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Status of Environment and Climate in Ukraine

Assessing the impact of war and its implications for reconstruction

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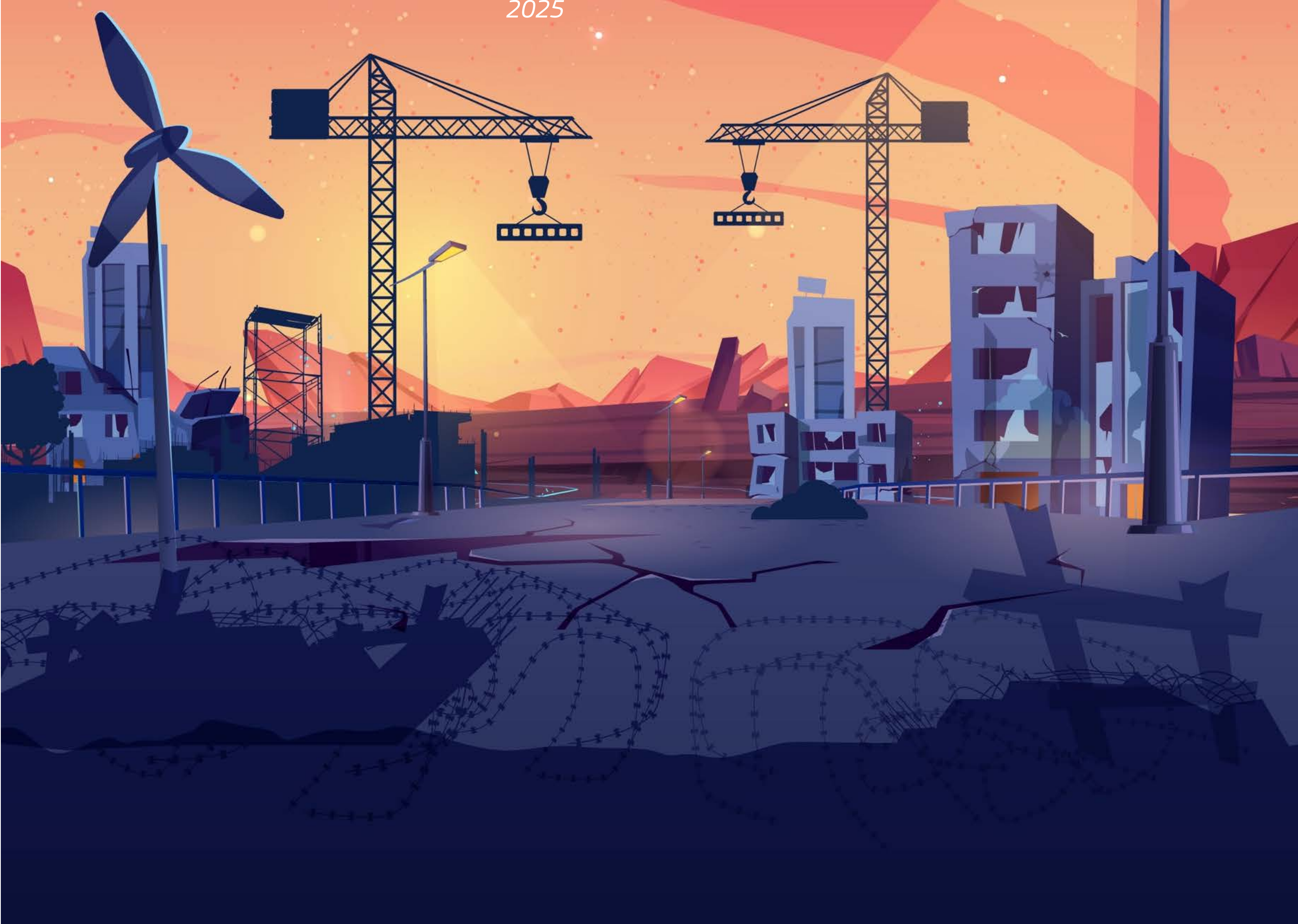

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Contents

Abstract

The present report provides an overall picture of the **status of environment and climate** - air quality, emissions of air pollutants and greenhouse gases - (GHG), forests, soil and marine environment in Ukraine. The analysis is based on available studies by JRC and other sources. However, the report does not cover all environmental areas as completeness and quality of data varies across the different topics. The ongoing conflict between Russia and Ukraine has exacerbated pre-existing challenges related to environmental monitoring and the enforcement of environmental regulations, further complicating this assessment.

The information summarised in this study provides for the first time the basis for assessing the **impact of war** in Ukraine with reference to specific environment and climate aspects, including relevant elements for the reconstruction of the country. Moreover, the report provides additional information for benchmarking the EU accession process of Ukraine, with particular reference to Chapter 27 of the EU Acquis on Environment, as well as for monitoring the progress in the green transition, with an emphasis on zero-pollution, low-carbon and nature-preserving dimensions.

In the last decade, Ukraine made efforts to align its **environmental strategy** with EU standards including the definition of key strategic goals and a roadmap for its participation in the Green Deal. The concentration of pollutants regulated by Ukrainian legislation meet the EU criteria, with the exception of NO_2 and CH_2O. National standards for atmospheric particulate matter with diameter <2.5 μm and <10 μm ($PM_{2.5}$ and PM_{10}, respectively) are not in place yet. Emission of pollutants have decreased over the past decade due to the impact of COVID-19 pandemic and the war.

Over the past decade, climate change and the war have significantly increased the risk of **large forest fires**, with the worst situation in the last five years. Wildfires account for 45-65% of the total forest cover losses every year. Although **soils** in Ukraine contain high levels of organic matter and nutrients, they are also **vulnerable to degradation**, such as nutrient mismanagement, acidification, erosion, compaction, salinisation, contamination. Erosion is the most widespread threat since it affects 40% of the Ukrainian soil.

The war and the presence of military equipment and units hampered the ability to monitor and respond to changes in the environment. The **war contributed to devastation of environment** by releasing potentially toxic elements, munitions and landmines, as well as the habitat alteration and destruction, deforestation, increased potential of causing wildfires, negative impact on human health and biodiversity.

The Ukraine Plan provides a solid foundation for planning the country's reconstruction. The findings outlined in this report are intended to inform and enhance the implementation of individual measures, therefore, it is recommended to take them into consideration to ensure the reconstruction efforts move forward in a sustainable fashion.

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Executive summary

This report summarises the state of the **environment and climate in Ukraine** with a special emphasis on the **impacts of military actions** based on available data and their implications for the **reconstruction of the country** in the aftermath of the war. The status of air pollution, greenhouse gas emissions, mitigation and adaption by local authorities, forest resources, soil and marine environment is assessed in a time window between the 2010's and the 2020's which includes COVID-19 pandemic and the intensification of the war in Ukraine (February 2022). However, the report does not cover all environmental areas as completeness and quality of data varies across the different topics and due to length constraints. The report is structured in **three sections**: a) an overview of the study area, including a description of the policy background, b) a systematic collection of environmental and climatic information divided in thematic chapters, and c) options for policy action to address the identified challenges considering the existing framework.

Policy context

In 2017 the EU-Ukraine **association agreement** entered into force, as the main tool for bringing Ukraine and the EU closer together, providing the basis for legal approximation. Ukraine has official **EU candidate status** since 2022 following the Commission's Opinion on the European perspective for the country. The launch of the accession negotiations took place in June 2024 after the green light of the European Council in December 2023.

The **Ukraine Facility,** a comprehensive support package (50 billion Euro from 2024 to 2027) was created in 2024 to support Ukraine's recovery as well as fostering Ukraine's EU accession path. It supports the transition towards green, digital and inclusive economy, which is progressively aligned with EU rules and standards. The Ukraine Facility supports the implementation of the **Ukraine Plan**, a comprehensive roadmap developed by the Government of Ukraine that outlines the key reforms and investments to be undertaken by 2027.

In the latest decade, Ukraine made efforts to align its environmental strategy with EU standards including the definition of **key strategic goals and a roadmap** for its participation in the Green Deal. Under Chapter 27 of the *EU Acquis on Environment,* Ukraine has developed **some level of preparation** in the field of environment and climate change and has made **some progress** including enhanced public access to environmental information, adoption of legislation on waste management, industrial pollution, chemicals, and air and water quality.

In 2024, the Ukrainian law on State **climate** policy set ambitious goals for climate neutrality in the energy sector by 2050, along with the adoption of the National Energy and Climate Plan 2030 (**NECP**) established in the frame of the **Energy Community**. Moreover, EU-funded regional initiatives such as the European Union for Environment (**EU4Environment**), for climate (**EU4Climate**) and energy (**EU4Energy**) Programmes in the Eastern Partnership countries have played a key role in enabling progress towards climate and environmental resilience in the region, including Ukraine.

The **Bucharest Convention** on the Protection of the Black Sea against pollution, ratified by Ukraine in 1994, addresses trans-boundary issues through enhanced cooperation among involved countries. Therefore, coordination among the Black Sea countries including EU partners, is of great importance for implementation of EU legislation, in particular, EU Water Framework Directive (WFD) and the EU Marine Strategy Framework Directive (MSFD).

Main findings

Air quality monitoring and management in Ukraine are affected by the transition in progress from an outdated system, in terms of regulated pollutants and monitoring methods, towards one aligned with current international guidelines. Between 2018 and 2022, country annual average concentrations of SO_2, NO, CO and total suspended matter met the National air quality standards (NAAQS) criteria while NO_2 and CH_2O levels were above them. NAAQS for $PM_{2.5}$ and PM_{10} are not in yet place and consequently the number of state automated measuring stations is limited. Between 2018 and 2022, annual concentrations of PM_{10} and $PM_{2.5}$ in Kyiv were below the annual EU limit values while higher than the stricter WHO guidelines. In 2019, 42,900 premature deaths and 953,500 disability-adjusted life years in Ukraine were due to air pollution (10 % of all morbidity and mortality).

The emission trends of pollutants and **greenhouse gases** in the latest decade were influenced by the measures to contain the COVID-19 pandemic and the intensification of the war in 2022. The regions with the highest emissions were Donetska, Dnipropetrovska, city of Kyiv, Zaporizka, Ivano-Frankivska, and Kyivska. Since 2016, the emissions from the power generation sector followed a decreasing trend while those of mobile sources increased until 2019 and then decreased. In the period 2016-2020, the total GHG emissions (including Land Use, Land-Use Change and Forestry - LULUCF) dropped by 5.6%. By 2021, Ukraine had **achieved a significant reduction in GHG emissions (-62.5% compared to 1990)**, although there was an increase of 7.5% compared to 2020 levels, largely attributed to the recovery of industrial activities after the COVID-19 pandemic. Since 2022, destruction of industrial and energy facilities caused by war led to a drop in GHG emissions (**23-26%** reduction in 2022 compared to 2021) and to the **emergence** of new GHG emissions associated with **military operations** which in the first 18 months amounted to **77MtCO_2-eq.**

Ukrainian local authorities have contributed to the climate and energy policies through the **Covenant of Mayors (CoM)** in the Eastern Partnership countries with 363 signatories, covering 51% of the national population. Overall, Ukrainian CoM signatories committed to **reduce 33% GHG emissions** by 2030, and have planned adaptation measures to address **extreme heat and floods & mass movements** in their territories, with particular emphasis on river basin management planning, collection and use of water quality monitoring.

Wildfires account for 45-65% of the Ukrainian **forest** cover losses every year. The pressures on forest resources expanded since the outbreak of military activities, leading to intense forest cover loss and habitat destruction. Explosive remnants and other potential causes further increase the risk of wildfires, and reallocation of fire-fighting resources makes it more difficult to prevent or control large fires. Climate change also contributed to forest cover loss by significantly increasing the risk of large forest fires, especially in the last five years.

Soils are exposed to degradation due to nutrient mismanagement, acidification, erosion, compaction, salinisation, and contamination. Erosion stands out as the most widespread threat, since 40% of the soil in Ukraine is affected. The war contributed to devastation by releasing toxic elements, such as lead, mercury, and arsenic. These elements may cause serious consequences for public health by penetrating into food chains.

The Black Sea is exposed to numerous anthropogenic influences, such as nutrient and contaminant overload (including microplastics), intensive marine traffic, climate change, invasive species, etc. Western Black Sea exhibited higher pollution levels compared to those of the Open and Eastern Black Sea. Plant protection products are the most common identified class of emerging pollutants. Since

2022, there is a growing concern about increased release of chemicals and habitat destruction, both with long-term consequences, due to military actions.

Key conclusions

The conflict between Russia and Ukraine has exacerbated pre-existing challenges related to environmental monitoring and the enforcement of environmental regulations.

Despite the efforts to **improve ambient air monitoring**, thanks to contribution from non-governmental organisations, the temporal and spatial coverage of air quality data is insufficient to assess exceedances and impacts on health at the national level. Action is needed to **align data collection and processing** with EU and international guidelines in terms of data coverage and monitored pollutants.

There is an urgent need for an **effective governance and law enforcement to protect forest resources** (e.g. due to illegal logging) and to re-establish and reinforce forest fire prevention systems. The capacity to manage crises (e.g. fires) is limited, and monitoring in certain areas has ceased.

Soil health is of utmost importance in Ukraine considering that **agriculture** is one of its main economic activities and it is one of the main producers of primary crops worldwide. Action to protecting soil from erosion, the main cause of **soil degradation** in the country due to poor management practices, is essential for the Ukrainian economy and to guarantee the security of the food supply in many African and Asian countries which rely on its grain exports.

In a wider frame that includes the association and accession efforts, one of the priorities for Ukraine is to control pollution in the **Black Sea**, in particular the release of plant protection products and plastic pollution. **Monitoring of the marine environment** had significantly developed since 2016, mainly through the implementation of the **EUEMBLAS project**. The project also built capacity in national institutions, developed novel monitoring methods, and facilitated sharing of environmental data. Marine environmental field monitoring is not possible due to **limited accessibility of the sea.**

The destruction of industrial and energy facilities led to a **decrease in anthropogenic emissions**, however, the ongoing war has introduced new emissions due to military operations and **contaminated soils and sediments** with toxic chemicals, posing significant risks to both human health and the environment. Long-term effects may include, among others, further environmental degradation, secondary pollution events, **health and biodiversity deterioration**. Extensive research and long-term monitoring will be necessary to quantify the impacts of war and to support action aimed at preventing further environmental degradation and health impacts in the aftermath.

The **Ukraine Plan** represents a unique opportunity for the country to address its environmental and climate challenges while promoting **innovation and growth**. It can contribute to leverage the foreseen **reforms and investments** to improve the status of air quality, greenhouse gas emissions, forest health, soil conservation, and marine environment protection.

Related and future JRC work

The JRC provides scientific support to the EU Enlargement policy in the field of environment and climate since 2013. The JRC contribution to the Danube Strategy was followed by the support to the EU macro-regional strategies and subsequently by foresight and gap analysis concerning the EU Acquis. In 2024, the JRC published a report on the Western Balkans. The JRC support to the Enlargement policy continues in the frame of the JRC project SCENARIO under Portfolio 'Science for

Global Gateway and neighbourhood policy' where scientific analyses and follow up science for policy deliverables are planned.

Quick guide

Chapter 1 provides an overview of the country current situation. **Chapter 2** describes the air quality monitoring system and the trends and patterns of pollutants' concentrations. **Chapter 3** presents the emissions of ambient air pollutant and greenhouse gases. **Chapter 4** introduces the work of Ukrainian cities under the Covenant of Mayors. **Chapter 5** provides an overview of the forest environment as well as the estimation of forest cover losses. **Chapter 6** discusses the soil properties of Ukrainian soils and the status of their health. **Chapter 7** depicts the status of marine environment with a special reference to the Black Sea. **Chapter 8** illustrate the impacts of war on the environment. **Chapter 9** introduces the environmental aspects of the Ukraine Plan and **Chapter 10** presents the main conclusions of the study.

1 Introduction

The territory of **Ukraine** is 603,700 square kilometers. Ukraine borders Russian Federation, Belarus, Poland, Moldova, Slovakia, Hungary and Romania. It is washed by the Black Sea and the Sea of Azov (**Figure 1**). From the administrative point of view, Ukraine is subdivided in 24 oblasts and the Autonomous Crimea Republic.

The last official data on the population of Ukraine is that it had about 41,167,300 inhabitants (January 1, 2022) (State Statistics Service of Ukraine, 2022). However, after the onset of the war with the Russian federation (February 24, 2022) it is unknown. According to the International Organization for Migration (IOM) report (IOM, 2023), as of September 25, 2023, there are 3.7 million internally displaced persons in Ukraine, while 6 to 9 million people emigrated, according to various estimates.

Figure 1. Geographical setting of Ukraine.

Source: United Nations Geospatial, 2023.

In 2017 the EU-Ukraine Association Agreement (EU-Ukraine AA, 2017) entered into force, as the main tool for bringing Ukraine and the EU closer together. Since 2022, **Ukraine has official EU candidate status**, following the Commission's Opinion on the European perspective for the country. The launch of the accession negotiations took place in June 2024 after the green light of the European Council in December 2023. Moreover, Ukraine has been a member of the Energy Community since February 2011.

The **Ukraine Facility** was created in 2024 to support Ukraine's recovery as well as fostering Ukraine's EU accession path. It supports the transition towards green, digital and inclusive economy which is progressively aligned with EU rules and standards. The Ukraine Facility supports the implementation of the **Ukraine Plan** (Ukraine Plan 2024-2027), a comprehensive roadmap developed by the Government of Ukraine that outlines the key reforms and investments to be undertaken by 2027.

Under Chapter 27 of the *EU Acquis on Environment*, the EU promotes strong climate action, sustainable development and protection of the environment. EU rules contain provisions addressing horizontal environmental issues, climate change, water and air quality, waste management, nature protection, industrial pollution, chemicals, noise and civil protection. Ukraine has some level of preparation in the field of environment and climate change and has made some progress including enhanced public access to environmental information, adoption of legislation on waste management, industrial pollution, chemicals, and water quality (SWD(2024) 699 final 2024). Annex I reports the main legislative packages adopted in the context of Chapter 27 of the *EU Acquis on Environment*.

Moreover, EU-funded regional initiatives such as the European Union for Environment (**EU4Environment**), for climate (**EU4Climate**) and energy (**EU4Energy**) Programmes in the Eastern Partnership countries have played a key role in enabling progress towards climate and environmental resilience in the region, including Ukraine.

- The EU4Environment Programme is funded by the European Union (EU) and implemented by Organisation for Economic Cooperation and Development (OECD), the United Nations Economic Commission for Europe (UNECE), the United Nations Environment Programme (UNEP), the United Nations Industrial Development Organization (UNIDO) and the World Bank. It aims to support the five Eastern Partnership (EaP) countries (Armenia, Azerbaijan, Georgia, Moldova and Ukraine) to pursue a path of green economic transformation providing environmental, economic, and statistical expertise to help each country preserve its natural capital and increase well-being by supporting environment-related action (OECD, 2024; OECD, 2021).

- The Implementation of the EU4Climate activities, funded by the EU and implemented by the United Nation Development Programme (UNDP), started in Ukraine in 2019, supporting the country in implementing the Paris Agreement, planning and developing a National Adaptation Strategy and aligning the national climate change legislation with the EU Acquis.

- The EU4Energy programme, funded by the EU and implemented by International Energy Agency, Energy Community and the Council of European Energy Regulators, supports the implementation of sustainable energy policies in the Eastern Partnership (EaP) countries, including Ukraine.

Bucharest Convention on the Protection of the Black Sea against Pollution addresses trans-boundary problems through enhanced cooperation among signatories. Therefore, coordination among the Black Sea countries including EU partners, is of great importance to allow implementation of EU legislation, EU Water Framework Directive (WFD) and the EU Marine Strategy Framework Directive (MSFD).

The JRC provides scientific support to the EU Enlargement policy in the field of environment and climate since 2013. The JRC contribution to the Danube Strategy was followed by the support the EU macro-regional strategies and subsequently by foresight and gap analysis concerning the EU Acquis. In 2024, the JRC published a report on the Western Balkans. More JRC work to support the Enlargement policy is in progress in the frame of the JRC project SCENARIO under Portfolio 'Science for Global Gateway and neighbourhood policy', involving Ukrainian experts and institutions.

2 Status of air quality

Ukraine is among the countries most affected by air pollution in Europe. On the basis of the average annual exposure to atmospheric particulate matter with diameter <2.5 µm ($PM_{2.5}$) it is the 9th highest in Europe (World Bank Group, 2024). According to the Global Burden of Disease (GBD) database in 2019, 42,900 premature deaths and 953,500 disability-adjusted life years (DALYs) in Ukraine were related to air pollution, which corresponds to about 10% of all cases of morbidity and mortality. This proportion has halved from the peak values in mid-1990s. In Ukraine, a clear majority (93%) of all air pollution related health loss is due to particulate matter exposure (Institute of Health Metrics and Evaluation, 2024). The entire population (100%) is exposed to levels of $PM_{2.5}$ concentration above the WHO threshold. By comparison, in the entire European and Central Asian region this proportion is estimated at 85.1% (2017), having decreased from 94% in 2011 (World Bank Group, 2024).

2.1 Air quality monitoring system

The system of ambient air monitoring in Ukraine is based on the Law of Ukraine «On Air Protection» and the Resolution of the Cabinet of Ministers. It is a component of the state system of environmental monitoring. In Ukraine, the new procedure for conducting state monitoring in the field of atmospheric air protection must be carried out in accordance with the Resolution of the Cabinet of Ministers No. 827 dated 14 August 2019 «On issues of state monitoring in the field of atmospheric air protection» (Cabinet Of Ministers of Ukraine, 2019) and the order of the Ministry of Internal Affairs of Ukraine dated 21 April 2021 No. 300 «On the approval of the Procedure for placing monitoring points for atmospheric air pollution in zones and agglomerations» (Ministry of Internal Affairs of Ukraine, 2021), which take into account the current trends of Ukraine's foreign policy regarding the implementation of EU regulatory documents and recommendations of Directive 2008/50/EC and Directive 2004/107/EC (EC, 2008 and EC, 2004).

The competent authorities in charge of atmospheric air monitoring are: the Ministry of Environmental Protection and Natural Resources of Ukraine (general organisation and coordination role), the Ministry of Health of Ukraine (MHU), the State Emergency Service of Ukraine (SESU), including the Ukrainian Hydrometeorological Center (UHMC), the State Agency of Ukraine on Exclusion Zone Management (SAUEZM); the Regional Kyiv city state administration, and the executive bodies of city councils

The main responsibility for monitoring of ambient air in zones and agglomerations still remains with the **Ukrainian Hydrometeorological Center**, which is a branch of the SESU. The monitoring network was created under the Soviet Union. It consists of stationary sites equipped with non-automated instrumentation and located according to the principle of territorial community which does not meet modern requirements. In the pre-war period, the Ukrainian Hydrometeorological Center of the Ministry of Internal Affairs of Ukraine (MIAU) performed the monitoring of ambient air in **39 cities** and towns at **129 non-automated** stationary stations and 2 stations to monitor transboundary pollution where background information was presented in mg/m^3 and as indices of atmospheric pollution (IAP).

As a result of hostilities, by the end of 2022, the number of cities decreased to 33, and sites to 113 (because of the occupation of Donetsk and Luhansk oblasts) (Central Geophysical Observatory, 2023). The concentration of 22 pollutants (NO_2, NO, SO_2, CO, NH3, total suspended particles - TSP, H2S, phenol, formaldehyde, soot, HF, HCl, benzo(a)pyrene, CxHy), including eight heavy metals (Cd, Mn, Cu, Zn, Pb, Cr, Fe, Hg) is detected in ambient air (Central Geophysical Observatory, 2024). The daily sampling of SO_2 and NO_2 is carried out by monitoring stations for transboundary transfer of pollutants (Central Geophysical Observatory, 2023).

The second most extensive air quality monitoring network is the one including regional units of **MHU Direction for Prevention – Regional centers for disease control and prevention (RCDCP)**. MHU provides state social and hygienic monitoring of air quality in the places of residence and rest, including natural territories, sanitary protection zones of industrial facilities and highways with heavy traffic. The studies performed by the RCDCP of the MHU provide general information on the maximum allowable concentrations of specific pollutants (NO_2, SO_2, CO, NH_3, TSP, H_2S, CS_2, formaldehyde, sulfuric acid, F, Cl, benzo(a)pyrene, phenol, CxHy, Cd, Mn, Cu, Zn, Pb, Cr, Fe, Hg, soot, ozone, gasoline, benzene, toluene, xylene, nickel) in the air in per-unit indices – exceeding of maximum allowable concentrations (MAC – Ukrainian hygienic standard of air quality). Despite the large number of conducted studies (170,546 air samples in 2021), RCDCP monitoring campaigns have serious limitations: measurements are irregular (from 1 to 12 times a year), **samples are first collected by field crews in manual mode,** and then transported and **analysed in the laboratory** as reported in the National report on the state of the environment (Ministry of Environment Protection and Natural Resources Ukraine, 2021).

Currently, the entities in charge for ambient air monitoring in accordance with the EU requirements are regional, Kyiv city state administration and executive bodies of city councils. As of 2023, **24 reference fixed automatic observation points** (that belong to the state monitoring system) were installed in the territory of Ukraine to measure the concentrations of: NO_2, NO, SO_2, CO, NH_3, TSP, PM_1, $PM_{2.5}$, PM_{10}, H_2S, O_3, C_6H_6, heavy metals (Cd, Pb, As, Hg, Ni) and gamma radiation doses (μSv/hour). 16 of them are located in the Kyiv region (Ministry of Environmental Protection and Natural Resorces of Ukraine, 2023), 7 of them are in the city of Kyiv (Kyiv City Council, 2022; 2024), 1 – in the city of Sheptytskyi, Lvivska region (Lvivska Regional Council, 2024; Ministry of Environmental Protection and Natural Resorces of Ukraine, 2024). Also, in Kyiv and Brovary, state administrations have established **indicative measurement points** (46 and 4, respectively) for the following substances: NO_2, NO, SO_2, CO, $PM_{2.5}$, PM_{10}, O_3. The level of air pollution in the city of Kyiv is assessed by the common air quality index (CAQI, common $PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3, CO), which can be consulted in real time on the online map at the link http://asm.kyivcity.gov.ua/ and in the mobile application «Kyiv Digital» (Kyiv City Council, 2023). In addition, recently indicative measurement points have been added in Konotop, Sumy, Kharkiv, Vinnytsia, Kryvyi Rih, Stryi, Boryslav, Dobrotvir, and Sokilnyky. At the same time, there are 15 automated points on the balance sheet of The Environmental Monitoring Center of the Dnipropetrovsk Regional Council (without competences on monitoring): 1 – reference (city of Dnipro), which measures NO_2, NO, NO_x, SO_2, CO, $PM_{2.5}$, PM_{10}, O_3, NH_3, H_2S and 14 indicative (4 – in the city of Dnipro, 10 - in 6 cities of Dnipropetrovsk) NO_2, SO_2, CO, TSP, $PM_{2.5}$, PM_{10}, O_3, NH_3, H_2S (Informational and analytical review, 2021); three mobile stations - NO, NO_2, NO_x, H_2S, SO_2, CO, O_3, NH_3, $PM_{2.5}$, PM_{10}, C_6H_6, C_7H_8, ethylbenzene (C_8H_{10}), $C_6H_4(CH_3)_2$, CH_2O, C_6H_5OH (Dnipropetrovsk Regional Council, 2024). Since the beginning of the war, due to a lack of funds, monitoring of air has been interrupted (Informational and analytical review, 2023). Nevertheless, a stationary automated point with reference measurements of PM_{10} and $PM_{2.5}$ operates based on the Laboratory for Air Quality, SI «Marzieiev Institute for Public Health, NAMSU».

