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Application of GIS for greenhouse gas emissions monitoring

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SUMMARY

This article examines the relevance of greenhouse gas (GHG) emissions monitoring in Ukraine in the context of international climate commitments and European integration processes. Traditional GHG accounting methods are analyzed, and the necessity of combining them with modern geoinformation technologies is substantiated. The possibilities of applying remote sensing and GIS for collecting, analyzing, and visualizing spatial data, particularly in the land use, land-use change, and forestry (LULUCF) sector, are highlighted. Special attention is given to examples of international experience in using GIS and satellite monitoring systems (NASA, GOSAT, LUCAS). Results of retrospective and predictive analysis of GHG emission volumes in Ukraine are presented, taking into account realistic and pessimistic scenarios. The obtained results emphasize the potential of integrating GIS into national inventories as a tool for enhancing transparency and accuracy of climate policy.

Keywords: GIS technologies; environmental monitoring; greenhouse gas emissions inventory

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Introduction

Ukraine's climate policy is defined by several international and domestic documents, including: the Paris Agreement, Ukraine's Low-Carbon Development Strategy until 2050, the Covenant of Mayors, the European Green Deal, and others. In June 2022, Ukraine joined the European LIFE program for climate and environment. On October 8, 2024, the Verkhovna Rada of Ukraine adopted the draft framework climate law No. 11310 "On the Fundamental Principles of State Climate Policy," defining the architecture of Ukraine's climate governance and committing to reduce greenhouse gas emissions by 65% by 2030 (from 1990 levels) and achieve climate neutrality by 2050.

In June 2022, the European Commission and the European Council officially approved the decision to grant Ukraine EU candidate status. The greatest challenge for Ukraine on the path to EU membership is compliance with the environmental component (including existing climate policy and green transformation potential). At this stage, the European Commission's initial assessment of Ukraine's compliance with EU acquis for criteria related to environment and climate change was "one," which is the lowest score among all sectors. The following year, according to the assessment published in November 2023, the European Commission noted "some level of preparedness" of Ukraine in environmental and climate spheres. At the same time, it stated in the Report that "Ukraine needs to do more to consistently mainstream climate considerations in all dimensions of public policy in a whole-of-government approach" (Commission staff working document Ukraine, 2023).

Theory and/or Method

Traditionally, methodical approaches are used for greenhouse gas emissions accounting, for example, the use of standardized coefficients that establish the relationship between the volume of certain activity and the quantity of emissions, and the direct measurement method of emissions from sources using continuous emissions monitoring systems. Traditional methods remain the foundation for most national emissions inventories, but they are increasingly supplemented by modern technologies for verification and improving data accuracy. Unlike modern methods based on satellite monitoring, traditional approaches rely on ground-based measurements, calculations, and the use of standardized data.

Currently, the combination of remote sensing capabilities and geographic information systems (GIS) represents a powerful tool for greenhouse gas (GHG) emissions monitoring, as they allow for collecting, analyzing, and visualizing spatial data on sources, volumes, and dynamics of emissions. The objective of our study is to analyze the possibilities of practical application of GIS technologies for greenhouse gas emissions accounting, as well as to identify practical examples of integrating this method into national greenhouse gas emissions inventories.

Examples

However, developed countries have been actively using GIS tools for greenhouse gas emissions monitoring in the LULUCF sector for decades. Despite the fact that the USA is withdrawing from the Paris Agreement for the second time, the National Aeronautics and Space Administration (NASA) has several programs, such as the Carbon Monitoring System (CMS, 2010), which use data from various satellites (Landsat, OCO-2, OCO-3).

Japan was one of the first pioneers in this field. Its GOSAT satellite (Greenhouse Gases Observing Satellite), launched in 2009, became the first specialized satellite designed to monitor the concentration of carbon dioxide (CO_2) and methane (CH_4) on a global scale. The goals of the GOSAT mission are to contribute to environmental management by monitoring the global distribution of greenhouse gases (GHG), assessing CO_2 sources and sinks at sub-continental scale, and verifying GHG emission reductions required by the Kyoto Protocol.

New Zealand's Ministry for the Environment implemented ESRI GIS software for analyzing, measuring, and reporting greenhouse gas emissions and land-use changes 15 years ago in 2009. The

Land Use and Carbon Analysis System (LUCAS) is built on a geospatial system that supports complex carbon sequestration calculations using verified and quantified information about land use and changes therein. This step was conditioned by the specifics of greenhouse gas emissions in New Zealand and the commitment to achieve climate neutrality by 2050. Unlike many countries where energy or industry is the main source of emissions, in this country almost half of all greenhouse gas emissions come from agriculture. This is related to the large number of livestock: for 5 million residents, there are approximately 10 million head of cattle and 26 million sheep (New Zealand's GGI, 2025).

