or 65.29% without LULUCF. From 1990 to 2010 and in 2020 (excluding 2008), the LULUCF sector exhibited a GHG absorption trend, while from 2011 to 2019 and in 2021, it became a net emission source. LULUCF values ranged from -31.4 $MtCO_2e$ in 1990 to 14.2 $MtCO_2e$ in 2021, with a peak of 24.9 $MtCO_2e$ in 2018 (Fig. 1) (Ukraine's greenhouse gas inventory 1990-2021, 2023).

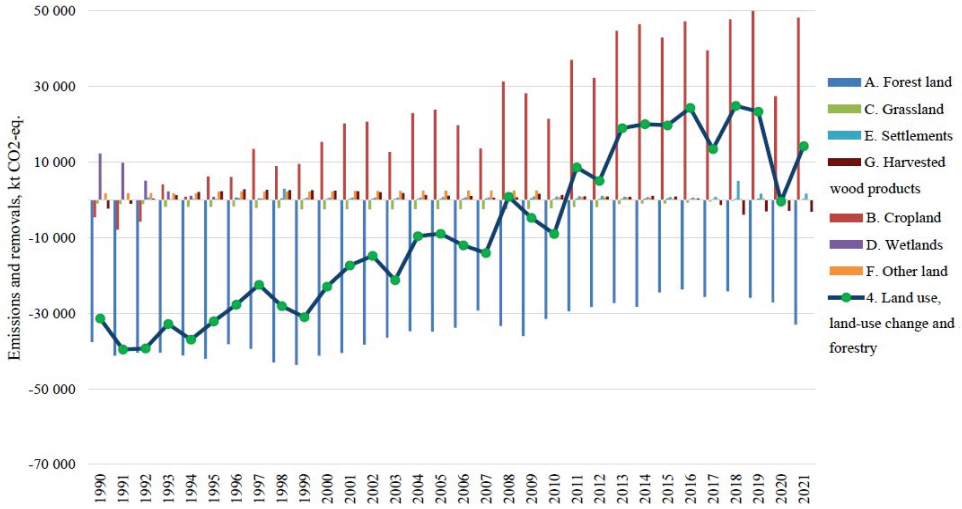

Figure 1 *Emissions and removals in the LULUCF sector in Ukraine.*

Significant imbalances exist within this sector. The Forest Land category is the primary source of absorption (exceeding -30.0 $MtCO_2e$ annually over the last 15 years), while the Crop Land category is the main GHG emission source (ranging between 30.0-50.0 $MtCO_2e$ since 2011). In the Forest Land category, the total GHG removal level is between 23.7-43.7 $MtCO_2e$ throughout the time series shown in Fig. 1.

According to Global Forest Watch (GFW) data, significant losses in green forest cover were observed from 2001 to 2023, with the peak in 2016 at 107,000 hectares, or 0.96% of the 2000 figure. The analysis of forest-related GHG emission/absorption flows from 2001 to 2023 shows emissions at 21.2 $MtCO_2e$/year and absorption at 90.6 $MtCO_2e$/year, resulting in a net absorption of approximately 70 $MtCO_2e$/year. GFW figures differ from official NIR data (2023), likely due to methodological inconsistencies. The Crop Land emission and sequestration trend ranges from -7.9 $MtCO_2e$ absorption in 1991 to 48.3 $MtCO_2e$ emissions in 2021, with a maximum of 50.0 $MtCO_2e$ in 2019. This trend is largely driven by the shift of crops to more demanding mineral soils with reduced organic fertilizer application (Ukraine's greenhouse gas inventory 1990-2021, 2023). Compared to 1990 (260,727 thousand tons), organic fertilizer use decreased 23-fold, and mineral fertilizer use halved by the early 2020s. Secondary but important factors also play a role. Climate change and soil moisture levels directly impact the soil's role as a source or sink of atmospheric CO_2. Increasing air temperature decreases soil organic carbon (SOC) content, while higher precipitation increases it (Polevoy et al., 2023; Panchenko et al., 2024).

Results

Using predictive and comparative data analysis methods, we aim to assess the GHG emission/absorption potential of Ukraine's LULUCF sector. The predictive analysis to 2032 is conducted through mathematical modeling of data under three likely scenarios: realistic scenario – assumes that the annual trend continues toward decreasing total GHG emissions; optimistic scenario – considers possible improvements due to strategic changes in Ukraine's climate policy, especially in

the context of EU integration; pessimistic scenario – accounts for possible adverse socio-economic and/or geopolitical factors, particularly the ongoing war. The projected outcomes of this modeling are presented in Fig. 2.

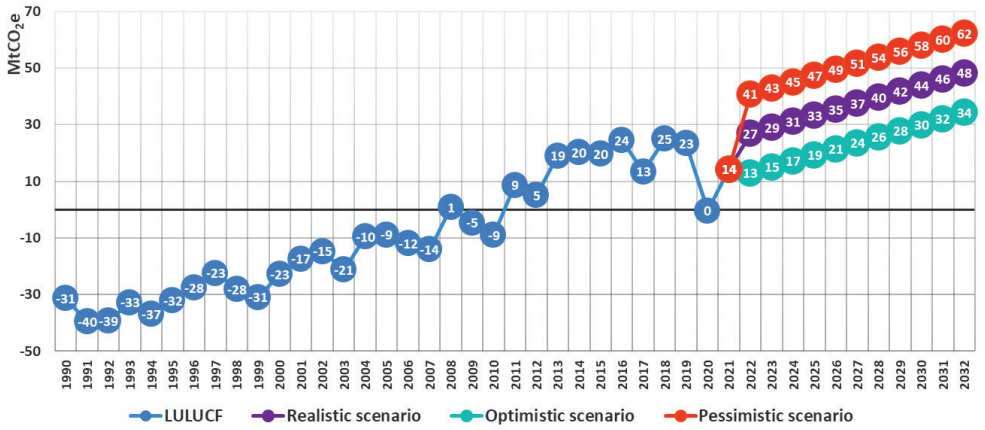

Figure 2 *Projected GHG Emission/Absorption Potential of the LULUCF Sector for Ukraine.*