Air monitoring is also carried out with **seven mobile environmental laboratories of the RCDCP**, regional or city state administrations. The pollutants measured are: TSP, PM_{10}, $PM_{2.5}$, NO_2, NO, SO_2, CO, NH_3, hydrogen fluoride, hydrogen chloride, H_2S, O_3, formaldehyde, chromium+6, chromium and its compounds, chlorine, sulfuric acid, manganese and its compounds, non-soluble inorganic fluorine compounds, phenol, carbon disulfide, acetone, benzene, ethylbenzene, gasoline, xylene, toluene, mercury, lead, soot. On the basis of SI «Marzieiev Institute for Public Health, NAMSU» also operates a mobile reference laboratory (measurements: NO_2, NO, NO_x, SO_2, CO, O_3, H_2S, CH_4, cyanides, CH_2O, sums of mercaptans and hydrocarbons). Citizen air monitoring, implemented mainly on the platforms of active non-governmental organisations, which contribute to the development of the state air monitoring system in Ukraine, has gained wide popularity. **More than 1,000 citizen-operated monitoring stations** have been installed throughout the country, mostly equipped with sensor devices, which, unfortunately, do not meet the requirements of reference assessment methods for fixed measurements. The following substances are measured: PM_{10}, $PM_{2.5}$, SO_2, CO, NO_2, O_3, CH_2O, radiation background, and AQI is determined by $PM_{2.5}$ (Skok *et al.,* 2023). Despite the outbreak of war, Ukraine air monitoring networks expanded to cover more people and a greater geographic area. **Collected data represents almost triple the number of cities in 2022 than in 2021 thanks to the combined efforts of government groups and non-governmental organisations**.

2.2 Air pollution modelling

According to Directive 2008/50/EC of the European Parliament and of the Council of 21.05.2008 on ambient air quality and cleaner air for Europe, the assessment of ambient air pollution can be accomplished by modeling the concentration of pollutants in the surface layer of the atmosphere in line with (EC, 2008; WHO, 2013; Henschel *et al.,* 2013).

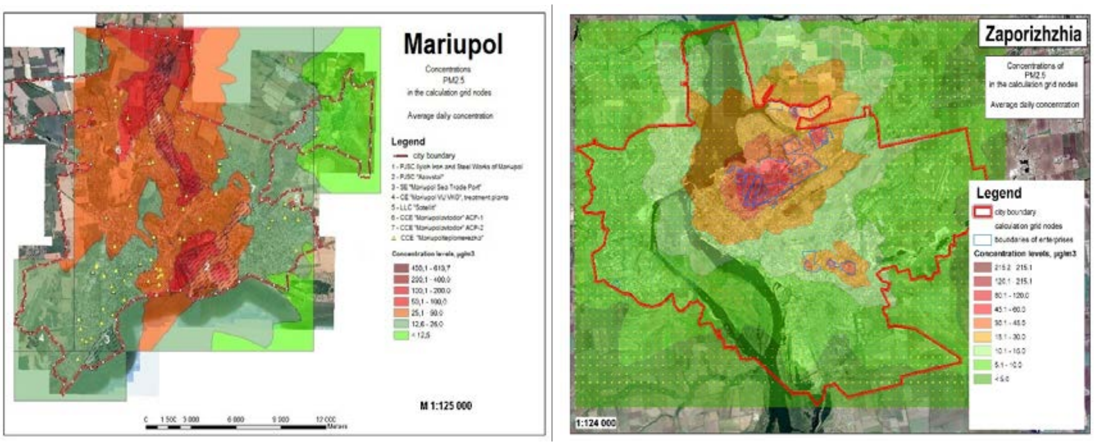
As in other regions in Eastern Europe, the assessment of ambient air pollution to comply with the requirements of international agreements (e.g. Air Convention) and EU legislation, (e.g. Directive 2008/50/EU), is challenging due to the limited financial support for instrumentation and skilled personnel. Therefore, **the use of modelling is a useful complement to measurements as it covers areas or time-windows that are not monitored by air quality networks**.

The software package (EOL) implementing the methodology OND-86 («Methodology for calculation of the concentrations of hazardous substances in ambient air in the emissions of enterprises», 1986) and adopted by the Ukrainian Ministry of Ecology and Natural Resources, calculates concentrations with averaging period of 20 minutes. This software is also used to model the dispersion of pollutants in the atmosphere from industrial facilities for the release of emission permits; for the design of industrial buildings in environmental impact assessments; for the design and dimensioning of sanitary-protective zones for the industrial sites. The abovementioned activities may be carried out either by public institutions or by other organizations.

The software package EOL assesses only the risk of acute inhalation impact and unlike analogous models recommended by the WHO and the US EPA, does not evaluate chronic exposure. To compute concentrations and risks for the health of the population affected by hazardous for different averaging periods (acute and chronic) the software package ISC-AERMOD was adapted and implemented at the Laboratory for Air Quality, SI «Marzieiev Institute for Public Health, NAMSU» for computing concentrations of ambient air pollutants deriving from the emissions of industrial sites and CalRoad View for those deriving from vehicle emissions to assess acute and chronic inhalation effects on the exposed population (**Figure 2**) (Petrosian, 2021; Maremukha, 2021; Davydenko, 2017).

Lagrangian air quality models such as CALPUFF and HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) are operational at the Institute of Mathematical Machine and Systems (NASU), the Ukrainian Hydrometeorological Institute (SESU, NSC) and the «Kharkiv Institute of Physics & Technology» (NASU) (Kovalets *et al.,* 2020; Kovalets *et al.,* 2017; Savenets *et al.,* 2020).

Figure 2. Average daily concentrations of $PM_{2.5}$ in some Ukrainian cities (Mariupol, 2021; Zaporizhzhia, 2023).



Source: SI «Marzieiev Institute for Public Health, NAMSU» (Environmental Protection and Rehabilitation Program for 2021-2030, 2022; Zaporizhzia City Council, 2023).

However, according to the Ukrainian legislation, the results of air quality models is strictly for scientific purposes and have no legal value for the assessment of ambient air pollution and/or its impact on the health. Results of research studies were used in the development of national standards and policy documents on strategies to improve air quality in Ukraine.

2.3 Trends, measurements and exceedances of atmospheric pollutant concentrations

Globally, air pollution has negative impacts on human health and wellbeing and it is the third highest risk factor of death from non-communicable diseases after high blood pressure and tobacco use worldwide. Emissions from human activities such as heating, traffic, electricity generation, industry, mining, construction, industrial agriculture and forest fires are among the main causes of pollution (Dattani *et al.,* 2022). Their impact on atmospheric air pollution has increased recently, despite the adoption and implementation of regulatory measures to abate emissions. Ukrainian national air quality standards have partially implemented the current Air Quality Directives (AAQD),– Directive 2008/50/EC (EC, 2008) and Directive 2004/107/EC (EC, 2004). However, the WHO air quality Guidelines (WHO AQGs) adopted in 2021 and the new EU air quality directive EU 2024/2881 (EU, 2024/2881) changed the criteria for air quality assessment. It is reasonable to assume that air pollution will continue causing significant health problems also in the future (WHO, 2021).

The conducted analysis shows that monitoring of air pollution (particulate matter $PM_{2.5}$, PM_{10} and O_3) is still poorly implemented due to the limited number of automated points for fixed and indicative measurements.

Moreover, in Ukraine the assessment of exposure to atmospheric pollutants is still determined by establishing the limits of permissible concentrations: maximum allowable concentration maximum single ($MAC_{m.s.}$, 20-30-minute averaging period) and maximum allowable concentration average daily ($MAC_{a.d}$). The basic 20-30-minute pollutant concentration averaging interval is not considered in the EU legislation which instead refers to hourly and 8-hour intervals. Such differences hinder the comparison of results, in particular those of historical time series.

At present, Ukraine did not fully approve the main provisions of Directive 2008/50/EC (EC, 2008) and Directive 2004/107/EC (EC, 2004), despite the Resolution of the Cabinet of Ministers No. 827 goes in this direction. The main reason is the lack of approved national air quality standards (NAAQS) for $PM_{2.5}$ and PM_{10}. The available results useful for comparison with the limit values recommended by Directive 2008/50/EC and WHO guidelines have no legal status at the national level.

In Ukraine, monitoring with indicative measurements (passive sampling) is carried out by the Ukrainian Hydrometeorological Center for the main pollutants: TSP, NO_2, NOx, SO_2, CO, phenol and CH_2O in 39 cities (and since the beginning of the war in 33). During the last five years all the above-mentioned pollutants were monitored and significant exceedance of Ukrainian standards were observed only for of NO_2, CH_2O, phenol (**Table 1)** (Ministry of Environmental Protection and Natural Resorces o Ukraine, 2024; Central Geophysical Observatory, 2021; 2022; 2023).

In the period 2018-2022, the annual average concentrations of NO_2 and CH_2O were 1.5 and 2.3 to 2.7 times above the limit values (LVs) defined by NAAQS and Directive 2008/50/EC, respectively. In the same interval, levels of NO_2 and CH_2O above the NAAQS (in particular, maximum allowable concentration maximum single – MACm.s.; LV – 200 $\mu g/m^3$ and 35 $\mu g/m^3$) were observed at 50% of the sites with incidences of concentrations considered dangerous of up to 30 and 70%, respectively. The cities with highest CH_2O levels are: Mariupol, Kryvyi Rih, Mykolaiv, Dnipro, Zaporizhzhia, Odesa, Kyiv, Poltava, Kramatorsk, and Kremenchuk (Savenets *et al.,* 2023a).

Table 1. Average annual concentrations of TSP, NO_2, NO, SO_2, CO, C_3H_6O and CH_2O in Ukraine, $\mu g/m^3$.

	NAAQS	2018	2019	2020	2021	2022
TSP	150	130	130	150	120	110
SO_2	50	15	18	19	17	
CO	3000	1700	1600	1400	1400	
NO_2	40	60	60	60	60	60
NO	60	30	30	30	30	
C_3H_6O	3	4	4	3	3	3
CH_2O	3	7	8	7	7	7

Source: Ukrainian Hydrometeorological Center.

The annual average concentration of phenol in ambient air is above the NAAQS (LV – 3 $\mu g/m^3$) only in 2018-2019 when it reaches 4 $\mu g/m^3$. The average annual concentration of TSP was lower than the LV (150 $\mu g/m^3$) of NAAQS (Ministry of Environmental Protection and Natural Resorces of Ukraine, 2024; Central Geophysical Observatory, 2021; 2022; 2023) over the specified time window with the exception of 2020 when it equals the LV threshold. It should be noted that high concentrations of CH_2O and phenol are recorded in the ambient air of agglomerations, where industrial pollution is not predominant source. One possible explanation is the formation of substances from precursors (mainly from organic compounds of biological and anthropogenic origin, particularly NO_2) as a result of photochemical reactions in the atmosphere, especially in the urban microclimate (IQAir AirVisual, 2019).

The most polluted cities in terms of TSP concentration are: Kryvyi Rih and Kamianske where metallurgical, coke-chemical and mining enterprises are located. Recurrent exceedances of $MAC_{m.s.}$ are observed in these cities (range 20% - 50%) while the average concentrations are close to 300 $\mu g/m^3$. Exceedances from 5% to 15% are observed at some locations in the cities of Odesa, Kharkiv, Mariupol, Kropyvnytskyi, Zaporizhzhia, Chernivtsi and Poltava with concentrations ranging from 100 $\mu g/m^3$ to 300 $\mu g/m^3$ (Savenets *et al.,* 2023a).

In general, cities with levels above the respective NAAQS in terms of annual average concentrations, exceedances ranged from 56% to 67% for NO_2; 77% to 83% for CH_2O; 18% to 28% for TSP and 35%

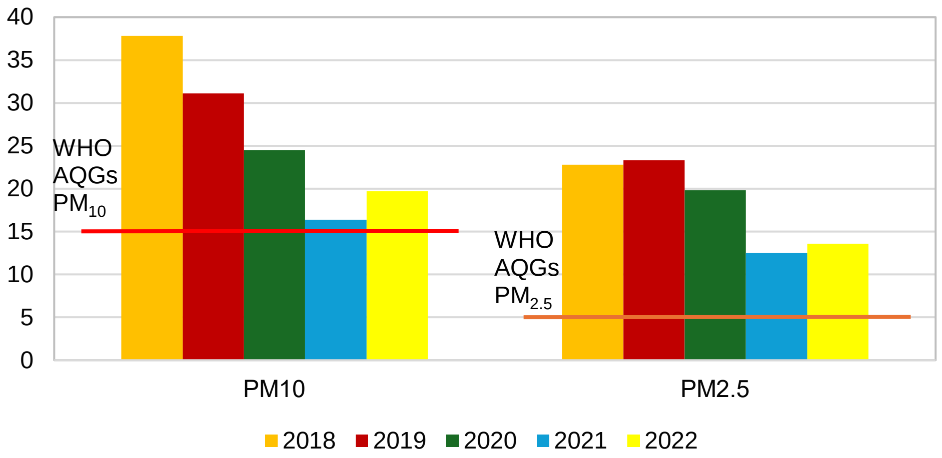
to 41% for phenol. A very high level of ambient air pollution was registered in four Ukrainian cities: Mariupol, Dnipro, Odesa, and Kamianskyi due to high concentrations of formaldehyde, phenol, hydrogen fluoride, ammonia, TSP, nitrogen dioxide, and carbon monoxide (Ministry o Environmental Protection and Natural Resorces of Ukraine, 2024; Central Geophysical Observatory Boris Sreznevsky, 2021; 2022; 2023).

In Ukraine PM_{10} and $PM_{2.5}$ measurements are carried out at 39 state reference and indicative automated monitoring stations run by regional or city state administrations (see section 2.1) and at more than 1,000 citizen-operated monitoring stations. Basically, all estimates regarding PM_{10} and $PM_{2.5}$ concentration levels are based on the analysis of all data available in Ukraine, regardless of whether the site belongs to the state monitoring system or not.

According to the World Air Quality Reports $PM_{2.5}$ annual concentrations in Ukraine grew from 14 µg/m^3 in 2018 to 19 µg/m^3 in 2020 and 2021 and then decreased to 9.7 µg/m^3 and 8.6 µg/m^3 in 2022 and 2023, respectively. Therefore, Ukraine moved from 43rd place among the most polluted countries in the world to 107th in 2023 (IQAir AirVisual, 2019; 2020; 2021; 2022; 2023). As for $PM_{2.5}$ studies conducted by UNDP (2019-2020) in the most polluted cities of Ukraine (Kyiv, Odesa, Dnipro, Zaporizhzhia, Lviv, Kryvyi Rih, Mariupol), average concentration levels ranged from 40 µg/m^3 to 60 µg/m^3. Such concentrations reached values of more than 100 µg/m^3 per day (quite often), especially in the cities of Dnipro, Kryvyi Rih, Zaporizhzhia and Kyiv (UNDP in Ukraine, 2023).

Studies conducted at reference monitoring sites in the city of Kyiv between 2018 and 2022 showed that annual concentrations of PM_{10} were the highest in 2020 (31.1 µg/m^3) and the lowest in 2022 (19.7 µg/m^3). Such levels are below the EU annual LV (40 µg/m^3, Directive 2008/50/EC) and above (1.1 to 2.5 times) the WHO AQGs (15 µg/m^3). In the same period annual $PM_{2.5}$ concentrations were the highest in 2019 (23.3 µg/m^3) and the lowest in 2021 (12.5 µg/m^3). Despite the decreasing trend all values are above (2.5 to 4.7 times) the WHO AQGs (5 µg/m^3) (**Figure 3**) (Turos *et al.,* 2022; 2023).

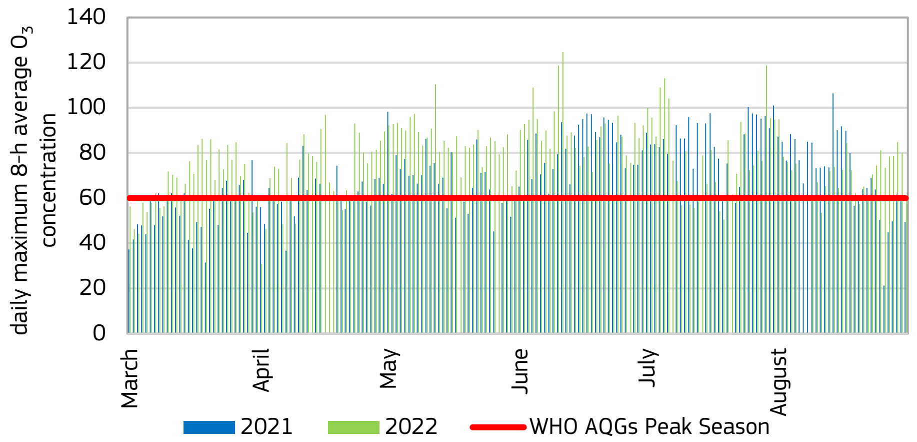
Figure 3. Average annual concentration of PM_{10} and $PM_{2.5}$ in Kyiv City (µg/m^3, 2018-2022).



Source: SI «Marzieiev Institute for Public Health, NAMSU» (Turos et al., 2022; 2023).

In addition, research conducted in Kyiv in 2021 and 2022 reported a peak season daily maximum 8-hour average O_3 of 70.3 µg/m^3 and 77.7 µg/m^3, respectively. **Figure 4** shows the time series of the daily maximum 8-hour O_3 concentrations in 2021 and 2022 (March-August).

Figure 4. Maximum daily 8-hour O_3 concentrations (μg/m³) in 2021 and 2022 (March-August).



Source: SI «Marzieiev Institute for Public Health, NAMSU» (Turos et al., 2024)..
Note: The red line corresponds to the WHO limit value in the peak season.

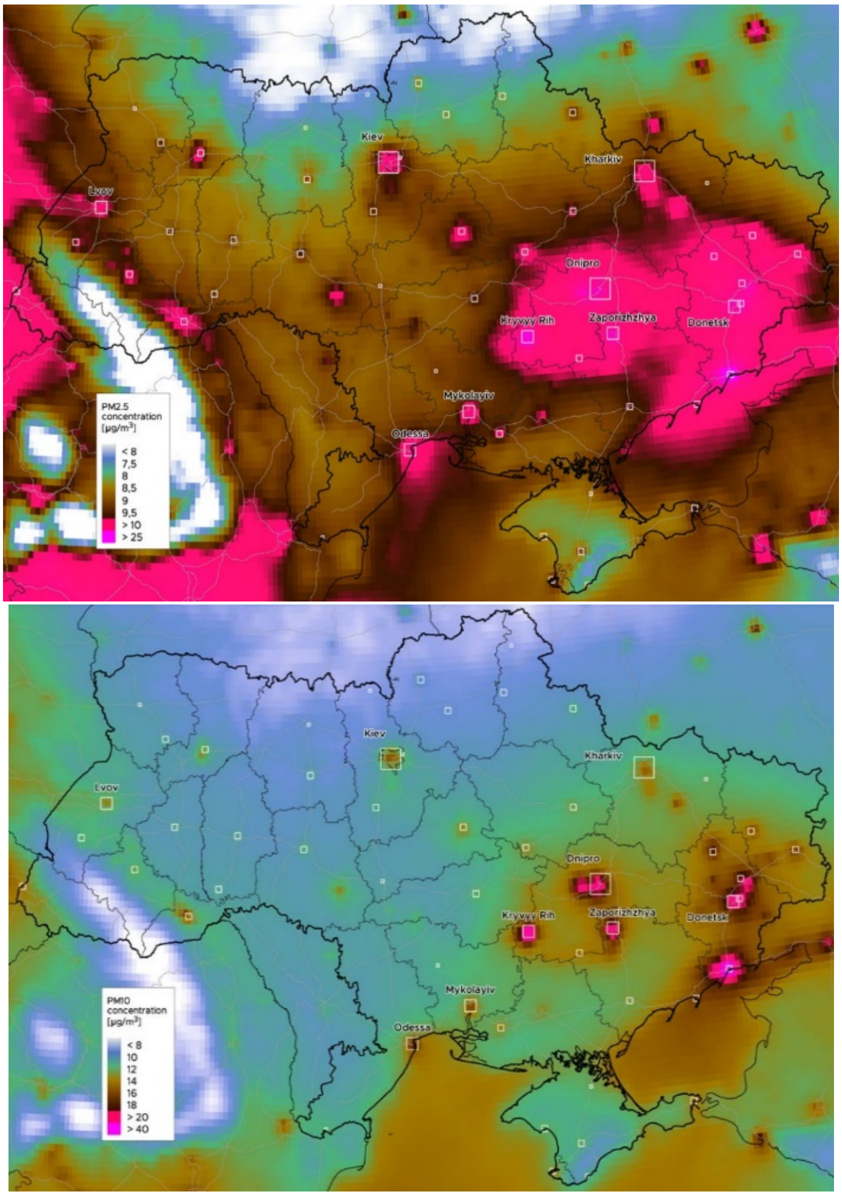
Air quality monitoring in 2021 and 2022 peak seasons detected several daily maximum 8-hour ozone (O_3) concentration above the WHO (60.0 μg/m³). Such concentrations led to a health risk for the exposed population in 70% (174 days) and 84% (181 days) of observations, with maximum exceedances reaching 1.7 and 2.1 times the recommended level, respectively (Turos *et al.,* 2024).

Due to the limited availability of monitoring data in Ukraine, satellite-measurements are also used to assess air quality. In this section are discussed the results of the Copernicus Sentinel-5 satellite imagery and quality-controlled air pollution data from the Copernicus Atmosphere Monitoring Service (CAMS) (Labohý *et al.,* 2020). Such analysis identified the most polluted areas and focused on them for more thorough analysis (Savenets *et al.,* 2023a; 2023b).

The study (supported by the Transition Promotion Program of the Ministry of Foreign Affairs of the Czech Republic) showed that the average $PM_{2.5}$ concentration in Ukraine reached a value of 9.0 μg/m³ between July 2017 and July 2020 (**Figure 5**). The amount of particulate matter decreases from the south to the north of the country, with the highest concentrations located in the industrial region of eastern Ukraine. The Donetsk region (11.9 μg/m³), Dnipropetrovsk region (10.9 μg/m³), Kyiv (city) region (10.8 μg/m³), and Zaporizhzhia (10.2 μg/m³) are among the most affected by long-term $PM_{2.5}$ exposure. The highest average concentrations were reached in the cities of Mariupol (25.7 μg/m³), Kryvyi Rih (18.9 μg/m³), Manhush (17.5 μg/m³), Dnipro (16.6 μg/m³) and do not comply with the WHO guidelines.

The PM_{10} average concentration over Ukraine was 11.8 μg/m³ in the period of observation. This pollutant presents the same N-S decreasing gradient as $PM_{2.5}$. PM_{10} concentrations are above the WHO guidelines annual mean values for coarse particulates in five cities: Mariupol, Kryvyi Rih, Dnipro, Zaporizhia and Donetsk, all of which are located in south-eastern Ukraine. Together with the capital city, Kyiv, and the city of Kharkiv, also the Dniester River valley presents high PM_{10} concentrations (Labohý *et al.,* 2020).

Figure 5. Average annual concentrations of $PM_{2.5}$ and PM_{10} in Ukraine between July 2017 and July 2020, µg/m³.



Source: Air pollution in Ukraine as seen from Space, ARNIKA (Labohý et al., *2020).*

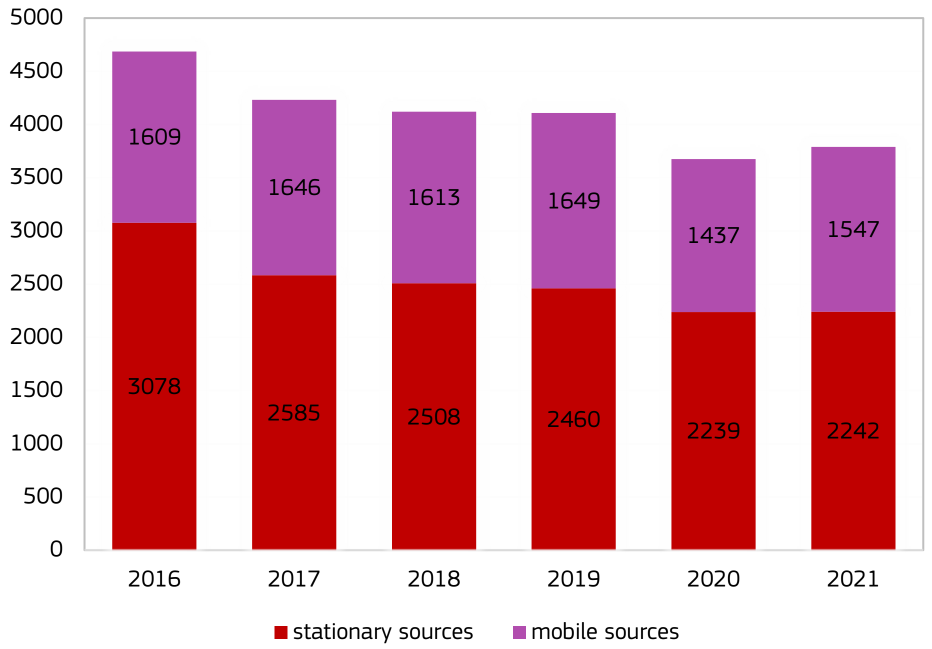
Note: Average annual concentrations of $PM_{2.5}$ and PM_{10} (µg/m³) in Ukraine (using the global model), obtained from the Copernicus Atmosphere Monitoring Service data (Source: CAMS, 2017-2020).

3 Emissions

3.1 Emission of atmospheric pollutants

Between 2016 and 2021, 3.7 to 4.7 Mton of pollutants were released into the atmosphere from 8410 (2021) Ukrainian stationary sources (including energy, industry, waste, agriculture and other sectors) and mobile sources (State Statistics Service of Ukraine, 2024). According to the national statistical service, the largest share of Ukrainian emissions of atmospheric pollutants and GHG (excluding CO_2, see subchapter 3.3) in 2021 were industrial sources including energy production (2.2 Mton) followed by the transport sector (1.5 Mton) (**Figure 6**).

Figure 6. Emissions of atmospheric pollutants and GHG (except CO_2) in Ukraine, Kton.



Source: State statistics service of Ukraine.

Note: For 2016-2021 data excluding the temporarily occupied territories of the Autonomous Republic of Crimea, the city of Sevastopol and a part of temporarily occupied territories in the Donetsk and Luhansk regions.

The trend of emissions from the transport sector between 2016 and 2019 is associated with the fast increase in the number of vehicles. During the observed time window, a relatively limited number of regions with a high density of industrial sites and vehicles are those with the largest share of national emission of atmospheric pollutants. In 2021 the following regions presented the highest emissions: Donetska, Dnipropetrovska, city of Kyiv, Zaporizka, Ivano-Frankivska, and Kyivska (**Table 2**).