Results

Each year, approximately 50 billion tonnes of GHG are emitted globally, measured in carbon dioxide equivalents (CO_2eq). The world emits around 50 billion tonnes of greenhouse gases each year [measured in carbon dioxide equivalents (CO_2eq)] (Ritchie, 2020).

The calculated volume of GHG emissions for Ukraine in 2022 was 318.8 Mt CO_2-eq, and in 2023 – 274.3 Mt CO_2-eq. Predictive analysis for 2024-2030 (shown in Fig. 1) was conducted through mathematical modeling of data under two probable scenarios: realistic (assuming that similar annual dynamics will continue to trend toward reducing the total amount of GHG emissions) and pessimistic (considering risk factors under war conditions and the urgent need to restore destroyed infrastructure and resume production in the post-war period) (Skyba et al., 2025).

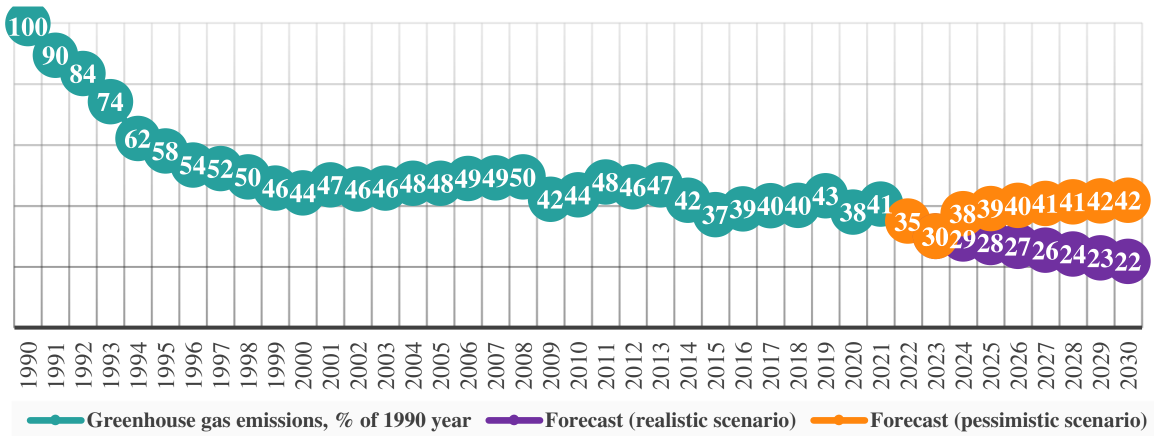

***Figure 1.** Retrospective and predictive analysis of GHG emission volumes (% to 1990)*

The generalized structure of GHG emissions has the following distribution: energy (electricity, heat, and transport) – 73.2% (of which energy consumption in industry – 24.2%, transport – 12.2% (of which road transport – 11.9%, aviation – 1.9%, shipping – 1.7%), energy use in buildings – 17.5%; direct industrial processes – 5.2%; waste – 3.2%; agriculture, forestry and land use (LULUCF) – 18.4% (Ukraine's, 2023).

The main institutional tool for assessing a country's economic activity and its domestic carbon footprint is the GHG emissions inventory. According to 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) of anthropogenic emissions by sources and removals by sinks of GHG (National Inventory Reports).

The main legislatively approved methodology for greenhouse gas emissions monitoring in Ukraine is the calculation-based method or the continuous measurement-based method:

- The calculation-based method consists of determining the volume of greenhouse gas emissions from material flows based on activity data obtained through measurement systems and calculation coefficients determined by laboratory analyses or using default values.
- The calculation-based method can be standard or a mass balance method.

Attempts to apply innovative technologies for greenhouse gas emissions inventory, namely values for the "land use, land-use change and forestry" (LULUCF) sector, have not yielded desired results to date, as noted in Ukraine's 2023 NIR report: "The current NIR was prepared using the approach and data sources as in the 2017 submission. Ukraine's efforts to transition to using remote sensing data are described in section 6.1.2 of the NIR submitted in 2019. Unfortunately, the results had low accuracy and time series consistency to be used as the main data source for the land-use change matrix."

According to environmental approaches, this sector is of particular interest due to the fact that LULUCF is a greenhouse gas inventory sector that covers both emissions and removals of greenhouse gases (GHG) resulting from direct anthropogenic land use, land-use changes, and forestry activities. The basic concept is based on the fact that agricultural land management methods can produce both emission and absorption of GHG related to both biomass and soils. Since agricultural and forest lands occupy more than three-quarters of the EU territory, the land use sector is promising in the context of carbon sequestration and emissions reduction (Greenhouse gas, 2024).