The forecasted results shown in the graph indicate an unfavorable trend in GHG absorption by the LULUCF sector, with a likelihood that this sector will continue to be a GHG emission source. This forecast also underscores potential risks and environmental impacts due to the war initiated by the Russian Federation in Ukraine (Skyba et al., 2025). The next step in the analysis involves comparing the actual dynamics (based on retrospective analysis) of GHG emissions/absorption by the LULUCF sector for EU countries and Ukraine with the forecasted perspective. The average emission/absorption rate for Ukraine over the last decade, calculated based on, is 8.1 $MtCO_2e$. The estimated potential for the next decade, corresponding to the average value of the realistic scenario derived from mathematical modeling and data forecasting, is 35.5 $MtCO_2e$. Data for European countries is compiled based on, and results are presented in Fig. 3.

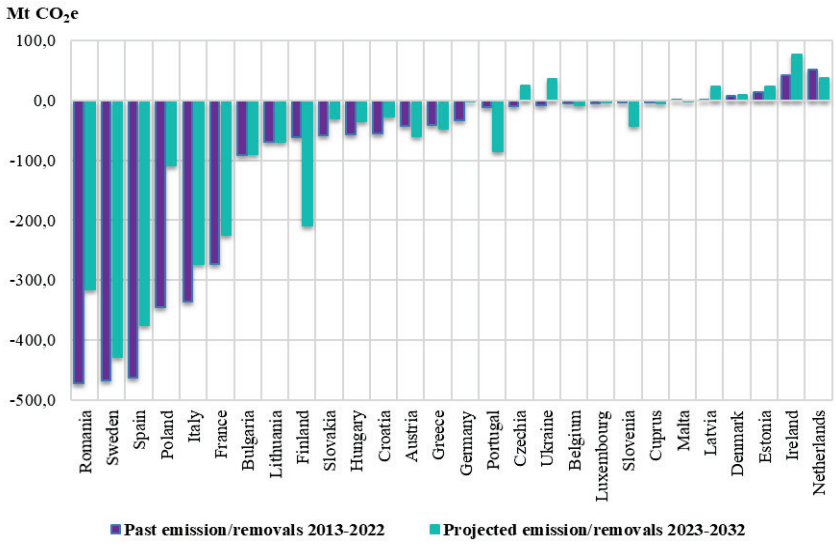

Figure 3 *Comparison of cumulative historical and projected LULUCF emissions and removals per Member State and Ukraine.*

Among the EU Member States, Romania, Sweden, Spain, Italy, Poland, and France were responsible for the largest cumulative net removals from the LULUCF sector in the past 10 years, contributing to approximately 85% of the EU's LULUCF sink. Although these countries are expected to remain large contributors, all project a reduction in removals in the coming decade.

However, Austria, Belgium, Cyprus, Finland, Greece, Netherlands, Portugal and Slovenia project increasing cumulative removals in the next decade. The LULUCF sectors in Denmark, Estonia, Ireland, Latvia, Malta and the Netherlands were a net source of emissions in the past decade and are projected to remain so in the coming decade. Czechia which had net cumulative removals in the past decade is projected to have net emissions in the coming decade (NIR, 2025). A similar trend is observed for Ukraine, where the LULUCF sector will likely become an additional emission source within the overall GHG emission structure for the forecasted period.

Given Ukraine's agricultural potential, the LULUCF sector could play a critical role in shaping national climate policy. Measures to intensify carbon sequestration in the LULUCF sector, as recommended by experts, should include approaches such as forest restoration, forest conservation, agricultural practice adjustments, and wetland management. To enhance soil absorption capacity, experts suggest several agronomic practices: growing cover crops, especially legumes in mixtures; crop rotation with at least three crops, including legumes; liming acidic soils; limiting or avoiding tillage; using organic fertilizers like manure, compost, and straw; protecting soil from erosion, e.g., through mulching. More substantial carbon sequestration efforts may involve transforming arable land into forests or permanent grasslands, implementing agroforestry practices, and restoring peatlands.

Conclusions

In summary, it is important to emphasize that the LULUCF sector plays a crucial role in the overall structure of GHG emissions. The core concept is that agricultural land management methods can drive both GHG emissions and absorption, related to biomass and soils alike. Analysis of the overall GHG absorption/emission dynamics in Ukraine's LULUCF sector reveals that from 1990 to 2010, the sector contributed to carbon sequestration, while from 2011 to 2021, it became a GHG emission source – a trend likely to continue. This imbalance is directly tied to agro-technological approaches in agriculture and losses within the Forest Land use category. Over the past decade, a decline in GHG absorption has also been observed among EU countries. However, implementing effective institutional approaches can lead to improved outcomes. Considering Ukraine's agricultural potential, the LULUCF sector could play a significant role in shaping the broader architecture of national climate policy.

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