During the same period, the overall country emissions decreased by 20% with highest reductions in the Donetska, Dnipropetrovska and Luhansk regions. Such reductions are due to the operation of the United Forces in the east of the country, part of Donetsk and Luhansk regions (- 8.6%). Moreover, the decline in industrial production related to COVID-19 pandemic and the introduction of environmental protection measures contributed on average to a 16.9% reduction in these regions. At the same time, there was a gradual increase in pollution in «relatively clean» regions of Zhytomyrska, Volynska, Khmelnytska, Khersonska, and Sumska (on average by 6.2% annually) (Turos *et al.,* 2023).

Table 2. Total emissions of atmospheric pollutants and GHG (except CO_2) in Ukrainian regions, Kton.

	2016	**2017**	**2018**	**2019**	**2020**	**2021**
Vinnytska	173.4	214.4	163.2	157.8	129.6	134.5
Volynska	40.3	40.5	38.2	36.7	36.8	36.4
Dnipropetrovska	965.6	790	747.3	708.2	660.7	671.1
Donetska	1036.3	839.2	844.7	830.4	802.5	795.4
Zhytomyrska	69.9	74.4	73	73.3	53.9	58.7
Zakarpatska	54.4	50.3	49.5	41.8	36.6	42.6
Zaporizka	243.1	261.1	252	254.2	226.9	217.5
Ivano-Frankivska	241.9	240.9	260.9	242	173.4	210.3
Kyivska	210.2	162	197	215.7	200.7	197.2
Kirovohradska	57.2	54.8	53.7	56.3	49.2	51.7
Luhanska	193.2	92.4	63.4	54.4	50.6	51.3
Lvivska	204.6	199.8	192.9	173.7	148.1	159
Mykolaivska	58.8	63.2	59.3	60.8	54.3	58.8
Odeska	119.6	133.8	129.4	126.8	123.8	130.4
Poltavska	140.3	157.9	150.5	144.4	118	130.2
Rivnenska	47.4	46.7	44.1	45.1	39.5	42.4
Sumska	63.7	67.5	68.7	69.2	58.7	59.3
Ternopilska	45.2	45.4	42.9	42	37	39.4
Kharkivska	100.2	45.0	44.7	106.5	94.1	73.4
Khersonska	54.3	54.9	55.1	60.6	56.4	57.8
Khmelnytska	73.1	76.7	77.2	72.7	58.2	64
Cherkaska	52.3	48.3	57.9	51.8	51.4	47.7
Chernivetska	3	3.3	2.7	2.4	1.8	1.7
Chernihivska	77.7	79.9	71.5	66.6	63.3	52.5
City of Kyiv	182.3	202.7	200.6	230.3	203.6	225.6

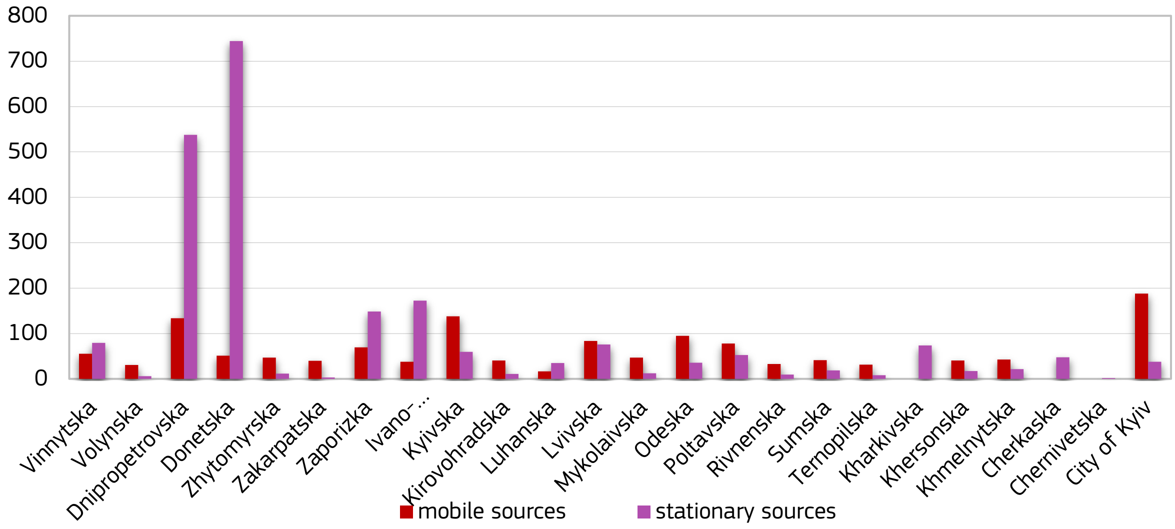
Source: State statistics service of Ukraine - regional departments.

Note: For 2016-2021 data exclude the temporarily occupied territories of the Autonomous Republic of Crimea, the city of Sevastopol and a part of temporarily occupied territories in the Donetsk and Luhansk regions.

The regions with highest emissions from stationary sources in 2021 were Donetska and Dnipropetrovska. These two regions are responsible for more than half of the country stationary emissions. Other important emitter regions are Ivano-Frankivska, Zaporizka, Vinnytska regions which represent slightly less than 20% of the country stationary emissions (**Table 2**).

During the observed period, the emissions from mobile sources increased between 2017 and 2019 and then decreased in 2020 and 2021 compared to 2016 likely due to the COVID-19 measures (**Figure 6**). The region with higher emissions from mobile sources in 2021 were the city of Kyiv, Kyivska, Dnipropetrovska, Odeska, and Lvivska which together contribute to more than 40% of the country total emissions from these sources (**Figure 7**).

Figure 7. Comparative emissions of pollutants and GHG (except CO_2) into the atmosphere from stationary and mobile sources by region in Ukraine (2021, Kton).



Source: State statistics service of Ukraine - regional departments.

Note: For 2016-2021 data excluding the temporarily occupied territories of the Autonomous Republic of Crimea, the city of Sevastopol and a part of temporarily occupied territories in the Donetsk and Luhansk regions.

Table 3. Atmospheric emissions of main pollutants and GHG (except CO_2) in Ukraine, Kton.

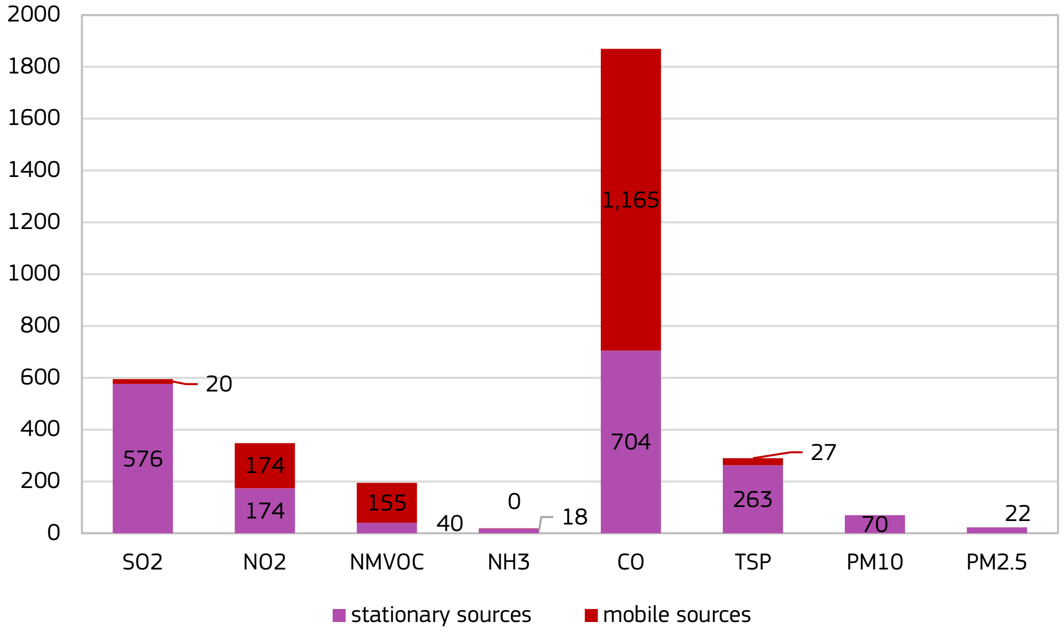
	2016	2017	2018	2019	2020	2021
SO_2	**1094**	**744**	**717**	**696**	**619**	**595**
stationary sources	1076	726	698	676	601	576
mobile sources	18	18	19	20	18	20
NO_2	**405**	**384**	**386**	**384**	**343**	**348**
stationary sources	240	216	215	205	181	174
mobile sources	164	169	170	179	162	174
NMVOC	**223**	**224**	**207**	**205**	**182**	**195**
stationary sources	52	53	44	43	41	40
mobile sources	171	171	163	163	142	155
NH_3	**19**	**17**	**17**	**18**	**18**	**18**
stationary sources	19	17	17	18	18	18
mobile sources	0	0	0	0	0	0
CO	**2030**	**1987**	**1975**	**2004**	**1792**	**1869**
stationary sources	803	728	744	748	707	704
mobile sources	1227	1259	1231	1255	1085	1165
TSP	**419**	**343**	**342**	**337**	**274**	**290**
stationary sources	396	320	318	310	249	263
mobile sources	23	24	25	27	25	27
PM_{10} (stationary sources)	**73**	**47**	**54**	**66**	**55**	**70**
$PM_{2.5}$ (stationary sources)	**34**	**14**	**21**	**25**	**22**	**22**

Source: State statistics service of Ukraine.

Note: For 2016-2021 data excluding the temporarily occupied territories of the Autonomous Republic of Crimea, the city of Sevastopol and a part of temporarily occupied territories in the Donetsk and Luhansk regions.

According to the Ukrainian Statistical Service, the emissions of specific pollutants from industrial and road transport see a downward trend of all substances over the period 2016 - 2021 (**Table 3**). SO_2 and TSP are the pollutants with the strongest decrease (-46% and -31%), mainly due to reductions in the industrial sector, followed by NO_2 and non-methane volatile organic compounds (NMVOC) (-14% and -12%, respectively). In the same period, NH_3 and CO remained relatively stable with a decrease of -6% and -8%, respectively. Although there was a trend of decreasing emissions of the above-mentioned pollutants after 2019, there was a slight increase in 2021, caused by easening of strict COVID-19-related restrictions introduced in 2020. The most significant contribution to the emissions from industrial and road transport in 2021 are CO and SO_2 followed by NO_2, TSP and NMVOC (**Figure 8**). CO and NMVOC are mainly emitted from mobile sources, NO_2 emissions from both mobile and industry while the industrial emissions from the other considered pollutants are dominant when compared to mobile sources.

Figure 8. Ukrainian emissions of atmospheric pollutants from stationary and mobile sources in 2021 (Kton).



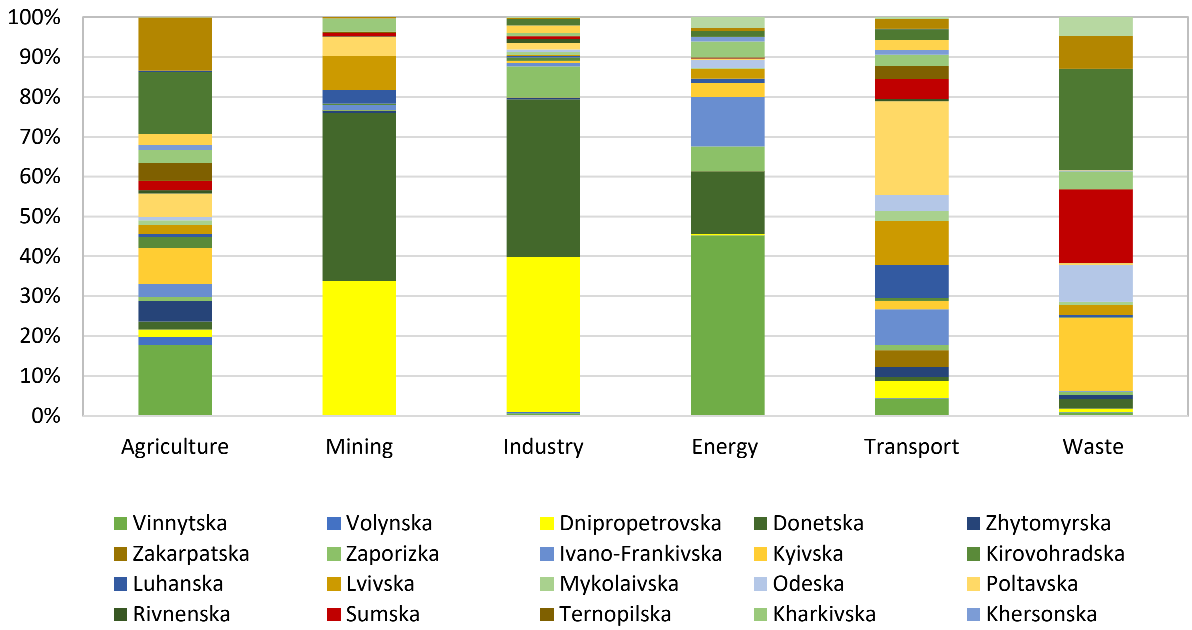
Source: State statistics service of Ukraine.

Note: For 2016-2021 data excluding the temporarily occupied territories of the Autonomous Republic of Crimea, the city of Sevastopol and a part of temporarily occupied territories in the Donetsk and Luhansk regions.

The emissions of Polycyclic Aromatic Hydrocarbons (PAHs) and Fe increased considerably in 2020 compared to previous years, due to the increased use of surfactants in the agricultural, chemical and energy industries, while the other heavy metals show a decreasing trend between 2016 and 2021.

In Ukraine, the economic activities with the highest atmospheric emissions are: Power generation and the Energy distribution industry, which emits 776.4 Kton of pollutants per year followed by Metallurgical production (689.1 Kton), Mining (401.8 Kton), and Agriculture and Food production (67.3 Kton). **Figure 9** shows the total emissions into the atmosphere from stationery and mobile sources of pollution by type of economic activity by region (Turos et al., 2023).

Figure 9. Total Ukrainian emissions of atmospheric pollutants by sector and by region, %.



Source: State statistics service of Ukraine.

Note: For 2016-2021 data excluding the temporarily occupied territories of the Autonomous Republic of Crimea, the city of Sevastopol and a part of temporarily occupied territories in the Donetsk and Luhansk regions.

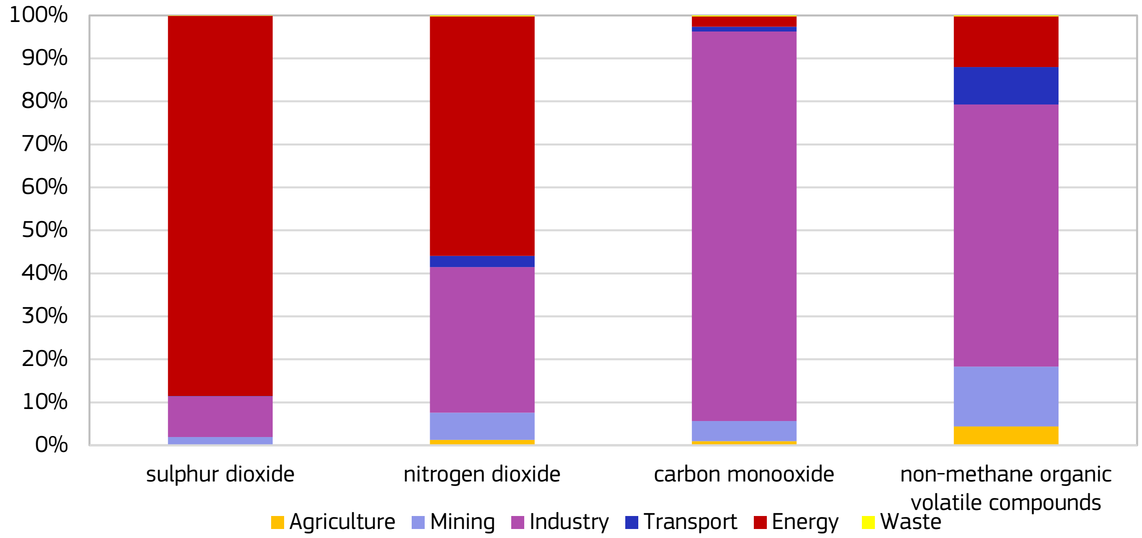
The largest pollutants emissions are characteristic of:

a) **industrial processes** (the eastern and southeastern part of Ukraine – Donetska, Dnipropetrovska, and Zaporizhzhia regions, where the main metallurgical, coke-chemical, and machine-building enterprises are concentrated); b) **Energy** (east and southeast - Donetska, Dnipropetrovska and Zaporizka regions; central part of Ukraine – Vinnytska; west – Ivano-Frankivska regions, where the most powerful state-owned energy facilities are concentrated); c) **Mining** (east and southeast - Donetska and Dnipropetrovska regions); and d) **Agriculture** (the central part of Ukraine – Vinnytska, Cherkaska and Poltavska regions; and the north – Chernihivska), where the main agricultural enterprises are located (farms; elevators, seed factories, etc.).

As for **mobile sources**, the highest levels of pollution of the above-mentioned chemical substances are observed in Dnipropetrovska, Odeska, Lvivska, Kyivska, Poltavska, Kharkivska regions and in the city of Kyiv. These data are the result of a high concentration of vehicles in these regions, as they are business centers of Ukraine (Turos *et al.,* 2023).

The largest contributions to air pollution by **SO_2** and **NO_2** derive from the Energy sector (84% and 54%) and Industry (9% and 33%). The main sources of **CO** are the Industry (90%) and Mining (5%) sectors. As for **NMVOC**, the leading role belongs to the Industry (54%), Mining (12%), Energy (11%) and Transport (8%) sectors. At the same time, about 70% of all emissions of $PM_{2.5}$ and 50% of **PM_{10}** belong to combustion in the Energy and Industry sector (**Figure 10)** (State Statistics Service of Ukraine, 2024).

Figure 10. Total emission of air pollutants by sector economy in Ukraine, %.



Source: State statistics service of Ukraine

Note: For 2016-2021 data excluding the temporarily occupied territories of the Autonomous Republic of Crimea, the city of Sevastopol and a part of temporarily occupied territories in the Donetsk and Luhansk regions.

3.2 Key messages (atmospheric pollutants)

The national policy on atmospheric air quality protection and management in Ukraine requires the alignment with the EU Acquis and international obligations: e.g. Directives 2008/50/EC, 2004/107/EC repealed by Directive (EU) 2024/2881 since 12th Dec 2026, 2010/75/EC, (EU) 2016/2284), CLRTAP. Despite the efforts, there are still many obstacles to the implementation of solutions to reduce emissions and improve air quality. A preliminary gap analysis highlighted the following issues:

- Inappropriate coverage of monitoring stations to assess the exposure of population to pollutants and their impact on the health in the entire country;
- Limited spectrum of monitored chemical substances and limited knowledge of toxicological aspects associated with them including the territorial peculiarities.
- Lack of centralised aggregation of data from monitoring networks owned by different subjects with an appropriate software to guarantee free access to data for competent authorities and citizens.
- Limited financial support to monitoring activities;
- Fragmented monitoring and research on ambient air pollution which is insufficient to assess its impact on health.
- Inefficient and outdated energy production technologies;
- Low penetration rates of modern emission abatement technologies and their effectiveness in technological processes (BATs and BREFs);
- Use of poor quality fuels in the vehicle fleets.

3.3 Emissions of greenhouse gases

Climate change is the most significant global environmental challenge of the 21st century, facing humanity at the local, subnational, regional and international dimensions (Plyushch *et al.,* 2017). In the framework of the United Nations Framework Convention on Climate Change (UNFCCC), countries are committed to develop national emissions inventories and propose/implement actions to mitigate GHG emissions.

Global CO_2 emissions, which are the main contributor to global GHG emissions, are still increasing despite climate change mitigation agreements. Because of the COVID-19 pandemic, global emissions decreased by 3.7% in 2020 compared to 2019 levels, interrupting a more than ten-year growing trend. Nevertheless, global GHG emissions restarted to grow just after the break in 2020 and 2021 due to the pandemic, reaching in 2022 the level of 53.8 Gt CO_2-eq, which is 2.3% higher than 2019 and 1.4% higher than 2021. In 2022, global GHG emissions primarily consisted of CO_2, resulting from the combustion of fossil fuels (71.6%). Methane (CH_4) contributed 21% to the total, while the remaining share of emissions comprised nitrous oxide (N_2O) (4.8%) and F-gases (2.6%). As far as EU27 is concerned, its GHG emissions amounted to 3.59 Gt CO_2-eq in 2022, 0.8% lower than in 2021. It is noteworthy that despite their 2021 rebound, EU27's emissions remained below the pre-COVID-19 levels, continuing their decades-long decreasing trend (Crippa *et al.,* 2024).

Ukraine signed the UNFCCC in June 1992 and became Annex I Party of the UNFCCC in August 1997. In order to ensure regulatory and organisational support for GHG inventory, the Ukrainian President Decree was signed, and several Resolutions of the Cabinet of Ministers of Ukraine were adopted.

Table 4. GHG emissions in Ukraine, Mton CO_2-eq.

Gas	2016	2017	2018	2019	2020	2021
CO_2 (excluding LULUCF)	234	223	232	222	207	210
CH_4	66	64	68	70	72	72
N_2O	37	35	39	41	38	44
HFCs*	921	1049	1396	1685	1752	1901
PFCs*,**	NO	NO	NO	NO	NO	NO
SF_6*	24	29	33	39	43	49
NF_3*	NO	NO	NO	NO	NO	NO
Net CO_2 from LULUCF	24	13	25	23	-1	14
CO_2 (including LULUCF)	258	236	256	245	206	224
Total (excluding LULUCF)	338	323	340	334	318	327
Total (including LULUCF)	362	337	365	357	318	342
Total (excluding LULUCF), including indirect CO_2 ***	338	323	340	334	318	327
Total (including LULUCF), including indirect CO_2	**362**	**337**	**365**	**357**	**318**	**341.5**

Source: Ministry of Environmental Protection and Natural Resources of Ukraine.

Note: *emissions quoted in Kton CO_2-eq.; ** there are no perfluorocarbons (PFC) emissions, as cooling agents containing the gas were not imported in 2011-2021. *** indirect CO_2 refers to carbon dioxide from the atmospheric oxidation of methane, carbon monoxide, and non-methane volatile organic compounds emissions that result from several source categories

Ukraine contributes to a 0.34% of the global GHG emissions. In 2021, the emission level was 327 Mton CO_2-eq excluding LULUCF, 2.9% higher than in 2020. With the LULUCF sector, emissions in 2021 totalised 341 Mton CO_2-eq, 7.5% higher than 2020 (**Table 4**). In 2021 GHG emissions were influenced by the recovery from the pandemic and the intensification of production in different sectors of Ukrainian economy (Ministry of Environmental Protection and Natural Resources of Ukraine, 2023).

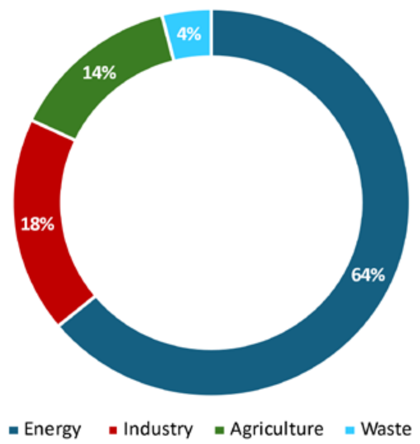
By 2021, Ukraine had **achieved a significant reduction in GHG emissions (-62.5% compared to 1990)**, although, more recently there was an increase of 7.5% compared to 2020 levels, largely attributed to the recovery of industrial activities after the COVID-19 pandemic.

In 2021 carbon dioxide remained the largest emitted gas – 65.7% of all the GHG emissions, followed by methane (21.0%) and nitrous oxide (12.8%). CO_2 emissions took place in all sectors, as well as removals of CO_2 in the LULUCF sector. Emissions of CH_4 represented the second largest share of total GHG emissions after CO_2. In 2021, CH_4 emissions amounted to 71.55 Mton CO_2-eq, 0.6% lower compared to 2020. N_2O emissions with the LULUCF sector amounted to 43.79 Mton CO_2-eq. in 2021, 15.0% than 2020. Emissions of HFCs, PFCs, SF_6, and NF_3 were insignificant in terms of volumes in comparison with the total GHG emissions (0.6% of the total emissions in 2021) (Ministry of Environmental Protection and Natural Resources of Ukraine, 2023).

The largest GHG emissions in Ukraine derive from the Energy sector (**Figure 11**). In 2021, the share of this sector accounted for around 64% without the LULUCF sector. About 76% of emissions in this sector are attributable to the Fuel Combustion category.

In 2020, the measures to contrast the global COVID-19 pandemics slowed the economy resulting in a decrease of GHG emissions from the Energy sector. It affected particularly energy industries, transport and other related sectors. In the Industry sector (18%) it was reported a growth of emissions in the metal industry following a drop in 2020. The share of the Agriculture sector in total GHG emissions without LULUCF was 14% in 2021. The major sources of emissions in this sector are enteric fermentation and agricultural soils, corresponding to 15% and 80% of the total emissions in the sector in 2021, respectively. The contribution of the Waste sector in 2021 to total emissions is 3.7%. The main source of emissions in this sector are landfills of municipal solid waste (MSW) and sewage treatment (UNFCCC, 2023).

Figure 11. The GHG emission structure by sources in Ukraine, % (2021).



Source: State statistics service of Ukraine.

Note: For 2016-2021 data excluding the temporarily occupied territories of the Autonomous Republic of Crimea, the city of Sevastopol and a part of temporarily occupied territories in the Donetsk and Luhansk regions.

The energy sector leads CO_2 emissions with 160 Mton in 2021 while the industry sector contributed with 50 Mton, which is 3.3% higher than in 2020, where the main source is the Metal industry (67%). The largest CH_4 source in the energy sector is coal mining, as well as the processes of production, transportation, storage, distribution, and consumption of oil and natural gas while in the agricultural sector, the main source is the enteric fermentation of cattle.

The economic decline and structural changes were accompanied by reduction in agricultural production, which led to reduced CH_4 emissions in 2021 (324 Kton). The dominant source of N_2O emissions, as in the previous submissions, is the Agriculture sector – 87.9% of total N_2O emissions in 2021. Emission sources in this sector are the categories of agricultural soils and manure management. Moreover, N_2O emissions take place in the sector Industry (5.7%), Energy (3.5%), Waste (2.5%), as well as LULUCF (0.4%). Emissions of HFCs, PFCs, SF_6, and NF_3 in Ukraine are not very significant in terms of volumes in comparison with total GHG emissions (0.6% of the total emissions in 2021) (UNFCCC, 2023).