From a scientific and practical point of view, the Global Carbon Project (GCP) is an interesting international scientific project that brings together scientists from around the world to quantitatively assess and understand the global carbon cycle. Its main goal is to provide scientifically sound and transparent information that is critical to climate policy. The GCP methodology is based on the collaboration of over 100 scientific institutions and researchers from around the world. This ensures transparency, verification, and high data quality, making the Global Carbon Budget one of the most authoritative sources of information on the global carbon cycle. The main product of the GCP project is the annual Global Carbon Budget report. This report is the most comprehensive and authoritative analysis of carbon emission sources (e.g., from fossil fuels and land use changes) and its sinks (oceans and terrestrial ecosystems). The project focuses on monitoring three key greenhouse gases: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The GCP methodology is based on combining data from various sources: national inventories, satellite monitoring, ground-based observations, and mathematical models. This ensures high accuracy and allows for verification of the information.

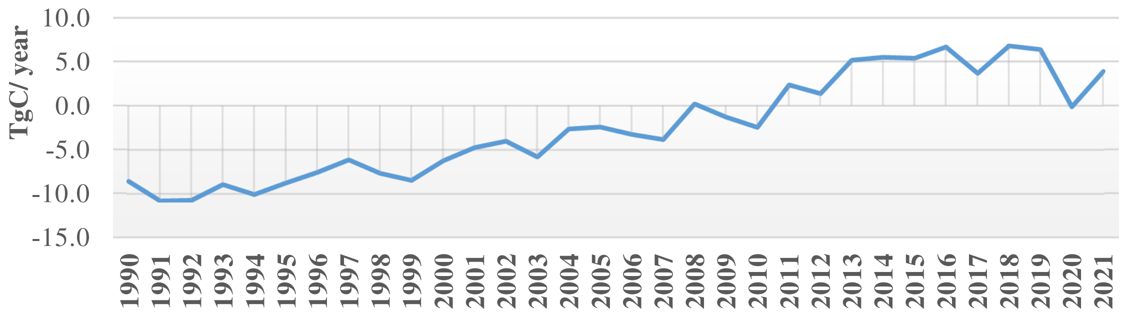

Figure 2. *Dynamics of total Net CO_2 from LULUCF in Ukraine (converted to TgC/year) according to NIR Ukraine data*

Let us compare the data for the LULUCF sector provided in Ukraine's NIR and those presented in the Global Carbon Atlas. First, we will convert the values from Mt CO_2 to TgC/year. It is important to note that Mt CO_2-eq is a unit that measures the mass of carbon dioxide (CO_2) or other greenhouse gases, converted to their equivalent in terms of global warming potential. In contrast, TgC/year measures the mass of elemental carbon (C) that is either emitted or absorbed per year. The conversion factor is 1 TgC/year ≈ 3.67 Mt CO_2/year.

It is worth noting that Figures 2 and 3 present time series, but the dynamics of different data for 1990-2021 are approximate. For example, the values for 2010 are: -2.5 TgC/year (NIR Ukraine data) and -0.2 TgC/year (Global Carbon Atlas). The deviation of the data is insignificant and fully reflects the overall dynamics in the LULUCF sector. For comparison, in 2022, the LULUCF sector in the EU caused a net absorption of 236 $MtCO_2e$ (64.3 TgC/year), which is equal to 7% of total EU greenhouse gas emissions. In 2024, this figure was 274 $MtCO_2e$ (74.7 TgC/year).

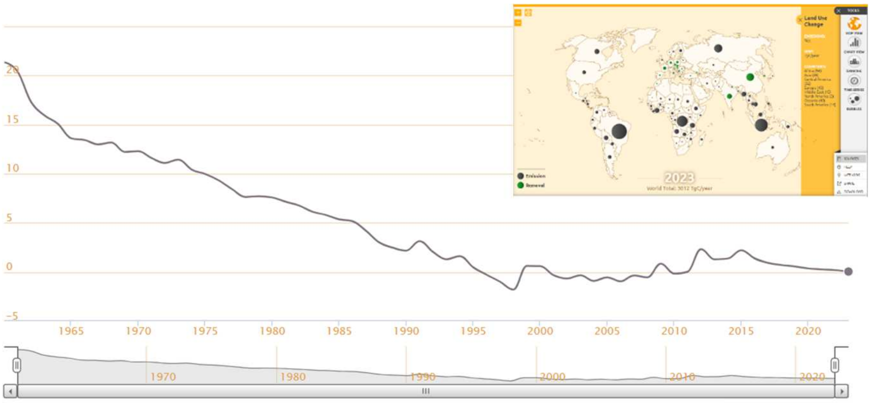

Figure 3. *Dynamics of total Net CO_2 from LULUCF in Ukraine (TgC/year), interactive platform data Global Carbon Atlas*

Conclusions

Ukraine has set goals to reduce greenhouse gas emissions by 65% by 2030 and achieve climate neutrality by 2050. Traditional inventory methods remain fundamental, but require supplementation with modern geoinformation approaches, particularly in the land use and forestry sector. International practice confirms the effectiveness of satellite monitoring, and its implementation in national inventories will ensure improved accuracy of accounting and transparency of Ukraine's climate policy.

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