Since 2022, destruction of industrial and energy infrastructure caused by war led to a drop in energy consumption. According to the National Energy and Climate Action Plan, natural gas consumption has significantly decreased (-28.7% in 2022 compared to 2021) as well as electricity consumption (-30-35%), and natural gas extraction has decreased (-6.7% in 2022 compared to 2021). Regarding emissions, according to the latest data from EDGAR - Emissions Database for Global Atmospheric Research, in 2022 the GHG emission level (excluding LULUCF) decreased by **23.2%** in comparison to 2021 in Ukraine.

Similarly, another scientific study *(Bun, et al., 2024*) in accordance with the IPCC guidelines, estimated a reduction of GHG emissions, in 2022, due to a reduction in traditional human activities of -89.65 $MtCO_2$-eq. This reductions accounts for **26%** compared to the total GHG emission levels in 2021 (i.e. 341.5 $MtCO_2$-eq) with the caveat that the uncertainty of the above data is **high** due to the significant uncertainty in the activity data, especially from temporarily occupied territories.

In addition, the study estimated the overall GHG emission reduction in traditional human activities for the first 18 months (February 2022-August 2023) of the war in Ukraine amounting to -157.68 $MtCO_2$-eq. Moreover, the study estimated the **war-related emissions** of carbon dioxide, methane, and nitrous oxide for the first 18 months of the war in Ukraine amounted to **77 $MtCO_2$-eq**. with a relative uncertainty of +/ 22% (95% confidence interval).

In conclusion, since 2022 destruction of industrial and energy facilities caused by war led to a drop in GHG emissions (**23-26%** reduction in 2022 compared to 2021) and to **emergence** of new GHG emissions associated with **military operations.**

4 Mitigation and adaption by local authorities

Achieving climate targets is contingent upon the active engagement of cities, as they play a crucial role in reducing GHG emissions, accounting for approximately to 67–72% of the global share of emissions in 2020 (IPCC, 2022). Recognising the importance of urban climate action, the European Commission has launched in 2008 the Covenant of Mayors (CoM) for Climate and Energy initiative.

To support the international dimension of CoM, the EC launched a number of initiatives to support it in the Eastern Partnership countries (Armenia, Azerbaijan, Georgia, Moldova and Ukraine). Ukrainian local authorities have been active in the CoM since the start of the initiative in this region with 363 signatories, covering 51% of the national population as of January 2025 (CoM East).

Local authorities who sign the CoM for Climate and Energy commit voluntarily to accelerating the decarbonisation of their territories, strengthening their capacity to adapt to unavoidable climate change impacts and allowing their citizens to access secure, sustainable and affordable energy. To translate the commitments into actions, signatory local authorities commit to develop a Sustainable Energy and Climate Action Plan (SECAP), which includes a comprehensive set of actions that local authorities plan to undertake to reach their climate mitigation and adaptation goals as well as energy access. The SECAP plan is based on the results coming from the previous assessments: the Baseline Emission Inventory (BEI), that measures the GHG emission level in a base year according to a common methodological approach and the Risk and Vulnerability Assessment (RVA).

This section summarises SECAPs submitted by Ukrainian local authorities to the CoM initiative, situating them within the country's broader policy framework for energy, climate, and environmental protection. Specifically, it examines the connections between the actions outlined in the municipalities' SECAPs and Ukraine's National Energy and Climate Plan 2025-2030 (NECP; The Ministry of Economy of Ukraine., 2024b), as well as the reforms and investments envisioned under the Ukraine Plan 2024-2027 (The Ministry of Economy of Ukraine, 2024a).

As a key instrument for Ukraine's recovery, reconstruction, and modernisation, the Ukraine Plan has the potential to accelerate the country's EU accession path, and this section explores how the SECAPs align with and can support this broader strategic agenda. All information for the present analysis is taken from the generated database which is taken from the on-line internet tool and curated by JRC (GCoM - MyCovenant, 5th release – January 2024) (Baldi *et al.,* 2023).

4.1 Mitigation pillar

To achieve the understanding of the progress of the signatories on the goal of reduction of GHG emissions by 2030 the analysis is divided in one part with a focus on the BEI and another describing the key actions affecting the GHG reduction.

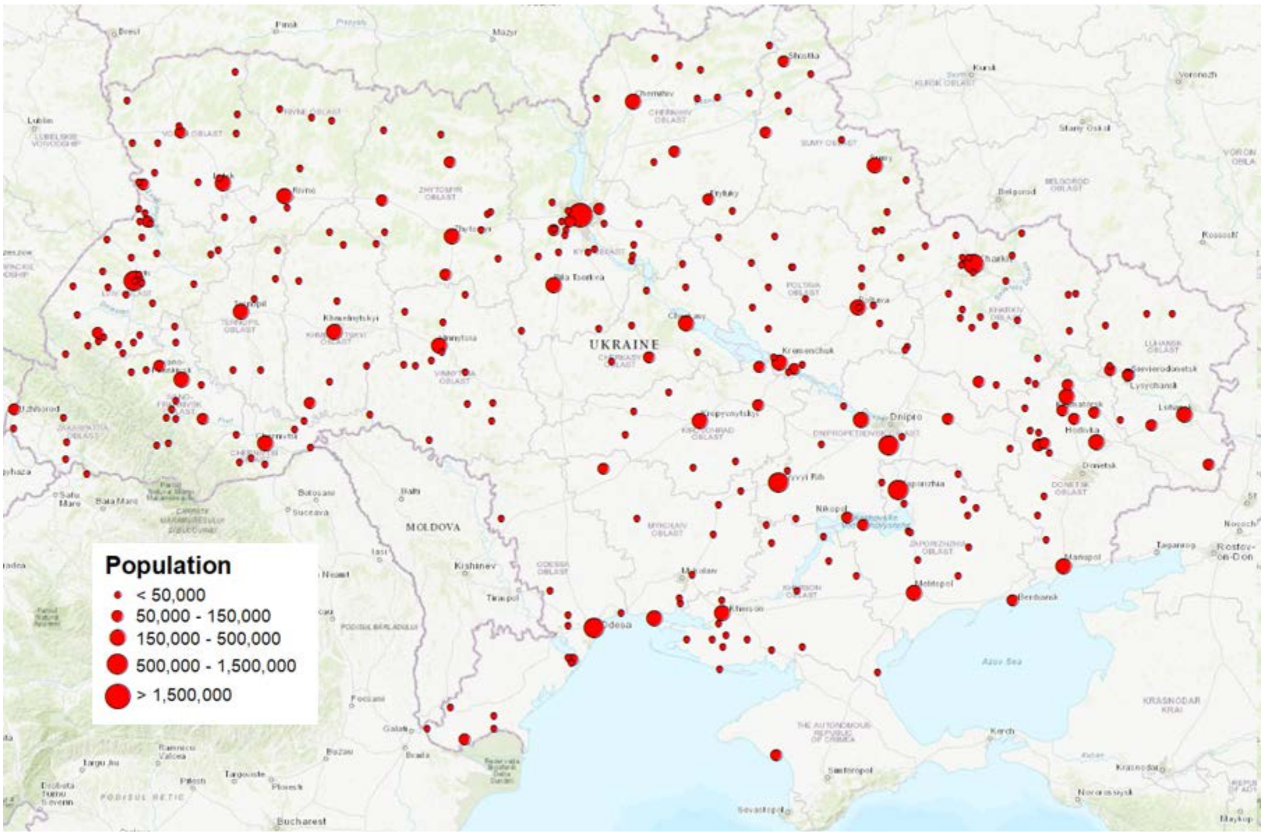
Baseline Emission Inventories

BEI is necessary to identify sources of CO_2 emissions on the territory of local authorities and facilitates the development of appropriate actions to reduce the emissions level. Emission inventories prepared for subsequent years allow to determine how effective the measures have been in terms of reducing CO_2 and whether additional measures are needed. For the BEI analysis the signatories are split by BEI year and sub sectors. This is done by aggregating emissions of GHG, which are indicated in the BEIs by signatories. All aggregated emissions are divided by sub-sectors, which allows to calculate the contribution of GHG emissions by each sub-sector. Upon receiving the results on GHG emissions from the BEI, they can be compared to the projected target that signatories aim to achieve by 2030. This comparison provides valuable insights into the trajectory of GHG emission reduction, offering a clear understanding of how the global goal will be implemented and progressed towards its target.

Out of 363 signatories (**Figure 12**), 198 signatories are active covering 18.5 million inhabitants (number of signatories with a plan for 2020 and/or 2030). Out of these 81 signatories have presented a SECAP (i.e. a plan for 2030), covering 5.2 million inhabitants.

This assessment focuses on the 81 SECAPs of the CoM dataset in Ukraine. It presents the greenhouse gas emissions in BEIs and the corresponding planned emission reduction by 2030. To compare the baseline with the GHG emissions reduction target it is important to further analyse the total volume of GHG emissions by the subsectors.

Figure 12. CoM signatories in Ukraine and their population size.



Source: GCoM - MyCovenant, 5th Release – January 2024. Backgound: ESRI World Topographic Map

Figure 13 shows the shares of GHG emission by sector and fuel/carrier. The total emissions amount to 16.3 $MtCO_2$-eq/year, with a preponderant contribution from the Stationary Energy/ Buildings sector (88%) followed by the Transportation sector (10%) and Waste sector (2%).

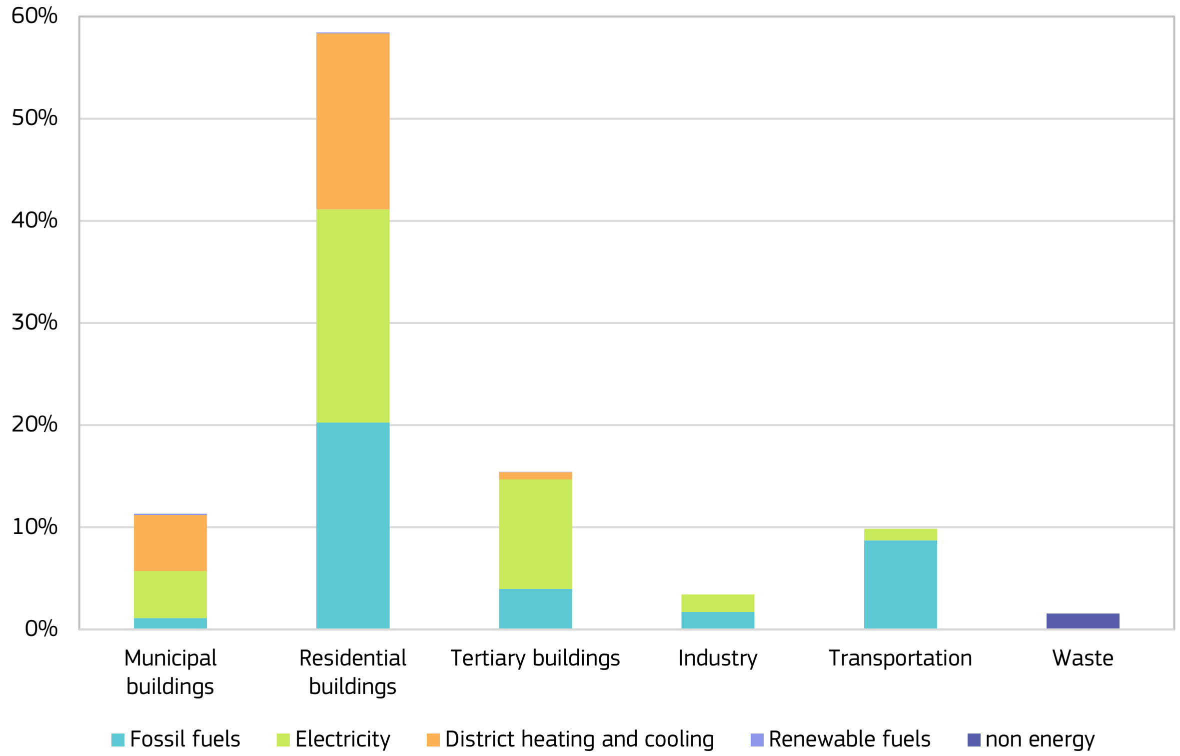
<u>Stationary Energy/Buildings:</u> The distribution of GHG emissions into the different CoM sub-sectors shows that the three most-emitting buildings sub-sectors are responsible for 58% (residential buildings), 11% (municipal buildings) and 15% (tertiary buildings), followed by 3% (industries) of the total CO_2-eq emissions.

<u>Transportation:</u> The emissions in the transport sector are largely dominated by the private and commercial transport sub-sector, which contribute almost 10% of total GHG emissions.

Waste: The macro-sector (2% of the total emissions) groups non-energy GHG emissions.

The total GHG emissions originates by 36% from fossil fuels, 39% from electricity consumption, 23% from district heating networks, 0.2% from renewable sources and 2% from non-energy activities. These data are in line with the recent JRC CoM east regional studies (JRC, Mariella et al. 2025)

Figure 13. The GHG emission shares by sector and fuel/carrier in CoM signatories from Ukraine.



Source: JRC elaboration

According to the Ukraine Plan (The Ministry of Economy of Ukraine, 2024a) the energy consumption in 2020 was 48 million toe, with natural gas accounting for 28%, electricity and oil for 20%, heat for 15%, coal for 12%, and bioenergy for 5%. The district heating was available in many homes (approximately 47%), especially in urban areas. District heating depends on fossil fuels, with about 90% of heat produced from natural gas, and accounts for about 1/4 of the country's natural gas consumption (about 7 billion m^3 by 2022). District heating covers large cities and provides up to a third of the total heating needs of the Ukrainian population. Similarly, in the CoM 30% of the final energy consumptions is supplied thought District heating, covering 23% of the total GHG emissions (17% in the residential buildings, 5% in the municipal sector and 1% in tertiary buildings).

Mitigation Actions

Figures on the committed emission reduction by 2030 are calculated as a sum of emissions reduction reported by the signatories in the CoM platform. **Table 5** shows the estimated GHG emissions reduction by 2030 per sector, as derived from the dataset GCoM - MyCovenant, 5th Release - January 2024. Although the minimum commitment requirement in the CoM is to reduce the emissions by 30% by 2030, the CoM signatories have committed on average to a **target of 33%** emission reduction**.** It is important to highlight that the largest contribution to the overall estimated GHG emission reduction by 2030 is expected from the stationary energy/buildings sector (77.2%), followed by transportation sector (9.6%) and the local heat and cold production (5.5%), while 7.7% of the emission reduction are not allocated in the subsector.

Table 5. Shares of estimated GHG emission reductions by 2030 per sector and sub sector

Macro-sectors	*Sub-sectors*	*Estimated GHG emissions reductions by 2030 [MtCO₂-eq/year]*	*Shares*
Stationary energy/Buildings	Municipal buildings, Equipment, Facilities	0.84	15.5%
	Residential buildings	2.71	49.9%
	Tertiary buildings, Equipment, Facilities	0.59	10.8%
	Industries	0.05	0.9%
	Subtotal	**4.19**	**77.2%**
Transportation	Subtotal	0.52	9.6%
Local electricity production	Subtotal	0.03	0.6%
Local heat cold production	Subtotal	0.26	4.8%
Other	*Not assigned in the macro-sector*	0.42	7.7%
Total		**5,428**	**100%**

Source: JRC elaboration

According to the CoM signatories' commitments, the GHG emissions in the stationary energy/buildings sector would be reduced by promoting energy efficiency within national policies as well as aligning legislation in accordance with the EU acquis. Specific local building-related policies bring energy efficiency improvement, particularly in the social housing sector, where they are targeted at reducing energy poverty. The most significant reduction of GHG emissions will be achieved in the residential sub-sector, which is 49.9%.

Second largest reduction of the GHG is expected in municipal sub-sector – committed emission reduction is up to 15.5%. It includes measures planned in the areas of municipal buildings and facilities (building renovation, energy management of public lighting, energy efficiency of the facilities, which generate heating and cooling energy, etc.). It is important as the municipality itself assumes an **exemplary role** in the implementation of the local action plan.

According to the Ukraine Plan, the rate of thermal modernisation of buildings in Ukraine is much lower than in the EU. Almost 80% of the residential building stock in Ukraine was categorised as energy inefficient as of 2021. The available potential to reduce energy consumption by buildings is 42%. A comprehensive policy plan for reforming and supporting investments in energy efficiency is envisaged in the Ukraine Plan under reform 7 and investments under Pillar 1 of the facility (chapter 10. Energy Sector). The reform aims at improving energy efficiency in public buildings and improvement of public procurement procedures taking into account energy efficiency requirements. While the investments planned by 2027 aimed to enhance Ukraine's energy infrastructure foresees:

- Financial contribution to the Energy Efficiency Fund to support improved energy efficiency in the residential sector;
- Improving energy efficiency in public buildings, in line with the Strategy for Thermal Modernization of Buildings until 2050;

GHG emissions in the **transportation sector** are estimated to decrease by 9.6% by 2030. In this sector, the main driver of lowering the GHG emissions and related energy demand is the improvement of the fuel efficiency driven policies and the uptake of cleaner technologies. The importance of reforms in the transport sector is emphasised in the Ukraine Plan in chapter 11. Transport sector, stating that it is crucial to restore socially important transportation services in war-affected communities by re-establishing and developing urban public transport. Investment priorities include the renewal and electrification of the public transport fleet, that will promote widespread use of the public transport system, lesser dependancy on private car usage and thus contribute to climate change mitigation and pollution prevention.

Actions in the **local energy production** sector like electricity, heat and cold production, would account for 5.5% of the GHG emission reduction by 2030. Local energy production options vary depending on local climate conditions and include solutions like decentralised power production from photovoltaics, mini-hydro and mini-wind power plants with community partnership, decentralised heat production such as solar thermal plants, geothermal, biomass and cogeneration plants combined with district heating networks. District heating networks are mostly under the control and management of the municipality (CASE – Ukraine, 2007). Most of these infrastructures were built with technologies during the Soviet Union time. At the moment, they are outdated and often obsolete in the context of energy consumption (IEA, 2024). Therefore, the potential for modernization of these networks is significant for achieving the targeted reductions of GHG emissions.

The importance of reforms in the energy sector is emphasised in the Ukraine Plan in chapter 10 Energy sector, under reform 6 (Improved efficiency in the district heating) covered in Pillar 1 of the facility. The reform foresees the adoption of the State targeted economic program for the energy modernization of heat generating enterprises for the period up to 2030 by the Cabinet of Ministers, with the focus on the following:

- Identifying measures to improve resilience, quality and availability of heat supply services;
- Identifying measures to support decarbonisation, reduction of greenhouse gas emissions and expansion of renewable energy sources;
- Providing measures to strengthen governance and management skills for local authorities in district heating sector

Moreover, investments are planned to strengthen the energy infrastructure of Ukraine, including the regional level (as part of the indicator in the decentralization section on allocating 20% to the subnational level), among others for the following:

- Improving energy efficiency in district heating, in line with the State targeted economic program for the energy modernization of heat generating enterprises for the period up to 2030;
- Supporting the development of renewable energy sources, in line with the new market-based framework for renewable energy, and for the construction of highly flexible capacities.

To conclude, the majority of action not assigned in the macro-sectors relates to **awareness raising, training and land use planning**. These actions contribute with 7.7% to the total estimated GHG emission reduction by 2030. Potential actions include the upscaling of energy efficiency skills, capacity-building measures (education, training and mentorship), land use planning, the provision of clear and consumer-friendly energy-related product information (labels on energy use, rating, etc.) and the inclusion of behavioural insights in the design of energy policies.

4.2 Adaptation pillar

From a policy perspective, in Ukraine, the Environmental Security and Climate Adaptation Strategy by 2030 (NAS) with an Operational Plan by 2024 was adopted in October 2021. The NAS establishes the basis for adaptation policy and focuses on the essential steps to assess climate-change impacts on society, economy, and the environment in Ukraine. It also addresses adapting sectoral and local policies and making better use of climate data.

Risk and Vulnerability Assessments

According to the WorlBank knowledge portal on climate, Ukraine is at risk of hydrometeorological hazards and natural disasters, which primarily affect the agricultural and human health sectors, through seasonal **flooding** and periods of **drought**. Threats from riverine, urban floods and wildfires are considered high. Impacts from climate change make Ukraine increasingly vulnerable to: droughts, high temperatures, heat waves, heavy precipitation, storms and floods.

Similarly, in the CoM initiative, Ukrainian signatories have reported in their Risk and Vulnerability Assessments (RVAs) the current hazards with their occurring impact and probability, as well as future expected intensity and frequency change. Out of 327 hazards mapped with their occurring levels of impact and probability, almost 80% have a high or medium impact. Climate change is expected to increase in intensity and frequency of hazards in Ukraine, indeed 266 hazards are expected to increase or not change their intensity and frequency impact in future (**Figure 14**).

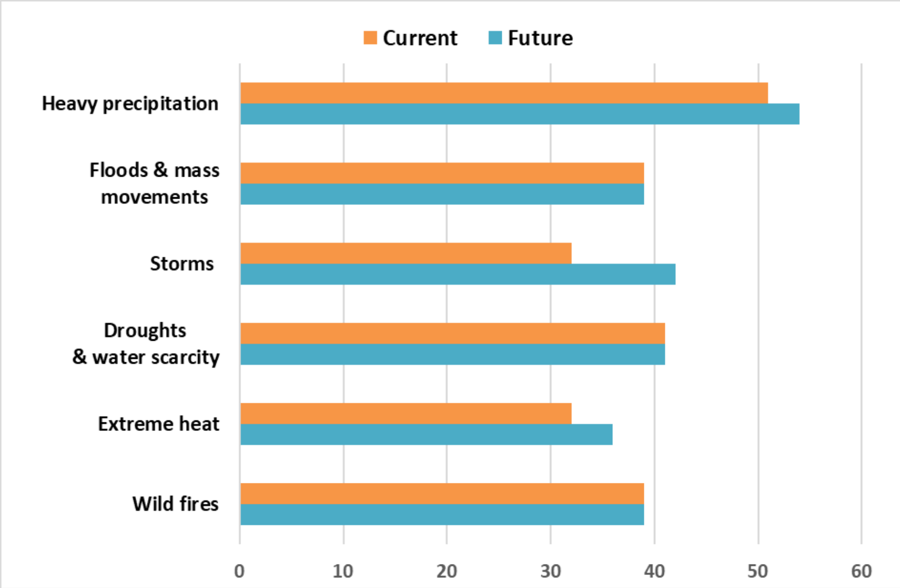
The most common hazards with high or medium impact are associated with heavy precipitations, floods & mass movements and storms (47%) that may cause mudslides as well as flooding of large areas of houses and industrial buildings, with an increased intensity and frequency impact in future of 49%. Secondly, impacts from climate change make Ukraine increasingly vulnerable to: droughts, high temperatures, heat waves, and wildfires covering 43% of all current hazards with high or medium impact. Indeed, more intense temperatures, prolonged heat waves, and water scarcity, is expected to increase or not change the current intensity and frequency of hazards in Ukraine (44%).

In recent years, the number of natural disasters has increased in the region and in many cases, they have been considered as catastrophic, causing fatalities and leading to significant economic losses.

Adaption Actions

The methodological framework for adaptation includes a sound assessment of the current conditions in terms of risks, vulnerabilities and impacts. On this basis the adaptation goals are defined and 490 adaptation actions are planned, out of which 57% has a sectorial impact reported. **Figure 15** shows the number of actions planned by the local authorities by sector and type of hazards, where the majority of actions are planned to tackle **Extreme Heat (28%),** followed by **Floods & mass movements (23%)**.

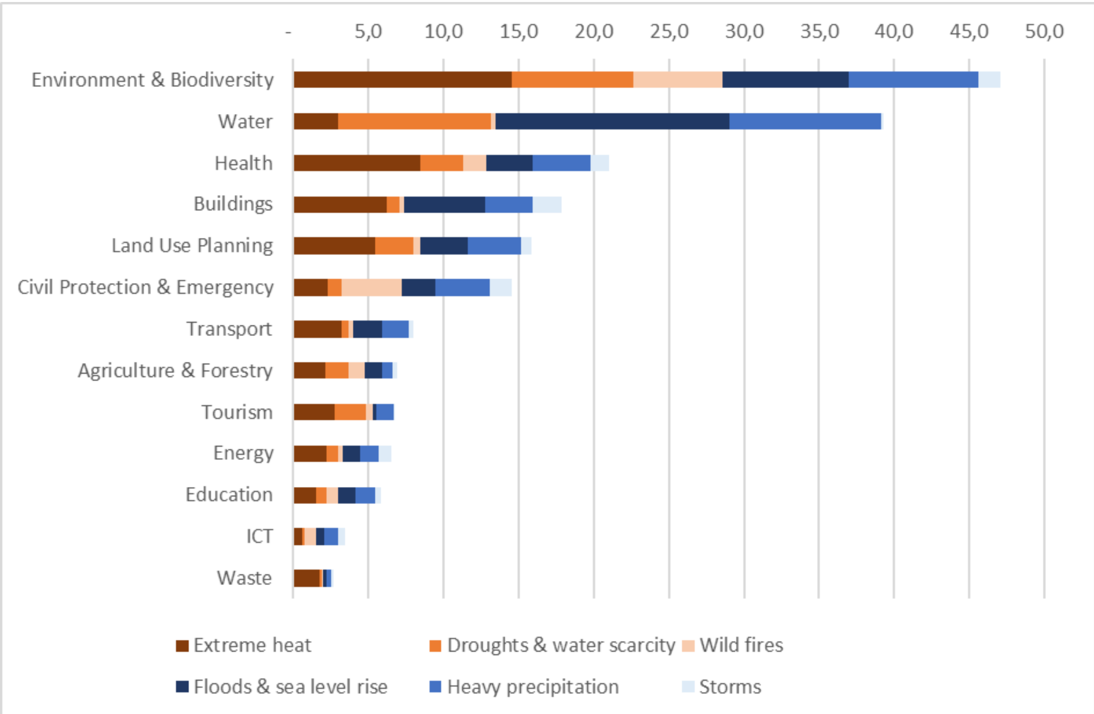
Figure 14. Number of current and future climate-related hazards increased or not changed in intensity and frequency as reported by CoM Ukraine



Source: JRC elaboration

In response to **Extreme heat** events**, Droughts & water scarcity** and **Wild fires**, local authorities have planned a range of measures to tackle adaptation in the **Environment and biodiversity** sector with **14.5%** of the measures (**Figure 15**). While in relation to **Floods & mass movements, Heavy precipitation and Storms,** local authorities have planned a range of measures to tackle adaptation in the **Water** sector with **13.2%** of the measures (more details in Annex II).

Figure 15. Number of actions planned by CoM signatories in Ukraine by sector and type of hazard



Source: JRC elaboration

5 Forest environment and Climate

5.1 Forest resources

Ukraine is among the European countries with the greatest forest area (11.3 million hectares) even if forests only cover about one fifth of Ukraine's territory (Myroniuk *et al.,* 2024). Forests are irregularly distributed across the country due to varying climatic conditions and human influence. The flat regions of the country are divided into three main biogeographical zones: the forest zone, the forest-steppe zone, and the steppe zone (**Figure 16**). The forest zone in the Polissia region has a forest cover of 37%. The forest-steppe zone in the Centre-North has a forest cover of approximately 29%. The steppe zone in Centre-South, which is about 11% forest covered, is further divided into two sub-zones: the northern steppe, characterized by scattered forest plots on hilly terrain, and the southern steppe, which is largely forestless. In contrast, the mountainous regions of Ukraine, including the Carpathians in the West and the Crimean Mountains in the southern peninsula, are dominated by forests that cover up to half of the land area (Shvidenko *et al.,* 2017).

Figure 16. Ecozones of Ukraine.

Source: Myroniuk et al., 2024.

Conifers make up about 41% of Ukraine's forests, with pine trees (mainly Scots pine, *Pinus sylvestris*) the most dominant tree species, covering around 28% of the forest area and spruce (*Picea abies*) 9%. Oak forests (mostly pedunculate oak, *Quercus robur*), and beech (*Fagus sylvatica*) comprise 15% and 7% of all forests respectively. Pine forests grow mainly in Polissia, oak forests in the central part of the forest-steppe zone, while beech, spruce and silver fir (*Abies alba*) are more common in the mixed mountainous forests of the Carpathians (Myroniuk *et al*., 2024).

The total growing stock of all Ukrainian forests is estimated at 2.8 million cubic meters, and, at national level, the forest productivity is high, with an average growing stock of 251 m^3/ha (Myroniuk *et al.,* 2024). Ukraine's forests have been steadily increasing in both area and volume over the past 50 years. The percentage of forest cover has grown by approximately 50%, while the growing stock has increased by 150%. This growth has been attributed to the Ukrainian government's afforestation and reforestation policies (Lopatin *et al.,* 2011, Shvidenko *et al.,* 2017).

Forest ownership in Ukraine is predominantly under state control, with most of the forest fund (73%) managed by the State Forest Resources Agency, the state body responsible for the implementation of the national forest and hunting policy. The remaining forest areas are overseen by local municipalities, various Ministries and state departments. There is very little private forest ownership in Ukraine (0.1% of the total forest fund; State Forest Resources Agency of Ukraine, 2024).

Most Ukrainian forests are managed for their recreational and nature-protective functions (64% of total forest land), rather than commercial purposes (36%). This is reflected in the country's conservation efforts, with national parks, protected areas, and conservancy territories covering around 14% of the forestlands (Kobylynska *et al.,* 2020).

5.2 Forest disturbances

5.2.1 Timber harvesting

Ukraine's forest management system has retained its traditional model, characterized by state-owned forests, harvesting, and small-scale processing. A key aspect of this system is the preparation of forest management plans, which are updated every 10 years and should ensure the sustainable use of the country's forest resources (Buksha, 2004).

In Ukraine, all forests, regardless of ownership (state, municipal, or private), can be subject to temporary use. This allows for the transfer of forest management rights and responsibilities from public administration to individuals or households through long-term leases or management agreements. This approach enables a more decentralized and flexible management of forest resources (Buksha, 2004).

When it comes to timber harvesting, most of the activity is organized by state and private forest harvesting companies. According to data from the State Forest Resources Agency, in 2022 and 2023 in non-occupied areas, forest logging produced over 15 million cubic meters of wood, divided about equally between industrial roundwood and fuelwood (Buksha, 2004). The main species harvested from the country's forests is pine, which accounts for 50% of the total logged volume. Other notable species being harvested include oak (12%), spruce (9%), and beech (5%) (State Statistics Service of Ukraine, 2024).

When it comes to forest treatment practices, clear-cutting is the most prevalent method, used in approximately 47% of all fellings. In contrast, selective and progressive logging, which involves the targeted removal of specific trees or sections of trees, are used in only around 4% of treatments. Interestingly, salvage logging is a relatively common practice in Ukraine, accounting for approximately 45% of all forest treatments (State Statistics Service of Ukraine, 2024).

Over the past four years, Ukraine's forests have yielded an average of 16 million cubic meters of wood annually (State Statistics Service of Ukraine, 2024). With a total forest cover of approximately 11 million hectares, this translates to a harvest rate of 1.45 m^3/ha. In comparison, the total mean annual increment (MAI) of Ukraine's forests is estimated at around 4 m^3/ha (State Forest Resources Agency of Ukraine, 2024), indicating that the country's forests are being harvested at a third of the rate at which they are growing. The MAI varies significantly depending on the region, ranging from 5 m^3/ha in the Carpathian Mountains to 2.5 m3/ha in the steppe zone (State Forest Resources Agency of Ukraine, 2024). Despite these variations, the overall harvest rate remains relatively low, with less than 40% of the annual increment being utilized. This low intensity of forest utilization is a key factor in the increase of forest cover in Ukraine over the past 50 years, as recorded in the country's Forest Inventories (Storozhuk & Polley, 2016).

5.2.2 Forest fires

Climate change has significantly increased the risk of large forest fires in Ukraine over the past decade. Rising temperatures have led to more frequent heatwaves, droughts, and windy weather, creating conditions that are ripe for catastrophic fires. Unfortunately, Ukraine's forest management and emergency response systems were not adequately prepared to deal with these challenges (Sidorenko, 2021).

Historical data on forest fires in Ukraine indicates that the worst years in the country have been the last five years, with the exception of 2021 (**Figure 17**). Record-breaking burned areas occurred in 2024. It is noteworthy that the increase in the number of fires and burned areas in the country since the start of the Russian invasion can be tied to the areas of the war front lines. Data from the European Forest Fire Information System (EFFIS) for 2024 show that wildfires burnt over 880 thousand hectares of natural land, with almost 220 thousand hectares of forested areas (European Forest Fire Information System, 2024).

Figure 17. Trend of burnt areas and number of fires above 30 ha from 2020 to 2024.

Source: European Forest Fire Information System, 2024.

5.2.3 Pests

Ukraine has experienced a significant increase in the extent and intensity of forest disturbances over the past few decades. The rate of tree die-off has grown from 4,000 hectares per year in the 1990s to over 20,000 hectares per year in 2015 (Spathelf *et al.,* 2024). This increase is largely attributed to unfavourable weather conditions, such as droughts and heatwaves, the spread of insects and pathogens, and the occurrence of forest fires.

Scots pine forests, which cover approximately 33% of Ukraine's forested area, have been particularly vulnerable to these disturbances. In some regions, Scots pine forests make up over 80% of the forest cover, with natural pine forests accounting for less than 20% of the total. Increasing drought due to rising temperatures and decreasing precipitation has created unfavourable conditions for pine growth exacerbating the decline of Scots pine forests in particular. Over the past 15 years, the area of Scots pine forests has declined by two to threefold, with pine forest mortality currently seen in more than 10% of the forest area in Polissia (Meshkova, 2021).

Norway spruce monocultures in the Ukrainian Carpathians have also been affected by forest disturbances. In 2015, an estimated 19,300 hectares of Norway spruce forest (approximately 3% of the total area) were impacted, resulting in the loss of 5.8 million cubic meters of wood. The decline of these monocultures not only affects the forestry sector but also has significant ecological and environmental implications for the region (Parpan *et al.,* 2019).

5.2.4 Illegal logging

Ukraine's legislation governing forest management is outdated and based on Soviet-era approaches, which has led to a lack of clarity and consistency in defining and addressing illegal logging. Official statistics on illegal logging only account for logging carried out without permits, also known as wood theft, and do not consider any logging that may violate the law (Hrynyk *et al.,* 2023).

According to the State Forest Resources Agency, in 2022 the cases of illegal logging registered in non-occupied areas involved a volume of 24.3 thousand m^3 (ca. 0.1% of the total harvested volume). However, independent organizations and researchers have estimated that the actual volume of illegally harvested timber nationwide may be significantly higher, ranging from 1-2% of the total harvested volume, according to the World Bank, to 6-7% according to the Swiss-Ukrainian Forest Development Project in Transcarpathia (FORZA). Moreover, studies have shown that in forested regions, the rate of illegal logging can be as high as 20-50% of the declared annual volume of legally harvested timber (Kuemmerle *et al.,* 2009, Hrynyk *et al.,* 2023, Kaplia *et al.,* 2023).

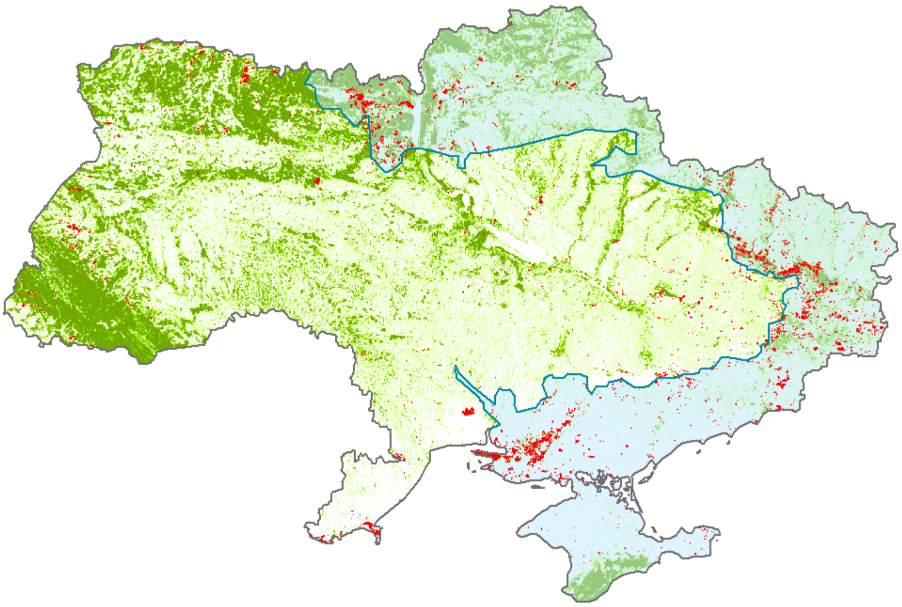
The most common form of illegal logging is not logging without permits, but rather “illegal logging with papers", which involves the use of fake origin certificates, under-declarations of weights, species, and value at customs, and other forms of corruption (Hrynyk et al., 2023). NGOs, such as Earthsight, and journalists have reported that the rate of illegal logging with papers is estimated to be between 5% and 30% of the total timber harvested. Furthermore, Earthsight has estimated that up to 40% of the timber exported from Ukraine to the EU may have been logged or traded illegally (Forest Trends, 2021).

The European Union has taken notice of these concerns, with the Competent Authorities for the implementation of the European Timber Regulation (EUTR) stating in December 2020 that timber harvesting in Ukraine posed significant risks regarding legality and required additional supply chain checks for the export of timber products from Ukraine (EC, 2020). The EU's Ukraine 2023 Integration Report also highlights the persistence of illegal logging in Ukraine, stating that "illegal logging is widespread, and despite efforts made in recent years, the illegal trade in timber persists" (EC, 2023). Moreover, in 2025, the National Agency on Corruption Prevention (NACP) in Ukraine has presented a study “Corruption Risks in Forestry”, which is intended to serve as a basis for creating a comprehensive strategy for reforming this sector.

5.3 Wildfires

The detonation of unexploded ordnance (UXO) and bombs not only poses a significant threat to human life but also has the potential to ignite fires that are extremely challenging to manage. The ongoing conflict in Ukraine has severely hampered efforts to prevent and control large fires. Restrictions on public access to forests and natural landscapes, introduced by Martial Law, have blocked fire prevention activities such as patrolling and establishing firebreaks. Additionally, UXO contamination poses significant risks to human safety, making it difficult to access forests and respond to fires in a timely manner.

Figure 18. Wildfires detected by the European Forest Fire Information System (EFFIS) in 2022 and 2023 inside and outside the war zone. In green the forest cover 2019, shaded in blue the war zone.



Source: Liu et al., 2023 (forest cover 2019), European Forest Fire Information System, 2024 (wildfires), Institute for the Study of War, 2024 (war zone).

The destruction or damage of fire management infrastructure, including communication systems and equipment, has further hindered the ability to manage wildfires. Additionally, the lack of forest firefighters, who have been enlisted in the Ukrainian Army, further reduced the capacity to respond to fires.

As a result, fires are often left to burn unchecked until they stopped at natural barriers such as roads, rivers, or hardwoods, or until all the available fuel is consumed. In dry conditions, these fires can spread rapidly and can persist for weeks or even months, causing widespread damage to forests, other ecosystems, and local communities (JRC, Zibtsev *et al.,* 2024).

In 2022, more than 50% of the wildfires in Ukraine recorded by the European Forest Fire Information System (EFFIS) occurred in areas directly or indirectly affected by active combat, particularly in occupied territories (**Figure 18**). In 2023, this figure was as high as 80% (European Forest Fire Information System, 2024).

The largest forest fires occurred in two main regions: the Eastern region, comprising Kharkiv, Luhansk, and Donetsk oblasts, and the Southern region, specifically Kherson oblast. Notably, these fires have tended to cluster along the front lines, underscoring the close relationship between conflict and forest fires. Significant fires have also been reported in the North region, encompassing Kyiv and Zhytomyr oblasts, located close to the border with Belarus.

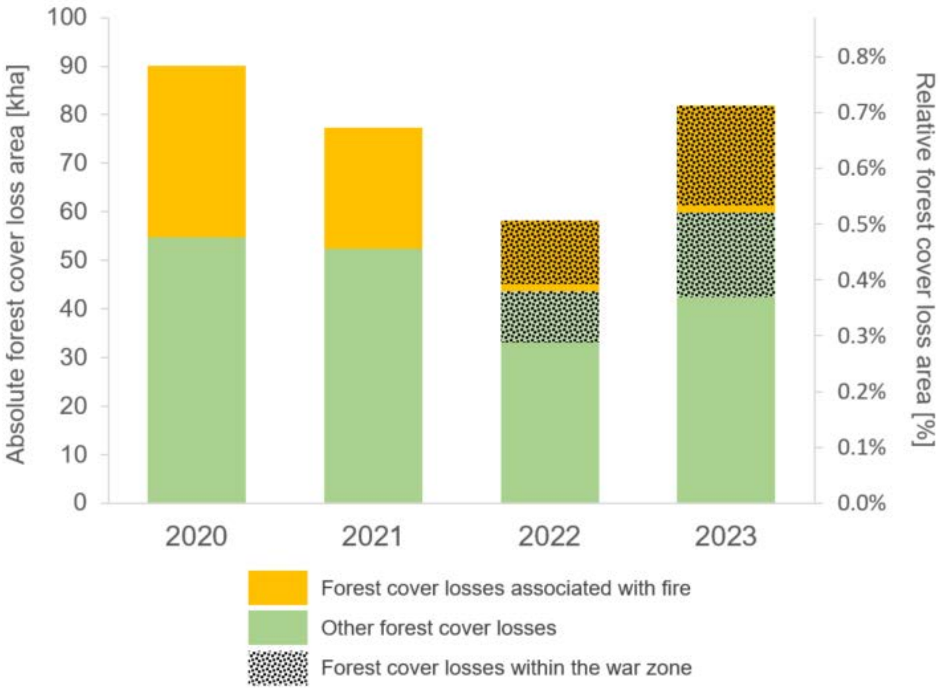
5.4 Forest cover loss 2020-2023

We estimated annual tree cover loss in Ukraine from 2020 to 2023 based on the Global Forest Change dataset, published by the University of Maryland's Global Land Analysis and Discovery (GLAD) laboratory (Hansen *et al.,* 2013). To calculate relative forest cover loss, i.e. tree cover loss as a fraction of total tree cover in Ukraine, we started from the tree cover in 2019 derived from a canopy height map based on PlanetScope satellites (Liu et al., 2023).

We then investigated the specific role wildfires played in driving these losses by computing the areas where forest cover loss coincided with wildfires detected by the European Forest Fires Information System (2024). For the years 2022 and 2023, we further delineated the war zone (Institute for the Study of War, 2024), which encompasses the Ukrainian territory invaded by Russia (regardless of whether it was later recaptured or remained under Russian control). This distinction allowed us to examine the impact of the conflict on forest cover loss in Ukraine and to identify areas of particularly high vulnerability.

The results reveal significant year-to-year variability in the extent of forest cover loss, ranging from a minimum of 58.000 hectares in 2022 to a maximum of 90.000 hectares in 2020 (**Figure 19**). However, when comparing the two periods, 2020-2021 and 2022-2023, we found no significant differences in forest cover loss, suggesting that the conflict has had a relatively small impact on national-level forest cover loss. Furthermore, the national rate of forest cover loss remains relatively low, ranging from 0.5% to 0.8% when using the forest cover in 2019 as a baseline.

Figure 19. Absolute and relative forest cover loss in Ukraine from 2020 to 2023. The forest loss values expressed in percentages are relative to the forest cover 2019.



Source: JRC, 2024.

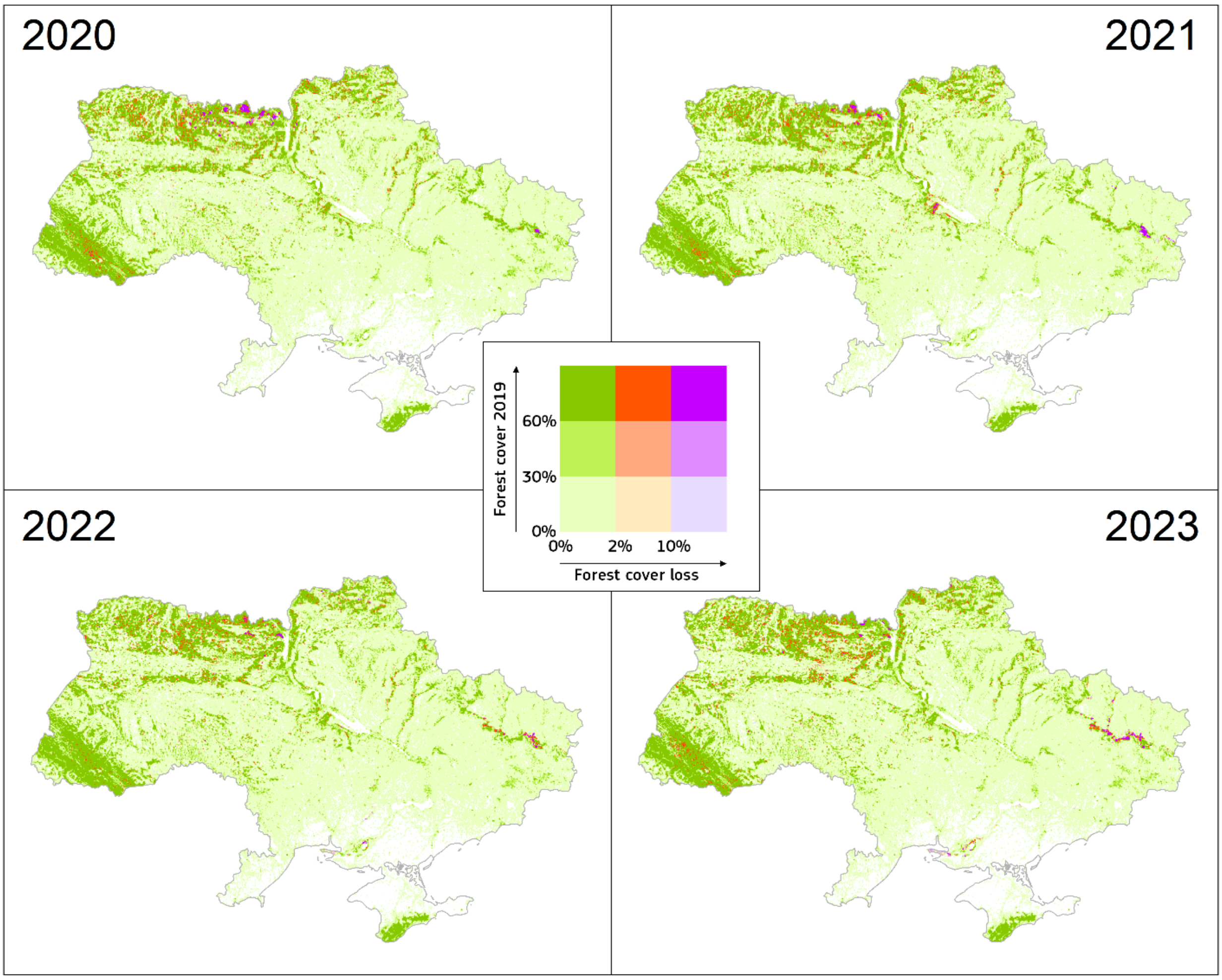
A notable pattern in the data is the consistent contribution of wildfires which account for 45-65% of the total forest cover loss every year. The situation has been further complicated by the Russian invasion, which has led to a significant increase in forest fires within the war zone. Indeed, in 2022 and 2023 more than 90% of the losses associated with fires were detected within this zone, while the forest cover losses within the conflict zones are around 40-45% of the total.

The spatial distribution of forest cover loss in Ukraine is not uniform, with the majority of losses concentrated in the forested regions of the country (**Figure 20**). As expected, the Carpathian Mountains and the Polissia region, which are home to a significant portion of Ukraine's forest cover, have experienced the greatest losses.

In 2020 and 2021, large areas of forest were lost in the North, in the Chernobyl area, which saw a major wildfire. More recently, in 2022 and 2023, large areas of forest were lost in the eastern region, particularly in the forest belt along the Donets River, which forms part of the front line. This is consistent with reports of large fires caused by the conflict in this region.

Forest losses have also been observed in the south, specifically in the Kherson oblast along the Dnipro River, another part of the front line. These findings highlight the significant impact of the conflict on Ukraine's forests, particularly in regions where fighting has been intense.

Figure 20. Relative forest cover loss intensity aggregated at ca. 2 km from 2020 to 2022.



Source: Liu et al., 2023 (forest cover 2019), Hansen et al., 2013 (forest cover loss).

5.5 Key messages (forest environment)

The absence of effective governance and law enforcement in certain areas has contributed to an increase in corruption and illegal logging.

Forest destruction and degradation resulting from war pose significant concerns for biodiversity. Soils have been contaminated, removed, or tilled, while water systems have been polluted or disrupted. It is estimated that approximately 1.7 million hectares of Ukrainian forests are affected, accounting for approximately 15% of the country's total forest cover.

Within the war zones, the accumulation of solid waste and abandoned or used military equipment in forests contribute to the release of heavy metals, radionuclides, and other toxic substances that are dangerous to both the environment and human health.

Ukraine's forests are also threatened by mines and unexploded ordnance (UXO), which can be accidentally triggered by contact or natural events like storms or wildfires. The presence of UXO in forests also poses risks to conventional forest management activities.

The ongoing conflict has hindered fire prevention efforts, reduced the number of firefighters, and led to an increase in forest fires due to shelling-related ignition. As a result, fires are often left to burn, unchecked, until they are stopped by natural barriers or until all the available fuel is consumed.

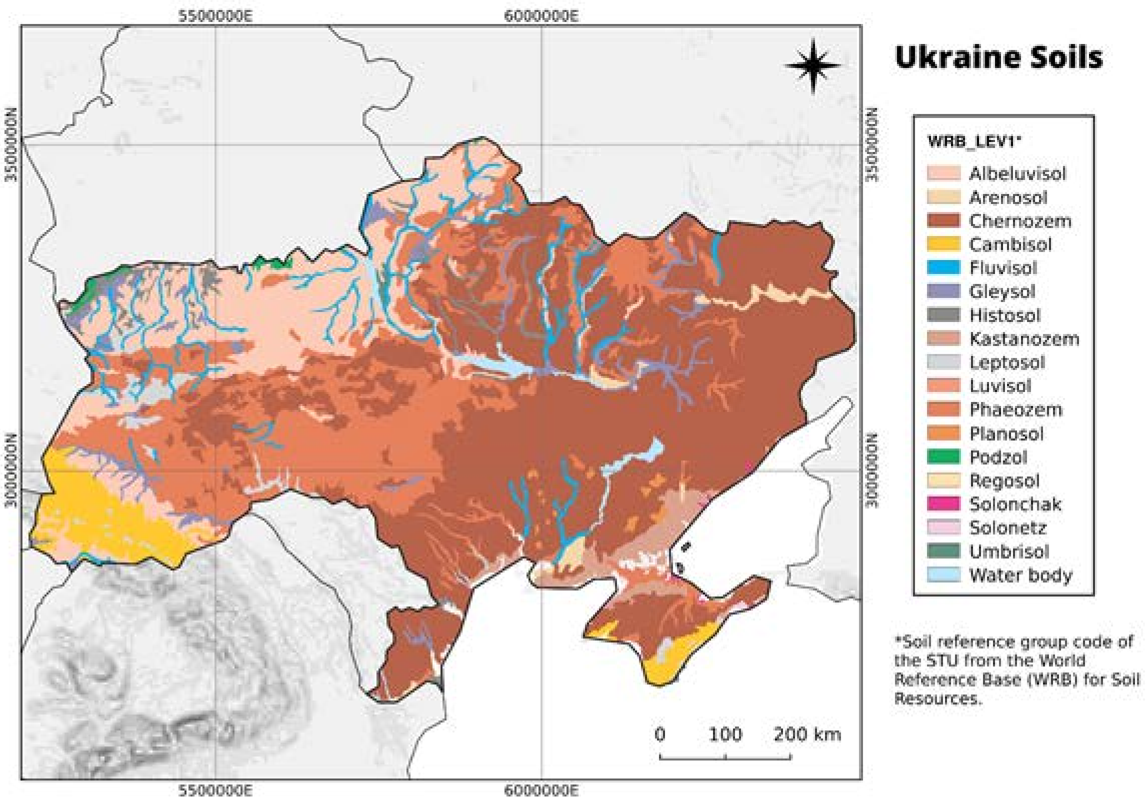
In 2022 and 2023, more than 90% of the forest cover losses associated with fire were detected within the war zones, corresponding to 13 - 21 thousand ha/year respectively, with forest cover losses in the conflict areas accounting for approximately 40-45% of the total losses.

6 Soil characteristics and degradation

6.1 Dominant soil types and distribution

Due to the large size of the country (circa 60 million hectares) and the variety of natural soil-forming factors (climate, geology, native vegetation, relief etc.), Ukraine has a large diversity of soil types. According to the European Soil Atlas (**Figure 21**), 15 Reference Groups (RGs), which account for nearly one-half of the RGs of the World Reference Base (WRB), are found in the country.

Figure 21. Soil map of Ukraine



Source: Own elaboration, based on the European Soil Atlas (European Commision, 2005) .

The north-eastern region is covered by Albeluvisols, Phaeozems and Histosols, which are common for mixed coniferous-deciduous and deciduous forests of the cold temperate regions of the Russian plain. The north-western part of Ukraine is dominated by Histosols. Histosols and Gleysols occupy the swampy depression shared with Belarus called Polissya also known as the Forest AEZ. The eastern and central parts of the country are covered mainly by Chernozems. Chernozems combined with Fluvisols are found in the flat valleys of the Dnepr and its tributaries. Chernozems are associated with Phaeozems, and to a lesser extent with Cambisols, on the Podolskaja and Predneprovskaja uplands of the central part. The southern region is a huge area of homogeneous Chernozems bordered on the south by the Krym peninsula (European Commision, 2005).

6.2 Soil properties and fertility

Ukraine is home to some of the most fertile soils in the world, with Chernozems (black earths) covering nearly two-thirds of the country's agricultural lands (Eckmeier *et al.*, 2007). These soils are characterized by their high humus content, optimal water-air regime, and active biological and biochemical processes The unusually thick organic accumulation has been attributed to continental steppe climate conditions, limiting organic matter decomposition (Dokuchaev, 1883; Eckmeier *et al.*, 2007). Chernozems are renowned for their fertility and productivity (Eckmeier *et al.*, 2007; Dmytruk *et al.*, 2014). In Ukraine, Chernozems are found in the forest-steppe and steppe zones, extending from the western to eastern border of the country (European Commision, 2005).

Ukrainian soils are characterized by their high levels of organic matter, which is essential for maintaining soil fertility and structure. The country's soils are also rich in nutrients, including nitrogen, phosphorus, and potassium, which are essential for plant growth. However, Ukrainian soils are also vulnerable to degradation which can have significant negative impacts on crop production and the environment (Fileccia *et al.*, 2014).

6.3 Status and trends of Soil Health in Ukraine

The assessment draws on the findings from the XI round (2016-2020) of agrochemical certification of agricultural land conducted by the State Institution "Institute of Soil Protection of Ukraine" (Institute of Soil Protection of Ukraine, 2023) and was included in the JRC's 2024 State of Soils in Europe Report (Arias-Navarro et al., 2024). **Table 6** provides an overview of the various soil degradation issues in Ukraine, highlighting the affected areas and specific details of each issue as identified in the assessment.

Nutrient mismanagement is a significant issue in Ukraine, with high levels of nitrogen, phosphorus, and potassium in some areas. The weighted average content of nitrogen, phosphorus, and potassium in soils is 110.7 mg/kg, 116.7 mg/kg, and 122.4 mg/kg, respectively. However, there are significant regional variations in soil nutrient levels, with some areas having high levels of nitrogen and phosphorus, while others have low levels of potassium. The trend analysis shows that there has been an increase in nitrogen content in soils compared to the previous round of surveys, particularly in the Polissya, Forest-Steppe, and Steppe zones. However, there has been a decrease in potassium content in soils in the Polissya zone. Among EU candidate countries, Ukraine appears to have experienced one of the most significant decreases in N and P budgets since 1990, with a negative P budget of -2.4 kg ha^{-1} yr^{-1} in 2020 (OECD, 2024). The soil organic (or total) carbon content is not determined as part of the monitoring and surveying of Ukrainian agricultural land, but the humus content (%) is measured. The weighted average humus content in soils decreased compared to the previous round of surveys from 3.16% in 2015 to 3.07% in 2020. According to the results, the lowest humus content was observed in the Polissya zone (2.43%), while in the forest-steppe zone it was 3.2%, and in the steppe zone - 3.31%.

Soil erosion is the most important form of soil degradation in Ukraine, with an estimated 40% of the country's territory affected. According to expert assessment, the total area of eroded soils (all types of erosion) in Ukraine is 10.5 million hectares (Baliuk *et al.*, 2021) AgroPolit.com, 2019). Surface water erosion is widespread on 17% of arable land, gully water erosion - on 3%; wind erosion - on 11% of arable land. Under the influence of human activity ("poor farming practices," traditional tillage, and lack of crop rotation), the annual amount of eroded land in Ukraine increases by 80-90 thousand ha because of erosion. The large proportion of land under intensive cultivation with a high percentage of row crops and the lack of contour reclamation farming have led to the development of erosion processes. They are also accelerated by poor land management practices, such as growing crops on steep slopes, excessive cutting of forests, shrubs and bushes, and overgrazing. Every year, 300 to 600 million tons of soil are lost to erosion. As much as 10-15 million tons of humus, 0.3-0.9 million tons of nitrogen, 700-900 thousand tons of phosphorus, and 6-12 million tons of potassium are removed with erosion materials, which is significantly more than is applied with fertilizers. Crop yields on eroded soils are 20-60% lower than on non-eroded soils. The annual value of eroded soils translates into a third of the agricultural gross domestic product (Fileccia *et al.*, 2014).

Table 6. Summary of soil degradation indicators and affected areas in Ukraine.

Indicator	Affected Area	Details
Nutrient Mismanagement	Various regions, particularly Polissya, Forest-Steppe, and Steppe zones	High levels of nitrogen, phosphorus, and potassium in some areas. Nitrogen content increasing, while potassium content decreasing in certain zones.
Soil Acidification	24.4% of soils (48.4% in Polissya zone)	Significant acidification with pH < 5.5, exacerbated by nitrogen mineral fertilizers leading to leaching of calcium and magnesium.
Soil Erosion	10.5 million hectares (40% of Ukraine's territory)	Widespread erosion: Surface water erosion on 17% of arable land, gully erosion on 3%, wind erosion on 11%. Loss of soil and nutrients significantly impacts crop yields.
Soil Compaction	Over 22 million hectares of arable land	Widespread soil compaction, particularly affecting Chernozems. Military activities may increase compaction areas. Can reduce crop yields by up to 60%.
Soil Salinisation	2.8 million hectares (4.1% of arable land)	Widespread in the Ukrainian Steppe, particularly affecting Kastanozems. Includes 2 million hectares of arable land and 0.7 million hectares of irrigated land.
Soil contamination	9-11% of arable land	Includes contamination by potentially toxic elements (PTEs) and pesticides. Notable areas include Pavlohrad, Mariupol, and Pervomaisk. Radioactive contamination also present. 5.35 million hectares of territory are still radioactively contaminated.
War impact on Soil	Over 10 million hectares degraded, out of 60 million hectares UA territory,	Military activities have caused unprecedented soil destruction, release of toxic elements, and loss of topsoil. Recovery could take decades or centuries.

Source: Arias-Navarro et al., 2024

Soil compaction in Ukraine is widespread on arable land of more than 22 million hectares (Baliuk *et al.*, 2021). Additional areas of possible soil compaction due to the maneuvers of heavy military vehicles are being assessed (Bonchkovskyi *et al.*, 2023). Chernozems are particularly vulnerable to compaction, which can temporarily cut crop yields by up to 60% (Sorokin & Kust, 2015). Soil compaction is also driven by the particle size distribution of the soil, except for heavy agricultural vehicles, as well as spring moisture. The pre-war dynamics were characterized by an increasing trend in areas with compacted soils. In addition, according to United Nations rankings, Ukraine is among the top thirty countries for urbanization, and there has been a notable increase in both the extent of **soil sealing** and urban development. At the moment, large areas are either occupied or subject to military actions and removed from agricultural land use. New challenges has arisen in connection with the military activities, and it is this range that poses new threats of total physical destruction of soils.

Soil salinisation and alkalization processes are widespread on 4.1% of Ukraine's arable land (Baliuk *et al.*, 2021). There are 2.8 million hectares of saline soils in Ukraine, 2 million hectares of which are used as arable land, and about 0.7 million hectares are irrigated. Salinisation processes are almost widespread on Kastanozems (Haplic Kastanozems, Luvic Kastanozems, Luvic Gleyic Kastanozems) of the Ukrainian Steppe. In some areas Solonetz (Mollic Gleyic, Stagnic and Gleyic) and Solonchaks are present.

Soil contamination is a significant issue in Ukraine, affecting 9-11% of arable land according to expert assessments. The State Sanitary Inspection conducts analyses of pollutant levels, particularly in urban areas, revealing that the most heavily contaminated soils, due to potentially toxic elements (PTE) (Cd, Mn, Pb, Cu, Zn), are found in Pavlohrad, Mariupol, and Pervomaisk. **Table 7** summarizes the extent of soil contamination exceeding the Maximum Allowable Concentrations (MAC) for lead (Pb) and cadmium (Cd) mobile forms.

Table 7. Soil contamination exceeding Maximum Allowable Concentrations (MAC) for lead (Pb) and cadmium (Cd) mobile forms in specific Regions.

Region	Contaminated Area (ha)	Pb Mobile Forms (mg/kg)	Cd Mobile Forms (mg/kg)
Dnipro Region	19,740	11.76	0.98
Odesa Region	2,700	7.16	0.9
Mykolaiv Region	300	8.05	0.71
MAC Value	-	6.0	0.7

Source: Ministry of Environmental Protection and Natural Resources of Ukraine, 2021

Soil contamination on agricultural lands is primarily driven by the use of plant protection products, fertilizers, livestock waste, and industrial waste. **Table 8** outlines the usage of pesticides statistics for 2020-2022.

Table 8. Annual Pesticide Application Data: 2020-2022.

Metric	2020	2021	2022
Total pesticide use (active substance, tons)	24,624.7	26,971.5	19,438.2
Pesticide use per unit of agricultural land (kg/ha)	1.195	1.309	0.944
Area treated with pesticides (million hectares)	16.2	16.6	12.3

Source: https://stat.gov.ua

In 2022, chemical plant protection products were applied to 47.6 million hectares, with pesticides containing Acetochlor as the most widely used. Soil contamination on arable land can arise from the use of fertilizers, pesticides, and sewage sludge. In 2021, the contribution of agricultural activities to overall pollutant loads was as follows: nitrates at 0.32%, nitrites at 0.046%, and ammonium nitrogen at 0.05%.

Significant pesticide pollution has been identified in various regions. In Polissya, dichloro-diphenyl-trichloroethane (DDT) contamination was found on 210 hectares (including 0.10 hectares in the Zhytomyr region and 0.11 hectares in the Zakarpattia region). In the Steppe zone (Zaporizhzhia oblast), contamination exceeding the Maximum Permissible Concentrations (MPC) was recorded on 50 hectares for Hexachlorocyclohexane and 360 hectares for DDT. In the forest-steppe zone of Ukraine, larger areas were identified where the MPCs for Hexachlorocyclohexane, DDT, and 2,4-D were exceeded, affecting 2,500 hectares, 6,120 hectares, and 2,500 hectares, respectively, particularly in the Cherkasy and Kharkiv regions (Ministry of Environmental Protection and Natural Resources of Ukraine, 2021).

Radioactive contamination in Ukraine remains a significant issue as a result of the Chornobyl disaster. Currently, 5.35 million hectares of territory are still radioactively contaminated, including 1.24 million hectares of agricultural land where soil contamination by radioactive cesium-137 (^{137}Cs) exceeds 37 kBq/m^2. On 14,800 hectares of surveyed land, cesium-137 contamination levels range from 5 to 15 Ci/km^2, while strontium-90 (Sr-90) contamination levels range from 0.15 to 3 Ci/km^2 across 23,700 hectares—both areas are classified within the zone of guaranteed voluntary resettlement.

6.4 Key messages (soil)

Ukraine possesses some of the **most fertile soils in the world**, with Chernozems covering nearly two-thirds of its agricultural land. These soils are rich in organic matter and essential nutrients, making them highly productive. Despite their fertility, Ukrainian soils face significant degradation. **Soil erosion affects 40% of Ukraine's territory**, removing vast amounts of soil and nutrients each year. Poor land management practices and intensive cultivation have accelerated erosion processes. Industrial and agricultural activities have led to **contamination of 9-11% of arable land** with metals, pesticides, and other pollutants. Radioactive contamination from the Chornobyl disaster still affects over 5 million hectares.

Nutrient imbalances have further exacerbated soil degradation, impacting crop yields and long-term soil fertility. Since 1990, Ukraine has experienced a significant decline in N and P budgets, with P depletion particularly concerning due to its critical role in plant growth.

In addition to these long-standing challenges, **soil compaction has become a major concern**, affecting over 22 million hectares of arable land. Chernozems are particularly vulnerable to compaction, which can reduce crop yields by up to 60%. Prior to the war, the extent of compacted soils was already increasing, posing a growing threat to agricultural productivity.

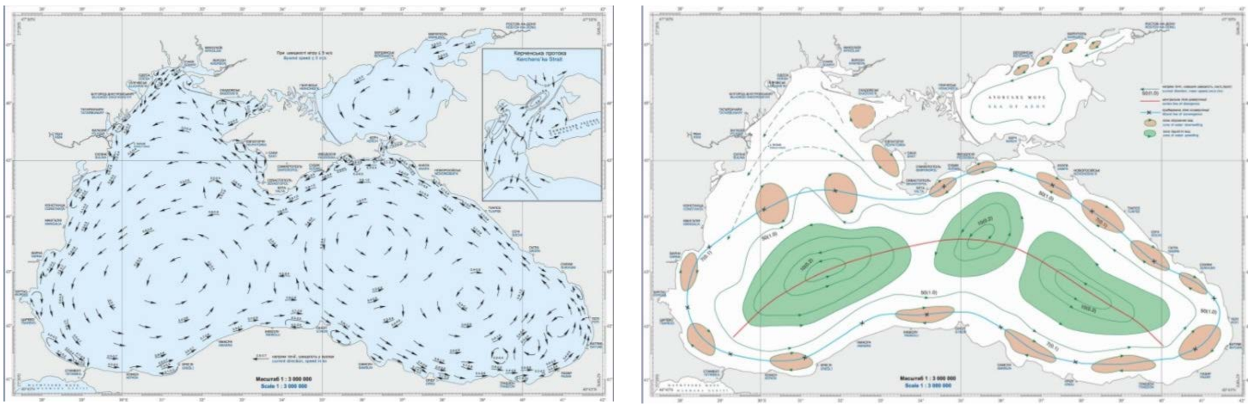
Addressing these issues requires improved land management practices, erosion control measures, and balanced nutrient management to sustain soil fertility and ensure the long-term productivity of Ukraine's agricultural lands.

7 Marine Environment

7.1 The Black Sea

Besides Ukraine, the Black Sea is bordered by Romania and Bulgaria, Turkey, Georgia and Russia. It is located between Eastern Europe, the Caucasus, and Western Asia, and connected to the Mediterranean Sea through the Bosphorus and Dardanelles straits. It is ca. 1200 km long and 600 km wide. It has a maximum depth of about 2200 m and an average depth of around 1200 m. The Danube is, with about 50% of the total inflow, the main river flowing into the Black Sea; besides that, the Dnieper, Don, Rioni, Kizilirmak, Yeastern Bug rivers, as well as the Dniester River are flowing into the Black Sea. The Ukraine borders the Black Sea in the north-west, including a part of the Danube estuary. The water mass circulation in the Black Sea is counter-clockwise, with 3 distinct gyres in the eastern, western and Azov Sea, as shown in **Figure 22**, thus contaminant input on the northern Black Sea is transported westward, with the estuary of the Danube in the north-western area, then influencing the costal marine environment southward towards Romania and Bulgaria.

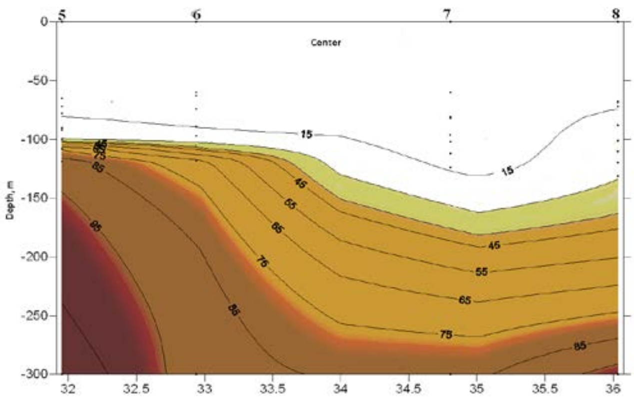
Figure 22. Water circulation in the Black Sea



Source: Eremeev at al., 2009.

The Black Sea as a particular hydrographic characteristic includes an anoxic zone that extends below 150-200 m to the bottom, with very low oxygen levels and hydrogensulfide presence (**Figure 23**).

Figure 23. Distribution of hydrogen sulphide concentration: Western Regions' transect in Summer 2019.



Source: EMBLAS, 2022.

7.2 Monitoring the status of the marine environment in Ukraine

The Black Sea is subject to numerous anthropogenic pressures, as nutrient input, wastewater input, contaminant input, e.g. pesticides. Besides that, the Black Sea is home of intense shipping route and intense fisheries. Invasive species, noise and oil spills are among the additional pressures.

The Commission on the Protection of the Black Sea Against Pollution (the Black Sea Commission or BSC) via its Permanent Secretariat is the intergovernmental body established in implementation of the Convention on the Protection of the Black Sea Against Pollution (http://www.blacksea-commission.org/). The environmental monitoring of the Black Sea at basin level is performed through the BSIMAP Black Sea Integrated Monitoring and Assessment Programme (BSIMAP 2017-2022). The latest report from the Black Sea Commission on the environmental status of the Black Sea considers data from 2009-2014 (Black Sea Commission, 2019).

Monitoring of the marine environment in Ukraine had significantly developed since 2016, in particular through the implementation of the EU4EMBLAS projects. The EU4EMBLAS projects (European Union for Environmental Monitoring in the Black Sea EMBLAS I + II, EMBLAS+ and EU4EMBLAS), co-funded by EU and UNDP, are aiming at improving environmental monitoring in the Black Sea area (https://emblasproject.org/). The European Commission Joint Research Centre has contributed through studies on assessment of the pollution by organic chemicals and marine litter, including related training activities, as well as by liaising with DG ENV and DG ENEST. The EU4EMBLAS project combined Joint Black Sea Surveys (JBSS) and National Monitoring Studies (NMS), which supported the countries in implementing national and regional monitoring programs, as shown in **Figure 24**. The project also built capacity in national institutions, developed novel monitoring methods, and facilitated sharing of environmental monitoring data.

The EU4EMBLAS projects aim at building national capacities and skills in use of the up-to-date monitoring and analytical techniques aligned with the MSFD and WFD principles and methodologies and the BSIMAP, including environmental data sharing and assessment. The project raises awareness on the key environmental issues and increase public involvement in the protection of the Black Sea.

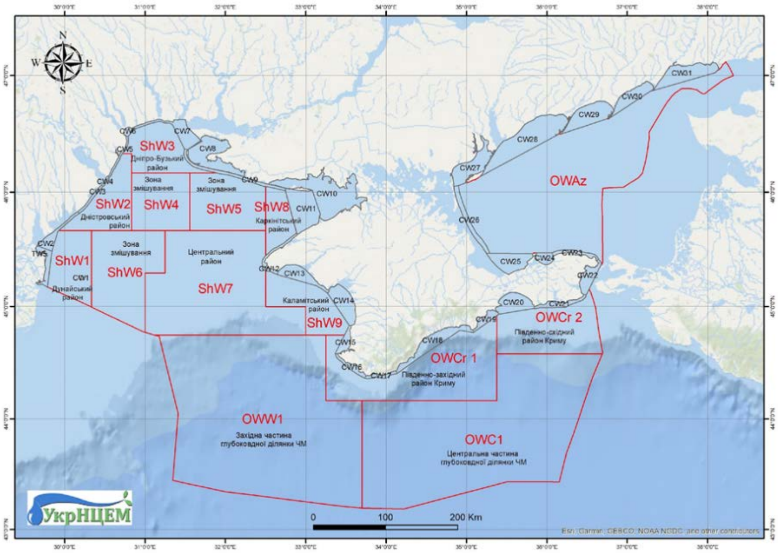
A limited number of Ukrainian marine research institutes is operating in the Black Sea. These Institutes include the Ukrainian Centre for Ecology of the Sea (UkrSCES), the Institute of Marine Biology of the National Academy of Sciences of Ukraine (IMB NASU) and the Odesa State Environmental University (OSENU).

A dedicated report (JRC, Komorin *et al.,* 2022) commissioned by EC JRC to a group of Ukrainian Scientists, provides an overview of existing and applied methodologies for environmental monitoring in the Black Sea. The report shows that already numerous protocols and monitoring approaches have been implemented in Ukrainian waters, enabling alignment with MSFD requirements.

The Ukraine has adopted in 2021 a Marine Environmental Strategy of Ukraine, amended in 2023 (Cabinet of ministers of Ukraine, 2021). This strategy establishes that the Ukrainian Ministry of Environmental Protection and Natural Resources, together with the interested central and local executive bodies, shall develop, within six months from the date of termination or cancellation of martial law in Ukraine, a six-year action plan to achieve and maintain the “good” ecological state of the Azov and Black Seas.

The war of Russia against Ukraine has, since February 2022, increased significantly a number of pressures. Environmental monitoring of the Black Sea in Ukraine (**Figure 24**) is since the start of the war not possible, due to inaccessibility of the coast and no possibility to perform marine surveys (JRC, Komorin *et al*., 2022).

Figure 24. Map of zoning of the Black and Azov Seas. (CW – Coastal Waters; ShW – Shelf Waters).

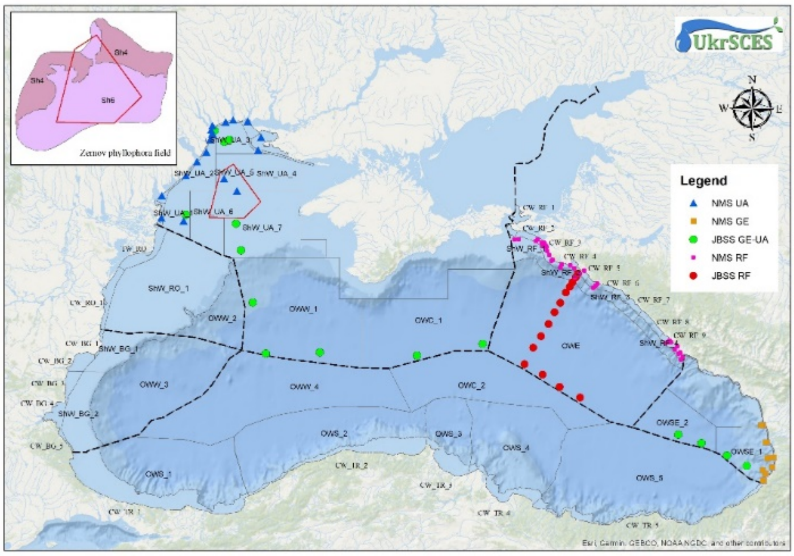


Source: JRC, Komorin et al., 2024.

7.3 State of the Ukrainian Black Sea Environment

Assessments of the Black Sea environmental status have been made during numerous surveys and at individual national sampling stations through the EUEMBLAS projects. **Figure 25** shows the sampling stations of the Joint Black Sea Surveys and other sampling campaigns performed 2016, 2017 and 2019. These included long transects from Constanta, Romania to Odesa, Ukraine and onwards to Batumi, Georgia and back, thus also including Ukrainian waters.

Figure 25. Overview map of sampling stations of the Joint Black Sea Surveys 2019.



Source: Slobodnik, 2022.

7.3.1 Hydrographical and climate related situation

The results of Joint Black Sea Surveys (JBSS) 2016, 2017 and 2019 showed in general the vertical distribution of thermohaline characteristics typical for these periods of the year in the studied coastal areas. As expected, the strongest water stratification, with the highest gradient values in thermo-, halo-, and pycnoclines, was observed in summer. During the survey carried out from 7 to 13 August 2019 the water temperature in the surface layer of the Black Sea region near the Kerch Strait was 23.0–25.0^{0}C. From depths below 22 m, the water temperature decreased to 10.0^{0}C (Slobodnik, 2022).

The spatial and temporal variability of the position of upper border of the hydrogen sulphide zone in the deep part of the Black Sea is primarily determined by synoptic and seasonal variations of the hydrological structure of waters of the sea. At the end of summer 2019 the upper border of the hydrogen sulphide zone in the Western and Central regions of the Black Sea fluctuated near the depth of 70 m. It went down to 135 m in Eastern region and to 150 m in South-eastern part of the Black Sea (EMBLAS, 2022).

7.3.2 Eutrophication

Eutrophication in the northwestern sector of the Black Sea has been characterized by a Natural State during the 1960s and 1970s, a period of Intensive Eutrophication due to heightened nutrient load in the 1980s, a phase of Stagnation during the 1990s and a consistent De-eutrophication trend observed in the 2000s through the 2010s.

The degradation of Phyllophora and mussel communities in the northwestern Black Sea shelf area serves as a testament to eutrophication effects also in the Black Sea. Recent decreases in average oxygen content within the upper layers of the sea, compared to the 1990s, can be ascribed to climatic changes, including increased winter air temperatures, reduced frequency of cold winters, and weakened winter water convection. Regular weekly observations from 2000 to 2019 in the coastal waters of the Odesa region on the northwestern shelf of the Black Sea (water body CW_UA_5) indicate a trend towards reduced annual average concentrations of mineral dissolved inorganic phosphorus (DIP) and total phosphorus (TP), as well as dissolved inorganic nitrogen (DIN), coupled with an increase in total nitrogen (TN) concentrations, predominantly in its organic form (JRC, Komorin *et al.,* 2024).

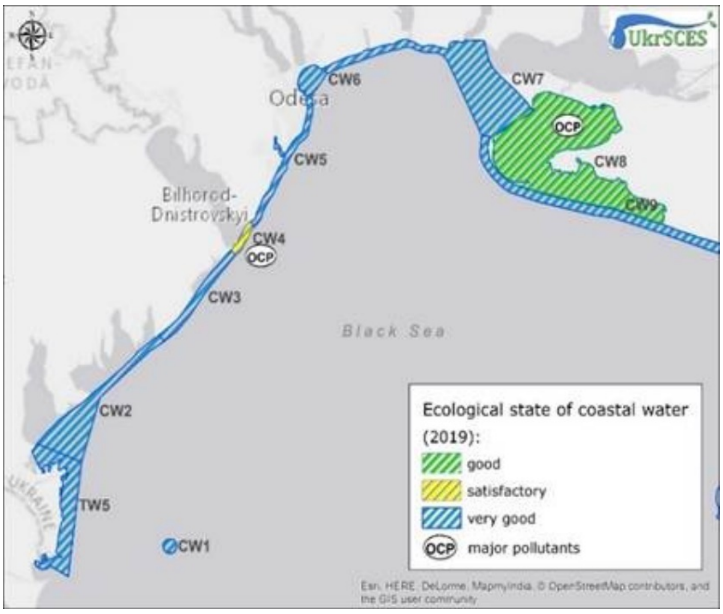
7.3.3 Contamination

A multitude of priority pollutants and emerging contaminants were identified within the sea water and sediment samples from EMBLAS Plus in 2019 (EMBLAS, 2022; JRC, Mariani *et al.,*2020). Notably, three sea water samples exceeded the Environmental Quality Standard (EQS) for Cd, with Hg levels surpassing the MAC-EQS value in all examined samples. Di(2-ethylhexyl)phthalate (DEHP) levels exceeded the EQS in 57% of the samples, while di-n-butyl-phthalate surpassed its Predicted-No-Effect-Concentration (PNEC) in 18 instances. In total, 61 emerging contaminants across nine categories were detected in the sea water samples. Among these, eight compounds were found at concentrations exceeding their respective PNEC values. Water samples from the Western Black Sea exhibited higher pollution levels compared to those from the Open Sea and Eastern Black Sea. Para-para-DDT emerged as the most abundant and frequently detected organochlorine pesticide in the sediments, with plant protection products being the most commonly identified class of emerging pollutants.

Considering the findings from both sea water and sediment analyses, several pollutants and emerging contaminants are recommended for classification as "Black Sea Specific Contaminants" for future regular monitoring. This list includes, but is not limited to, Cd, Hg, DEHP, di-butyl-phthalate, para-para-DDT, and a selection of other contaminants based on their frequency of appearance, extent of exceedance, and environmental impact.

The assessment of the quality of seawater and bottom sediments was conducted with a focus on specific pollutants: trace metals (TM), organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), and Polycyclic Aromatic Hydrocarbons (PAHs).

Figure 26. An integrated assessment of the ecological status of seawater in 2019.



Source: JRC, Komorin et al., 2024.

From 2016 to 2019, comprehensive evaluations of water pollution in different areas revealed marked changes in ecological conditions, attributed to pollutants such as Organochlorine Pesticides (OCPs), Polychlorinated Biphenyls (PCBs), and Polycyclic Aromatic Hydrocarbons (PAHs). Specific regions (see **Figure 26** for reference to sampling points), CW1 and TW5, maintained a consistently high ecological status, although CW1, experienced a rise in pollution levels by 2019. Conversely, areas such as CW2 and CW3, along with the Dnipro region, demonstrated significant ecological improvement by 2019, recovering from previously lower ratings. These findings highlight the intricate dynamics between various contaminants and their collective effects on water quality, underlining the importance of ongoing surveillance and efficient pollution control measures to protect aquatic environments.

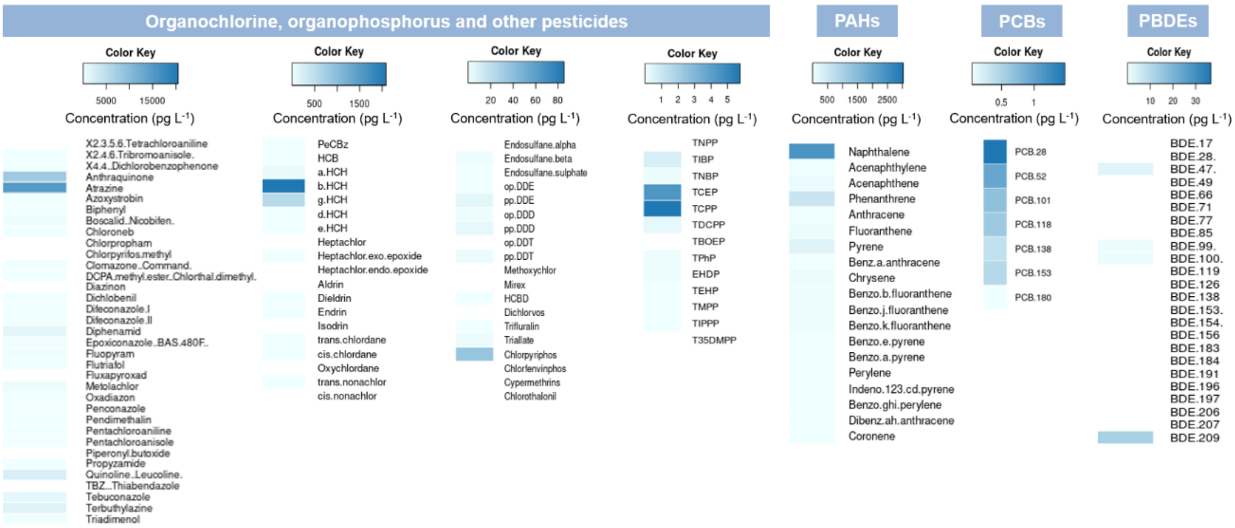
The comprehensive analysis of sediment pollution spanning from 2016 to 2019 across diverse regions reveals fluctuating ecological statuses, significantly impacted by the presence of OCPs, PCBs, and PAHs. Throughout this period, the CW1 region consistently exhibited a good ecological status, whereas the TW5 region progressed from a satisfactory to good status by 2019, successfully navigating pollution challenges. The ecological condition of the CW2 region was elevated to good by 2019, indicative of proficient PCB management. Both the CW3 and CW4 regions were characterized by very good ecological conditions, displaying resilience in the face of pollution events.

In contrast, the ecological status of the CW6 region declined in 2017, primarily due to PCB contamination, with a lack of subsequent assessments in 2019 to determine any recovery. The CW7 region witnessed variable conditions, culminating in a satisfactory status in 2019, attributed to OCP influences. The CW8 region, evaluated solely in 2019, was deemed to have a satisfactory status, largely as a result of PAHs. Significantly, the CW9 region attained a very good status by 2019, illustrating notable improvement.

7.3.4 Ultra trace contaminants and microplastics

In October 2021 the Belgian research vessel RV Belgica has been transferred to Odesa, Ukraine, where it was renamed to RV Boris Aleksandrov. During the transfer, supported through the EU4EMBLAS project, via the North Atlantic Ocean, Mediterranean Sea and the Black Sea, an environmental monitoring program has been performed. Multiple parameters, microplastics, environmental fish DNA, antibacterial resistance and contaminants have been measured. Target screening revealed significantly higher concentrations of organic contaminants in the Black Sea than in the other Seas. Microplastics concentrations are ca. doubled in the Black Sea in comparison to the North East Atlantic and the Mediterranean Sea, with a concentration of ca. 100 microlitter particles in 1 m^3 at N 45 49.9680 E 30 59.9730, ca. 50 km offshore from Odesa (Alygizakis, 2024). Ultra trace analysis of contaminants in seawater was performed by JRC on 9 transects. The final transect started at the Bosporus, crossed the western Black Sea and ended in Ukrainian waters, ca. 60 km from Odesa, sampling 897 L along the way.

Figure 27. Concentrations of organic contaminants in seawater during western Black Sea transect (pg L^{-1})



Source: Carravieri et al., 2025, in preparation.

The number of chemicals identified and quantified in that transect, see **Figure 27**, was 120 out of 300 target substances. The most abundant contaminant category was represented by Plant Protection Products with 51 pesticides found and the highest pesticides concentrations was Atrazine with 15 ng/L. Among the chlorinated pesticides a significant concentration of hexaclorocyclohexane (HCHs) was recorded as 2.72 ng/L (sum of alfa, beta and gamma isomers). The results were in agreement with previous studies (Mariani, 2019). 27 industrial compounds have been detected, mainly phosphate flame retardant (n= 10), brominated flame retardants (n= 8) and dielectric and coolant fluids (n= 7). (Mariani, 2025, in preparation)

7.3.5 Marine Litter

Floating Marine Macrolitter (FMML) in the Black Sea was monitored by visual observation from research vessels and ships of opportunity between 2017 and 2019. The mean FMML density across the Black Seas was 93.6 ± 128.3 items/km^2, ranging from 0 to 810.2 items/km^2. Around Odesa, most survey transects > 12 NM from the coastline showed no litter, while litter densities >200 items/km^2 were observed only occasionally in territorial waters, and particularly in proximity (<12 NM radius) to the city area of Odessa with a weighted mean of ~29 items/km^2 and max. ~580 items/km^2 (Gonzalez-Fernandez *et al.,* 2022).

7.3.6 Marine Biodiversity

Elements of marine Biodiversity are plentiful and complex, therefore here just a few examples are given. From 2016 to 2019, a decline in the ecological status of surface and near-bottom waters was noted, particularly within the "Zernov's Phyllophora Field", which is a unique protected habitat located in the northwestern Black Sea. At the site, there is a dense stand of agarophytes (red algae) and a high diversity of associated fauna. Favourable conditions for hydrobionts were identified near Cape Malyi Fountain, while the poorest ecological conditions were observed near Zatoka, Chornomorsk, Dacha Kovalevsky's, and Kobleve.

Zooplankton diversity and abundance increased in 2019 compared to previous years, with forage zooplankton being crucial for fish diets. However, the ecological status of most surveyed aquatic territories was classified as "Bad," with occasional observations of "Moderate" or "Poor" water quality classes. The Danube region and Odesa region were exceptions, achieving "High" water quality classes in some instances. Based on 48 stations performed in the Ukrainian shelf in 2016-2019 period, 80% of stations and 100% of habitats respectively, were achieving GES regarding the seafloor, assessed by the N-AMBI*(n) method (Slobodnik, 2022).

Overall, the study highlights the importance of monitoring and assessing the ecological and environmental status of the Black Sea to understand the impacts of human activities and climate change on this sensitive ecosystem.

7.3.7 Kakhovka Dam

The Kakhovka Dam was a dam in the Dnieper River, with the primary purposes of hydroelectric power generation, irrigation, and navigation. It was the sixth and last dam in the Dnieper reservoir cascade. On 6.6.2023 during the war against Ukraine, the Khakovka dam was destroyed while being under Russian control. A first initial environmental assessment has been made by consideration of available data (JRC, Komorin *et al.,* 2024). The destruction of the Kakhovka hydro-electric power plant dam by Russia has released a massive amount of water, pollutants, and sediments into the Black Sea, potentially causing severe environmental damage. The immediate effects include reduced water salinity and increased nutrient levels, leading to algal blooms, decreased oxygen levels, and toxin production. Stress on marine organisms, particularly sensitive species, which may decline in diversity and abundance, affecting the food web. Sedimentation and habitat alteration, potentially smothering benthic habitats and altering the physical landscape of estuarine and coastal areas.

Long-term consequences may include secondary pollution events, as previously buried pollutants are released back into the water column causing lasting changes in habitat availability and quality, affecting biodiversity and ecosystem services.

The destruction of the dam is a significant anthropogenic perturbation with far-reaching implications, highlighting the need for comprehensive monitoring, mitigation strategies, and concerted efforts from local, regional, and international stakeholders to restore ecological balance and ensure the resilience of affected marine communities. Immediate measures are needed to counteract the environmental damage, emphasizing water quality restoration and conservation of marine biodiversity. Ongoing surveillance and further research are crucial to fully comprehend the ecological ramifications of the dam's destruction and to devise effective strategies for the ecosystem's recovery.

7.4 Key messages (marine environment)

These pressures on the marine environment are likely to have long-term consequences for the health and biodiversity of the Black Sea and Sea of Azov ecosystems. Environmental assessments of the impacts are challenged due to the ongoing war of Russia against Ukraine, marine environmental field monitoring activities are not possible, due to limited accessibility of the sea. Currently the institutions related to marine monitoring and assessment are understaffed and under significant pressure. It is important even now to keep the institutions and their personnel active, involved and interacting at international level with relevant institutions. Knowledge must be preserved and developed, enabling continuity and restarting marine assessment work as soon as possible. Financial resources are therefore also now required to prepare future activities.

After critical remediation measures have been completed, the restart should then enable, as soon as possible, assessments based on state-of-the-art monitoring and assessment methodologies that are fit to support implementation of EU legislation and for international agreements. These assessments should be holistic, i.e. cover different pressures on the Black Sea and enable the identification of restoration activities wherever needed.

The security situation in the Black Sea region is clearly a major bottleneck for progress across environmental and climate areas and will be tackled in the new ES Strategy of the Black Sea. This strategy will address climate and environmental resilience in the region and related challenges. Continuing work on the Common Maritime Agenda for the Black Sea is seen very important in this regard too.

Moreover, Ukraine’s bid to become a full Member of the General Fisheries Commission for the Mediterranean (GFCM) under the framework of the UN FAO, which aims to ensure sustainable use of living marine resources in the Mediterranean and the Black Sea can be considered as an important milestone for biodiversity conservation. This would trigger multiple research activities to address specific needs for the management of key fisheries and conservation of vulnerable species. Among the GFCM initiatives concerning the Black Sea, can be cited the research programmes on Rapa whelk and Piked dogfish, the pilot project on Sturgeon and the mitigation trials on Dolphin bycatch[1].

[1] https://www.fao.org/gfcm/en/

8 Impact of war on the environment

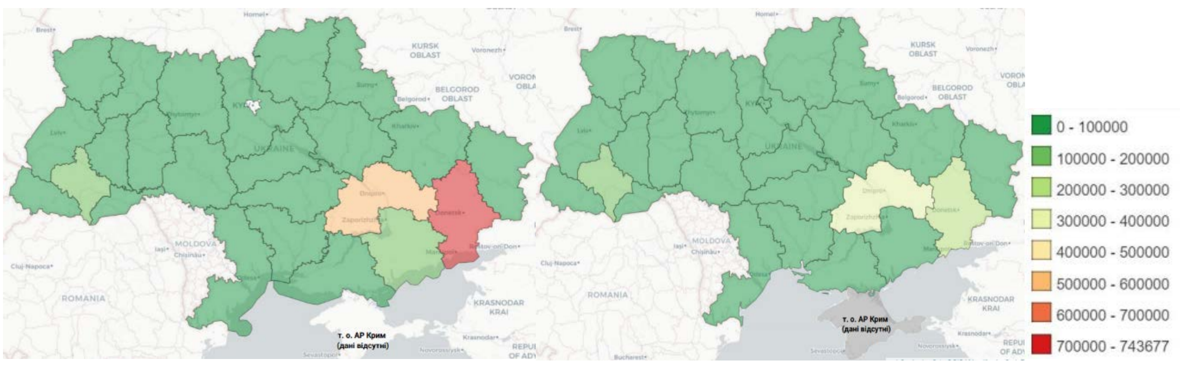
8.1 Impact of war on air pollution in Ukraine

The war in Ukraine led to the redistribution of pollution sources and fluxes, destruction of industrial facilities and introduction of new emission sources as a result of the military operations. During rocket attacks, shell explosions, destruction and fires in ecosystems, residential and non-residential premises, etc., the release of a large amount of air polluting substances led to a change in the spatial and temporal patterns of air pollution in the Ukrainian territory.

Due to the war, Ukraine lost part of the industrial and energy complex, business activity decreased, the fuel crisis reduced the intensity of road vehicle traffic and increased population emigration. According to UNHCR, in December 2022, more than 7.81 million refugees from Ukraine were registered in Europe (UNHCR, 2022). The JRC report «Ukraine`s population future after the Russian invasion» noted that the dynamic population decrease due to the Russian invasion, unlikely could be change back through the next decade. Even under the most optimistic scenario, the population will decrease by 21% by 2050. This means that migration will be as important as birth and death rates for Ukraine after the war (JRC, Ueffing *et al.,* 2023).

Figure 28. Comparing analysis of emissions in Ukraine (2021-2022), tonnes.

2021 **2022**

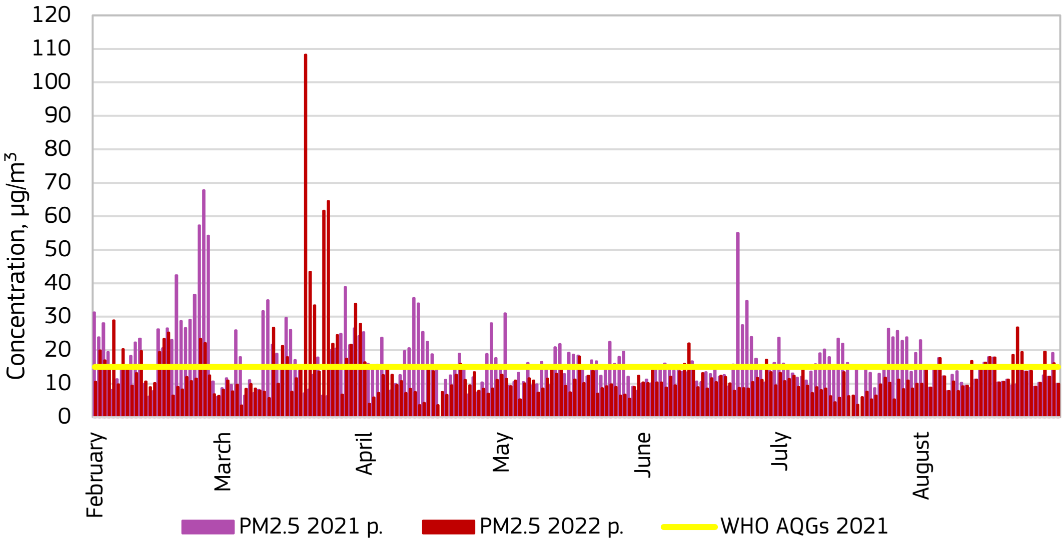


Source: (Skok et al., for SaveDnipro, 2023).

The war led to a decrease in emissions from economic sectors on the one hand, and to the emergence of atypical locations of air quality deterioration on the other. In 2022, there was a significant decrease in the industrial activity and related emissions in the regions with the highest share of national emissions in 2021 (Zaporizka, Dnipropetrovska and Donetska) (Skok et al., for SaveDnipro, 2023) (**Figure 28**).

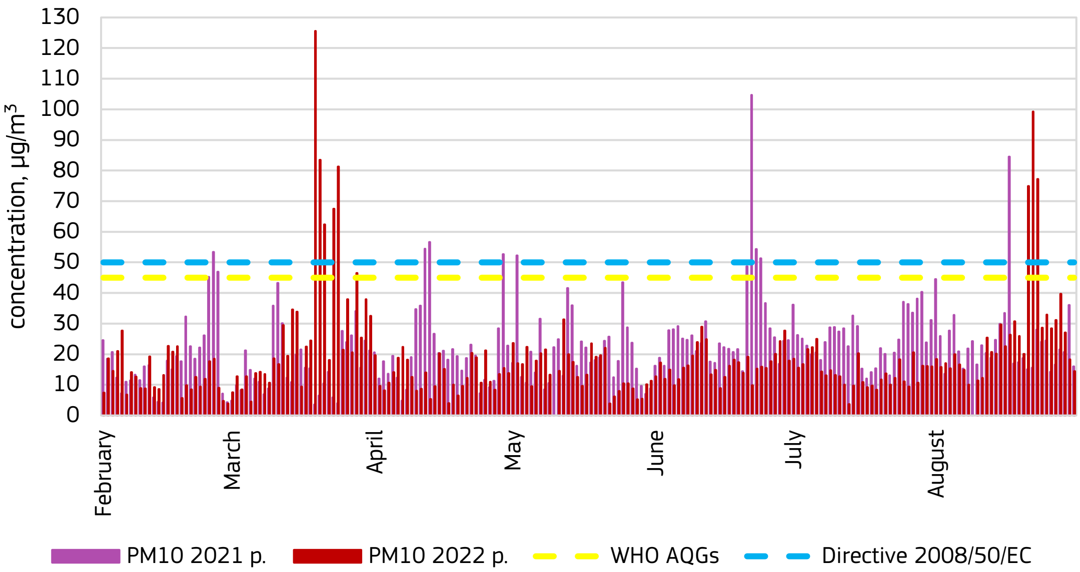
Research by the SI «Marzieiev Institute for Public Health, NAMSU» showed that pre-existing seasonal trends persisted in the city of Kyiv in 2022: high levels of $PM_{2.5}$ air pollution during the heating period (November-March), high level of PM_{10} in April-June (mainly associated with unfavorable meteorological conditions). Atypical high daily average levels of $PM_{2.5}$ air pollution observed in March, May, June and August and of PM_{10} in March and August were primarily caused by military actions and their consequences (fires, rocket attacks) (**Figure 29**, **Figure 30**) (Turos *et al.,* 2023).

Figure 29. Comparative analysis of average daily mass concentrations of $PM_{2.5}$ in the Kyiv city (February - August 2021-2022), µg/m³.



Source: SI «Marzieiev Institute for Public Health, NAMSU»

Figure 30. Comparative analysis of average daily mass concentrations of PM_{10} in the Kyiv city (February - August 2021-2022), µg/m³.



Source: SI «Marzieiev Institute for Public Health, NAMSU».

Atypical peaks in O_3 concentrations were observed during periods of active war actions and massive rocket attacks, which led to the ignition of large areas of biomass burning (in particular, forest fires, peat bogs, etc.) and additional emissions of a large number of pollutants (precursors) that are responsible for the formation of tropospheric O_3 (Turos *et al.,* 2024).

A study on the war impact on air quality in Ukraine was conducted using satellite and ground observations (three PurpleAir monitoring stations). (Zalakeviciute *et al., 2022*), with a focus on the city of Kyiv and the Kyiv region. It was observed a significant decrease in the concentrations of NO_2, CO, $PM_{2.5}$ compared to the pre-war period and an increase in O_3 and SO_2 in the first two weeks of the war. Starting from the third week of the war and until the end of March 2022, high values of NO_2 and $PM_{2.5}$ concentrations were recorded (Zalakeviciute *et al.,* 2022). These data coincide with those reported by the SI «Marzieiev Institute for Public Health, NAMSU» at the peak of active war actions around the city of Kyiv and mass fires in the Kyiv region (Turos *et al.,* 2023).

At the same time, World Air Quality Report data showed that in 2023 $PM_{2.5}$ levels have continued to fall across most of the country due to war-based deindustrialization with the annual average dropping by 11% in 2023 down to 8.6 μg/m^3 (Kyiv – 8.9 μg/m^3), compared to 9.7 μg/m^3 in 2022 (IQAir AirVisual, 2023). Attacks on Ukraine's energy infrastructure in the winter season of 2022-2023 resulted in a severe energy crisis requiring the use of solid fuel sources to heat homes (WHO, 2023). This trend is seen nationwide where monthly $PM_{2.5}$ levels peaked in January 2023, with cities in the province of Kyiv seeing on average a 65% increase in monthly average concentrations compared to 2022. The onset of the cold months in the 2023-2024 winter season again corresponds to increasing $PM_{2.5}$ levels with a secondary annual peak in the month of December.

A team of Ukrainian and Czech scientists (Soroka, *et al*., 2022) analysed the state and public monitoring data of atmospheric air quality city of Zaporizhzhia in the pre-war and war periods as the part of international program «Clean Air for Ukraine». The results show that in the first months of the invasion, there was an improvement of air quality city of Zaporizhzhia. This is primarily due to a significant decrease of industrial production and the curfew. The average monthly concentration of TSP in March-May 2022 was 26% -40% lower than the same periods in 2020 and 2021; NO_2 was 20% - 50% and VOCs (formaldehyde) 32% -55% lower. However, there was an increase in NH_3 and CO concentrations of 8% -16% and 56% -120%, respectively (Soroka *et al.,* 2022).

In Ukraine, there are no studies of the impact of atmospheric air pollution on health as a result of military operations. However, their relevance and necessity are foreseen by today's challenges and require urgent solutions, including the development of methodological approaches and quantitative assessments (Ukraine Government, 2022). A recent retrospective study of population hospitalizations due to cardiovascular and respiratory diseases in Poland (which is a country bordering Ukraine) proves the need for research in Ukraine (Harari S., Annesi-Maesano I., 2022). The study reports that the relative risk of hospitalization associated with the above pathologies due to an increase of 10 μg/m^3 of PM_{10} concentrations is - 1.0077 (95% CI 1.0062-1.0092) and 1.0218 (95% CI 1 .0182-1.0253) respectively; $PM_{2.5}$ – 1.0088 (95% CI 1.0072-1.0103) and 1.0289 (95% CI 1.0244-1.033), respectively (Harari S., Annesi-Maesano I., 2022).

Moreover, the energy urgencies caused by the conflict have led to the implementation of emergency solutions, such as the use of backup generators and other polluting technologies, which can further deteriorate air quality. These makeshift solutions, while intended to address immediate energy needs, often come at the cost of increased air pollution, highlighting the urgent need for sustainable and environmentally responsible solutions to mitigate the health and environmental impacts of the conflict.

8.2 Impact of war on GHG emissions in Ukraine

Since 2022, destruction of industrial and energy infrastructure caused by war led to a drop in energy consumption. According to the National Energy and Climate Action Plan, natural gas consumption has significantly decreased (-28.7% in 2022 compared to 2021) as well as electricity consumption (-30-35%), and natural gas extraction has decreased (-6.7% in 2022 compared to 2021). Regarding emissions, according to the latest data from EDGAR - Emissions Database for Global Atmospheric

Research, in 2022 the GHG emission level (excluding LULUCF) decreased by **23.2%** in comparison to 2021 in Ukraine.

Similarly, another scientific study *(Bun, et al., 2024*) in accordance with the IPCC guidelines, estimated a reduction of GHG emissions, in 2022, due to a reduction in traditional human activities of -89.65 $MtCO_2$-eq. This reductions accounts for **26%** compared to the total GHG emission levels in 2021 (i.e. 341.5 $MtCO_2$-eq) with the caveat that the uncertainty of the above data is **high** due to the significant uncertainty in the activity data, especially from temporarily occupied territories.

In addition, the study estimated the overall GHG emission reduction in traditional human activities for the first 18 months (February 2022-August 2023) of the war in Ukraine amounting to -157.68 $MtCO_2$-eq. Moreover, the study estimated the **war-related emissions** of carbon dioxide, methane, and nitrous oxide for the first 18 months of the war in Ukraine amounted to **77 $MtCO_2$-eq**. with a relative uncertainty of +/ 22 % (95 % confidence interval).

In conclusion, since 2022 destruction of industrial and energy facilities caused by war led to a drop in GHG emissions (**23-26%** reduction in 2022 compared to 2021) and to **emergence** of GHG emissions associated with **military operations.**

8.3 Impact of war on Ukrainian forests

8.3.1 Forest damages

Since the outbreak of military activities in February 2022, Ukraine has experienced significant environmental degradation, with almost 17 million hectares (28% of the country) affected by military operations. The presence of military equipment, units, and ongoing military actions in occupied and de-occupied areas has led to severe disturbances of aboveground ecosystems.

Intense deforestation and habitat destruction are drastically affecting the biodiversity. Soils have been contaminated, removed, or tilled, while water systems have been polluted or disrupted (Pereira *et al.,* 2022, Rawtani *et al.,* 2022). The impact on Ukraine's forests is of particular concern affecting approximately 1.7 million hectares of forests, which are 15% of the total forest cover and store around 377 million cubic meters of timber (Myroniuk et al., 2024). The State Forest Resources Agency has reported the accumulation of solid waste, abandoned military equipment that are releasing heavy metals, radionuclides, and other toxic substances, posing a significant threat both to the environment and human health (Poliakova & Abruscato, 2023).

The absence of effective governance and law enforcement in some areas has also led to an increase in corruption and illegal logging. The conflict has created an opportunity for uncontrolled timber extraction, undermining years of work to promote sustainable forest management. The Forest Stewardship Council (FSC) has been forced to suspend forest management certificates in conflict areas, further increasing the risk of illegal logging and jeopardizing the country's progress towards sustainable forestry practices (World Wide Fund, 2022).

8.3.2 Mines and explosive

Ukraine's forests have suffered not only from environmental degradation and destruction but also from the threat of explosive remnants, including mines and unexploded ordnance (UXO). The State Emergency Service of Ukraine (SESU) has identified at least 70 types of UXO, including anti-tank mines, ground force-targeting mines, and remnants from shelling, which have been found in war zones across the country (JRC, Zibtsev *et al.,* 2024). The presence of UXO in Ukraine's forests poses a significant threat to both human life and the environment as these explosive remnants can be triggered by accidental contact or natural events, such as storms or wildfires (see section 5.2.2).

The presence of UXO in forests also makes it extremely challenging to carry out conventional forest management activities. The personnel are at risk of injury or death due to the potential for accidental detonation. Moreover, the contamination of timber with projectile fragments reduces the quality and commercial value of the wood. This has significant economic implications for the forestry industry, which is already facing challenges due to the ongoing conflict (JRC, Zibtsev *et al.,* 2024).

The State Forest Resources Agency has estimated that at least 690,000 hectares of forests require demining actions, a figure that is likely to increase as further de-occupation efforts take place and new areas become accessible. Moreover, the ongoing mining process, particularly along the border with Belarus, is expected to add to the area requiring demining, highlighting the need for sustained and coordinated efforts to address this critical issue (Poliakova & Abruscato, 2023).

8.4 Impact of war on Ukrainian Soils

The ongoing war in Ukraine has devastating impact on the country's soils (Dmytruk *et al.*, 2023) (**Figure 31**). The use of explosives and ammunition has led to the release of potentially toxic elements, such as lead, mercury, and arsenic, into the soil. Soil contamination has serious consequences for public health, as heavy metals and other toxic substances can accumulate and enter the food chain (Núñez *et al.*, 2017; Ayuso-Álvarez *et al.*, 2019). The war has also led to the destruction of soil infrastructure, including irrigation systems, and the loss of topsoil. This can have long-term impacts on soil fertility and productivity, making it difficult for farmers to recover from the conflict. Additionally, the war has also disrupted agricultural production, leading to food insecurity and economic losses for farmers and rural communities (Dmytruk *et al.*, 2023; Shebanina *et al.*, 2024).

Figure 31. The impact of war on soil

source: P. Martyshev, O. Nivievsyi and M. Bogonos. https://www.ifpri.org/blog/regional-war-global-consequences-mounting-damages-ukraines-agriculture-and-growing-challenges/

As a result of the war of the Russian Federation against Ukraine, biota, water, air, and soil have been subjected to unprecedented destructive impacts. Dmytruk *et al.*, (2023) have identified the areas, including the qualitative and quantitative characteristics of the soil cover, which has been or is being affected by military actions. Scientists at Ukraine's Institute for Soil Science and Agrochemistry Research estimated that the war has degraded more 10 million hectares of agricultural land across Ukraine so far. The ongoing conflict in Ukraine involves the deployment of advanced military technologies, such as aircraft bombs ranging from 1500 to 3000 kilograms, ballistic missiles, extensive fires, toxic chemicals, and more. As a result, the environmental impact of these military actions is likely to be far more severe than anything previously recorded. Experiences from other conflict zones indicate that soils in areas of intense fighting, like Bakhmut and Avdiivka, may take decades, if not centuries, to recover. Although conducting a comprehensive assessment of soils affected by military activities is currently missing, it is clear that addressing the environmental consequences of the war will present a significant challenge in addressing global issues.

In conclusion, Ukrainian soils presenting important potential and a key resource, are facing significant challenges, including degradation, erosion, and contamination. The ongoing war has exacerbated these problems, with serious consequences for public health and the environment. The assessment of soil quality impacted by military activities in Ukraine underscores the urgent need for remediation efforts and proactive measures to mitigate further environmental degradation. Addressing these challenges requires coordinated efforts from government agencies, environmental organizations, and the international community to ensuring the long-term productivity of Ukrainian soils, restore soil health and safeguard the well-being of affected communities.

8.5 Impact of war on marine environment

The war between Russia and Ukraine has increased significantly pressures on the marine environment and water infrastructure. Some of the key pressures include:

- Oil spills, as the conflict has led to oil spills from land sources through waterways and through damaged or sunken ships, which can harm marine life and ecosystems.
- The war is resulting in the release of chemicals, including munitions and other pollutants, into the aquatic, including marine environment, which can harm marine life and ecosystems.
- Increased marine noise pollution from naval vessels, sonar, explosions and other military activities, which can disrupt marine life communication and behaviour.
- Changes in water circulation and chemistry, in particular through destruction of the Kakhovka Dam, to changes in water circulation and chemistry, including changes in salinity, temperature, and nutrient levels, which can impact marine ecosystems.
- The conflict has led to the destruction of habitats, reefs, seagrass beds, and coastal ecosystems, which provide crucial nurseries for many marine species.
- The conflict has resulted in damage to inland waterways and marine infrastructure, including ports, jetties, and coastal defenses, which can lead to increased pollution and habitat destruction.

- As a result of the destruction of the Kakhovka hydro-power plant alone and the related uncontrolled water leakage, more than 70% of the reservoir, was lost. Ukraine's water and wastewater infrastructure were outdated even before the war, but the damage caused by the hostilities to water resources and water infrastructure, including water supply, wastewater and hydraulic structures, is significant. This leads to large-scale pollution of watercourses and poor-quality drinking and sanitary water.

9 Leveraging the Ukraine Plan for Environmental and Climate progress

Inspired by the Recovery and Resilience Facility (RRF) – Next Generation EU, to benefit from the Ukraine facility, the country has submitted a national recovery and resilience plan *2024-2027*, hereafter referred as Ukraine Plan outlining the reforms and investment they will implement by end of 2027 (The Ministry of Economy of Ukraine, *2024a*).

This section explores opportunities from the Ukraine Plan to catalyse significant improvements in Ukraine's environmental and climate status analysed in the present report, with a focus on key areas such as air pollution, greenhouse gas emissions (at both national and local levels), forest health, soil conservation, and marine environment protection.

The Ukraine Plan prioritises the integration of green objectives into its reconstruction and recovery efforts, ensuring that future reforms and investments align with environmentally sustainable principles. Guided by the "do no significant harm" principle, the Plan supports the implementation of climate change mitigation and adaptation measures, safeguarding the environment through biodiversity conservation, sustainable waste management, and the promotion of a circular economy.

Ultimately, the Ukraine Plan aims to drive a successful green transition, addressing the associated challenges while promoting climate neutrality and adherence to the Paris Agreement. Convergence with EU environmental standards is a key aspect of this effort, underscoring the importance of environmental sustainability in the Plan's overall strategy.

The following highlights the main reforms and investments foreseen in the Ukraine Plan (i.e chapters 10 and 11 on energy and transport sector and chapter 15 on green transition and environmental protection) and makes links with the different chapters of the overall analysis of the environment and climate in the country.

Starting with the **green transition and climate**, Ukraine has made significant progress in establishing a framework for climate action and laid the groundwork for long-term climate action. The legislative framework for a long-term strategy and 2050 climate neutrality target has been established, providing a foundation for future climate policy.

To support the implementation of these climate targets and strategies, Ukraine has set up a national climate reporting system. However, to ensure the effectiveness of this strategy, a mandatory 5-year review and update, as required by the Governance Regulation, is still pending.

In addition to these long-term efforts, the country has defined its 2030 climate target in national legislation, which is aligned with the 2030 target set by the Energy Community. Furthermore, the Cabinet of Ministers of Ukraine has adopted the **National Energy and Climate Plan** *2025-2030* (NECP), providing a roadmap for achieving this target (Ministry of Economy of Ukraine, 2024b). The progress report on the implementation of the NECP is due in 2025.

The NECP of Ukraine is a strategic plan that coordinates the country's energy and climate policies to drive sustainable development and economic recovery. Moreover, the development of the NECP is a prerequisite for accessing financial assistance from the European Union under the Ukraine Facility, a comprehensive support package (50 billion euro from 2024 to 2027) designed to bolster Ukraine's resilience and facilitate its path towards EU membership.

The document envisages a reduction of Ukraine's total GHG emissions by 65% by 2030 compared to the 1990 emissions level. According to the Inventory of GHG Emissions for 1990-2021, GHG emissions amounted to 341.5 million tonnes of CO_2-equivalent (including the LULUCF sector) in 2021. This is 62.5% lower than the 1990 levels, but 7.5% higher compared to 2020.

Section 4 examines the connections between the actions outlined in the municipalities' Sustainable Energy and Climate Action Plans (SECAPs) and the reforms and investments (chapters 10 and 11 on energy and transport sector) envisioned under the Ukraine Plan.

Regarding the **Environmental Protection,** reducing air, water and soil pollution remains a major challenge for the country. Ukraine is a highly industrialised country with a large share of metallurgical, cement, chemical, and mining industries, which can have a significant harmful impact on human health and the environment. Improving the environment requires an effective and transparent system of environmental permits including Environmental Impact Assessment for industry and businesses in line with EU principles, as well as monitoring and enforcement of permit conditions by authorities and courts.

Concerning **air pollution**, the existing national limits for the emission of pollutants and discharge do not meet emission levels associated with the best available techniques set out under EU law. The first reform under chapter 15 on Green Transition and Environmental Protection (completed in Q3/2024) covered under Pillar I of the Ukraine facility had the objective to establish the legal and organisational framework on prevention, reduction and control of industrial pollution.

Regarding **industrial pollution**, alignment with the Directive 2010/75/EU and its recast on industrial emission is currently ongoing (Law on Integrated prevention and control of industrial pollution adopted in July 2024, secondary legislation ongoing), however many other issues related to industrial pollution persist. Alternative to this Directive, Ukraine has adopted a National Emission Reduction Plans (**NERP**), which provide an alternative to setting individual emission limit values for each plant. As of 2023, in the country there are a total of 248 large combustion plants, 90 out of which are subject to the NERP. Although the reported emissions of sulphur dioxide, nitrogen oxides, and dust increased slightly in 2023, compared to 2022, the **NERP** ceilings were met for the year (Energy Community - Annual Implementation report 2024). However, it is essential to note that this compliance is partially due to the lack of data.

Further work is needed on air quality information collection, processing, reporting and dissemination procedures as well as monitoring and control. The Ukraine Plan envisages the following reforms for this purpose:

- Ratify and implement the Protocols to the UNECE Convention on Long-Range Transboundary Air Pollution;
- The National Register of Emissions and Transfers of Pollutants (RETP), which is currently fully operational. Ukraine will continue to strive to improve public access to information;
- Reduce emissions from transportation, energy production, and industrial activities by approximating EU air quality directives in all sectors;
- Put in place effective air quality monitoring infrastructure and administrative bodies.

About the **restoration and conservation of natural resources,** the Ukraine plan envisages under reform 4 in chapter 15 on Green Transition and Environmental Protection (to be completed in Q2/2026) covered under Pillar I of the Ukraine facility, the entry into force of the legislation on reducing deforestation and forest degradation.

To conclude on Environmental protection, the Ukrainian **Environmental Assessment** (EIA) and **Strategic Environmental Assessment** (SEA) legislation are in place, although subject to derogations due to the legal regime of martial law in force in the country. The Ukraine plan envisages under reform 6 in chapter 15 on Green Transition and Environmental Protection, covered under Pillar I of the Ukraine facility, the development of a concept note defining the scope of deviations from the EIA and SEA rules.

To support the country's recovery, reconstruction, and modernisation, the Ukraine Plan can leverage five key areas of actions in the local authorities' plan:

— Prioritising reforms and investments in **energy efficiency**, focusing on improving the energy efficiency of existing buildings, particularly through upgrades to building fabric. All new construction, reconstruction, and renovation projects, including those for buildings damaged during the war, should incorporate high efficiency standards. To support this effort, it is essential to allocate sufficient funding to the **Energy Efficiency Fund** for projects that enhance energy efficiency in residential sectors. There is a need for a detailed roadmap for measures supporting the implementation of the **Thermal Modernisation Strategy** through 2030 (adopted in February 2024), with a focus on upgrading the building envelope and heating systems and integrating renewable energy.

— **Electrification of public transport fleet and urban transport and mobility planning.** Urban transport planning and regulations policy plays an important role in achieving the GHG emissions reduction by 2030. While fuel efficiency driven policies are the competence of national standards and national policies, local authorities' policies in transportation are related to urban transport planning, prioritising public transport versus private vehicles, and structural changes in the sector. It is crucial to restore socially important transportation services in war-affected communities by re-establishing urban public transport. Investment priorities in the Ukraine Plan include the renewal and electrification of the public transport fleet. Ukraine also need more sustainable approach into mobility planning. National transport strategy (Adopted in December 2024) foresees an adoption of Sustainable Urban Mobility Plans (SUMPs) in all Ukrainian cities and towns inhabited by more than 50 000 inhabitants. This action would require efficient cooperation with Covenant of Mayors to timely prepare such plans and switch into human centric approach in urban planning, where mobility in cities would planned for people, not cars. Cycling infrastructure, more efficient city logistics, public transport, development of emission free zones, better walkability, safety and security of vulnerable users are main features of SUMPs.

— Accelerate the **modernisation of Ukraine's District heating networks**, which are mostly under the control and management of the municipality. The modernisation of Ukraine's district heating network is long overdue and needs to be accelerated in conjunction with the modernisation of the country's building stock. There is a need for a detailed roadmap for carrying out the reforms to create better conditions for investments in high-efficiency district heating and high-efficiency cogeneration including measures to strengthen the resilience of the municipal heat supply systems

— Integrating adaptation measures from local authorities into the implementation of the national strategy for adaption to address **extreme heat and floods & mass movements**, with emphasis on **river basin management planning**, collection and use of water quality monitoring and other relevant data and applying economic instruments to facilitate investments in water infrastructure

— Finally, yet importantly, through wider **awareness, ownership and involvement of citizens,** local authorities mobilise public interest in sustainable energy and climate change mitigation and create broad-based political and social support for the implementation of the SECAP.

10 Conclusions and outlook

The present report provides an overall picture of the environmental and climate situation (air quality, emissions of air pollutants and GHG, forests, soil and marine environment) in Ukraine. The information for the first time summarised in this study provides the basis **for assessing the impact of war** in Ukraine, concerning specific aspects, and gives inputs for the **reconstruction of the country**.

The **scarcity of data** represents a significant obstacle for continuous spatial and temporal environmental monitoring in Ukraine. The availability of reliable field data is crucial to identify the critical environmental and climate aspects. Thus, the establishment and constant improvement of monitoring networks including transparent reporting, with appropriate financial and human resources for the implementation of plans, is pivotal.

The two most extensive **monitoring networks** use outdated non-automated instrumentation which **hinders a complete spatial and temporal coverage of air quality monitoring in Ukraine**. Air quality monitoring performed in accordance with the EU requirements are exceptional and regional. Moreover, the number of measuring stations has decreased as a result of the territory occupation during the war. Air pollution related to PM is still poorly regulated due to the lack of national air quality standards (alignment with current EU Air Quality Directives 2008/50/EC and 2004/107/EC not fully approved resulted in no legal implications of measuring these air quality parameters). According to different data sources, in the period of 2018-2023 annual concentrations of **PM_{10}** and **$PM_{2.5}$** were below the annual limit value set by Directive 2008/50/EC but above the stricter WHO AQGs. The highest concentrations are located in the industrialised regions in eastern Ukraine. During 2018-2022 annual average concentrations of **SO_2, NO, CO** and **TSP** met the NAAQS criteria, while **NO_2** and **CH_2O** exceeded such values.

The share of **mobile sources** in Ukraine increased in the period 2016-2019 because of a fast increase of vehicle fleet and decreased afterwards due to the combined effect of the COVID-19 pandemic and the intensification of the war in 2022. The largest SO_2 emissions derive from the energy and industry sector while NOx is mainly emitted by this and the transport sector. CO and NMVOC main sources are industry and mining sectors. **The regions with the highest emissions** are Donetska, Dnipropetrovska, city of Kyiv, Zaporizka, Ivano-Frankivska, and Kyivska. **Emissions of air pollutants decreased** in this period, mainly due to the military operations in the east of the country (Donetsk and Luhansk regions),, the decline in industrial production related to the COVID-19 pandemic and the introduction of environmental protection measures.

Ukraine has made **significant progress in establishing a framework for climate action** and laid the groundwork for long-term climate action. As Annex I Party of the UNFCCC Ukraine adopted regulations to ensure its annual GHG inventory covering emissions and removals of direct GHGs. By 2021, Ukraine had **achieved a significant reduction in GHG emissions (-62.5% compared to 1990)**, although, more recently there was an increase of 7.5% compared to 2020 levels, largely attributed to the recovery of industrial activities after the COVID-19 pandemic.

Regarding GHG emissions, destruction of industrial and energy facilities caused by war since 2022 led to a drop in GHG emissions (**23-26%** reduction in 2022 compared to 2021) and to the **emergence** of GHG emissions associated with **military operations in the first 18 months** amounting to **77MtCO_2-eq.**

Regarding energy and climate at local level, Ukrainian CoM signatories' **overall commitment is to reduce 33% of their GHG emissions by 2030** which is 3 percentage points beyond the minimum requested target. On adaption to climate change, Ukraine is particularly vulnerable to seasonal flooding and droughts. Climate change is expected to exacerbate the intensity and frequency of these hazards, with 80% of mapped hazards having a high or medium impact. The most common hazards with high or medium impact are **heavy precipitation, floods, and mass movements (47%)** and **droughts, high temperatures, heat waves, and wildfires (43%).**

Although forests only cover about one fifth of its territory, Ukraine ranks among the top European countries in terms of forest area. A larger share of forests is managed for their recreational and nature-protective functions, rather than commercial purposes. Forests are **under pressure** due to various factors: **forest fires, pests, illegal logging** and since the outbreak of military activities in February 2022, under the significant degradation manifested trough intense deforestation and habitat destruction, threat of explosive remnants and wildfires. Over the past decades, **climate change** has significantly increased the **risk of large forest fires** with the worst situation in the last five years.

Soil health is of utmost importance in Ukraine considering that **agriculture is one of its main economic activities** (11% of GDP, 60% of exports worth EUR 23.3 billion in 2023). Soils in Ukraine are characterised by **high levels of organic matter and rich in nutrients**, including nitrogen, phosphorus, and potassium, which is essential for maintaining soil fertility and structure. However, soils are also vulnerable to degradation such as: **nutrient mismanagement**, acidification, erosion, compaction, salinisation, contamination. Another aspect of the impact on soil resources is the **destruction of soil infrastructure**, including irrigation systems, and the loss of topsoil.

The **Black Sea** is subject to numerous **anthropogenic pressures**, as nutrient input, wastewater input, **contaminant** input, e.g. pesticides, ultra-trace contaminants and **microplastics**. Also, it is an intense shipping route and **intense fishery** resource. Invasive species, noise and oil spills are among the additional pressures. **Climatic changes** increased winter air temperatures, reduced frequency of cold winters, and weakened winter water convection causing the **decrease in average oxygen content** within the upper layers of the sea.

A multitude of priority pollutants and emerging contaminants were identified within the sea water and sediment samples including **trace metals** (TM), **organochlorine pesticides** (OCPs), polychlorinated biphenyls (**PCBs**), and Polycyclic Aromatic Hydrocarbons (**PAHs**). Western Black Sea exhibited higher pollution levels compared to those from the Open Sea and Eastern Black Sea. **Plant protection products** are the most common identified class of emerging pollutants. Considering the findings from both **sea water and sediment** analyses, several pollutants and emerging contaminants (Cd, Hg, DEHP, di-butyl-phthalate, para-para-DDT etc.) are recommended for classification as "Black Sea Specific Contaminants" for **future regular monitoring**. Environmental monitoring of the Black Sea in Ukraine is since the start of the war not possible, due to inaccessibility of the coast and inability to perform marine surveys.

Impact of war on Ukraine environment

The war conflict in Ukraine in 2022 led to the redistribution of pollution sources and volumes leading to a change in the spatial and temporal patterns of air pollution area in Ukraine. Losing part of the industrial and energy complex, including a fuel crisis, led to a decrease in anthropogenic emissions, and active military operations and migrations caused the emergence of air quality deterioration in atypical locations.

On top of the typical seasonal trends of particulate matter levels due to heating season and meteorological conditions, **high daily $PM_{2.5}$ and PM_{10} averages** were observed in unexpected periods of the year which were associated with the influence of military actions. Atypical **peaks in O_3 concentrations** may also be attributed to war activities. Massive rocket attacks led to the ignition of large areas of biomass burning and additional emissions of a large number of pollutants (precursors) that are responsible for the formation of surface O_3. More extensive analyses and monitoring are needed to assess the impact of war on atmospheric air pollution, but also the repercussion of the airborne contamination on the health of the population.

Since the start of the war, 28% of the country is affected by military operations, whereby more than 90% of the forest cover losses associated with fire were detected within the war zones. Forest cover losses in the conflict areas are accounting for approximately **40-45% of the total forest losses**. The analysis of annual tree cover loss in period 2020-2023 and the specific role wildfires played in driving these losses suggested that the conflict has had a relatively small impact on national-level forest cover loss. However, the war conflict and presence of military equipment, units and actions has severely hampered efforts to prevent and control large fires.

Moreover, the war conflict has devastating impact on the country's soils, by **releasing toxic elements**, such as lead, mercury, and arsenic that may cause serious consequences for public health through bioaccumulation and entry into food chains. Experiences from other conflict zones indicate that soils in areas of intense fighting may take decades, even centuries, to recover.

The war conflict has increased significantly the number of pressures through release of chemicals, including munitions and other pollutants, changes in water circulation and chemistry and habitat alteration and destruction (**in particular through destruction of the Kakhovka Dam**). Damage to inland waterways and marine infrastructure, including ports, jetties, and coastal defences, which can also lead to increased pollution and habitat destruction were present as well. These pressures are likely to have **long-term consequences for the health and biodiversity of the Black Sea and Sea of Azov** ecosystems. Long-term consequences may include secondary pollution events, changes in mobility and bioavailability of contaminants and lasting changes in habitat availability and quality, affecting biodiversity and ecosystem services.

The Ukraine Plan

The **Ukraine Plan 2024-2027** is a pivotal instrument for the country's recovery, reconstruction, and modernisation, with the potential to expedite Ukraine's EU accession path, enabled by the facility.

The Plan prioritises the **integration of green objectives** into its reconstruction and recovery efforts, ensuring that future reforms and investments align with environmentally sustainable principles. Ultimately, it aims to drive a successful green transition, addressing the associated challenges while promoting climate neutrality and adherence to the Paris Agreement. **Convergence with EU environmental standards** is a key aspect of this effort, underscoring the importance of environmental sustainability in the Plan's overall strategy.

From the **energy perspective**, the Ukraine Plan is complemented by the NECP of Ukraine, which is a strategic plan that coordinates the country's energy and climate policies to drive sustainable development and economic recovery. Improving the environment requires an effective and transparent system of environmental permits for industry and businesses in line with EU principles, as well as **monitoring and enforcement of permit conditions** by authorities and courts.

The Ukraine Plan envisages reforms to improve **environmental protection** like air quality data collection, processing, reporting and dissemination procedures as well as monitoring and control.

Concerning the **restoration and conservation of natural resources,** the Ukraine plan envisages under reform 4 (in chapter 15 on Green Transition and Environmental Protection - to be completed in Q2/2026- covered under Pillar I of the Ukraine facility) the entry into force of the legislation on reducing deforestation and forest degradation.

The Ukraine Plan also considers the implementation of the Ukrainian **Environmental Impact Assessment** (EIA) and **Strategic Environmental Assessment** (SEA) legislation which are in place, although subject to derogations due to the legal regime of martial law in force in the country.

The Ukraine Plan can leverage five key areas of actions to mitigate and adapt to climate change in the local authorities' plan:

- Prioritizing reforms and investments in energy efficiency
- Promoting electrification of public transport fleet and urban transport planning
- Accelerating the modernisation of Ukraine's District heating networks
- Integrating adaptation measures from local authorities into the implementation of the national strategy for adaption to address extreme heat and floods & mass movements
- Widening awareness, ownership and involvement of citizens

In conclusion, the Ukraine plan provides a solid foundation, and it is recommended to consider this report's findings for the implementation of individual measures to ensure a sustainable reconstruction of the country.

Annex I

Law of Ukraine No.4187-IX «On Amendments to Certain Legislative Acts of Ukraine on the Restoration of MRV of GHG Emissions» (Law No. 4187 January 2025) that aims to put again in force the mandatary registration and reporting requirements in the field of Greenhouse Gas (GHG) emissions established by the Law of Ukraine No.377-IX «On Principles of MRV of GHG emissions» dated 12 December 2019 (Law No. 377). https://zakon.rada.gov.ua/laws/show/377-20?lang=en#Text.

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Law of Ukraine No.3991-IX “About the main principles of state climate policy” adopted on 8 October 2024 : https://zakon.rada.gov.ua/laws/show/3991-20#Text

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Concept for the state environmental monitoring program (July 2023). Law of Ukraine "On introducing amendments to some legislative acts of Ukraine as to the state system of environmental monitoring, information as to the state of environment (ecological information) and information support of management in the environmental domain" . No.63. https://zakon.rada.gov.ua/laws/show/2973-IX#Text

Framework waste management law (July 2023). To comply with its commitments on waste management, Ukraine has adopted the 2017 National Waste Management Strategy for Ukraine until 2030. This framework legislation transposed certain provisions of the EU's Waste Framework Directive. Additionally, amid the war, a new Law on Waste Management was adopted in 2022. Verkhovna Rada of Ukraine. (2022b). Law of Ukraine "On waste management". No 2320-IX. https://zakon.rada.gov.ua/laws/show/2320-20#Text

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Resolution of the Verkhovna Rada (Parliament) of Ukraine № 1704-IX of 16 July 2021 On the implementation of the National Plan to reduce emissions from large combustion plants: https://zakon.rada.gov.ua/laws/show/1704-IX#Text.

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Annex II

In response to the increasing frequency and intensity of **extreme heat events, Droughts & water scarcity (11%) & Wild fires (6%)**, local authorities have planned a range of adaptation measures (e.g. creating a climate change adaptation plan that includes measures to address wildfires, droughts, and extreme heat) to mitigate the impacts on communities and infrastructure, in the following areas.

Urban Planning and Green Infrastructure

- Development and maintenance of green planted areas to reduce the urban heat island effect and improve air quality.
- Creation of green zones in areas of new construction to provide additional shading and cooling.
- Implementation of the principle of "The city of short distances" to reduce the urban heat island effect and improve air quality.

For example, the city of **Lviv** has implemented the principle of "The city of short distances" by increasing the comfort of pedestrian space, developing green lines between different parts of the city, and adapting transport to improve the ability to cover short distances on foot or by bicycle.

Water Management and Conservation

- Collection and reuse of rainwater for non-potable purposes, such as watering green spaces.
- Carrying out work on the gradual separation of the sewage system during reconstruction in those areas where this is possible.
- Improvement of water supply and sanitation reliability to reduce the risk of droughts and water scarcity.
- Use of plants adapted to arid conditions to reduce water consumption for irrigation.
- Restore rivers to their natural state to improve water quality and ecosystem health (e.g. removing dams and restoring wetlands)
- Construct mine water treatment plants to reduce water pollution (e.g. treating mine water to remove heavy metals and other pollutants)

For example, the city of **Lviv** has planned: the implementation of the "sponge-city" model to reduce the burden on city sewers: identification and selection of opportunities for optimal use of rainwater as a resource (for irrigation and watering of urban green areas, watering of streets in the heat, use in closed systems, etc.). Another example: the city of **Slavuta** has planned to develop a rainwater management system throughout the city (in particular, it is advisable to create/improve reservoirs for its accumulation and use for economic needs).

Infrastructure and Transportation

- Modernize housing stock to improve safety, comfort, and heat resilience for residents (e.g. retrofitting homes with heat-resistant materials and improving ventilation)
- Construct and reconstruct roads with materials resistant to temperature changes (e.g. using temperature-resistant asphalt and concrete)

- Implement water management systems and elaboration of waste management systems to reduce heat-related risks (e.g. decommissioning outdated water management systems and implementing new waste management systems).

Education and Awareness

- Development of information and educational campaigns on the importance of sustainable land use and climate change mitigation.
- Organization of training for stakeholders to achieve optimal results in climate change adaptation.
- Adapt community green spaces to climate change and promote heat stress management measures (e.g. creating shaded areas and cooling centers)

Secondly, in response to the increasing frequency and intensity of **heavy precipitation events (15%), floods and mass movements (16%) & Storms (3%)**, local authorities have planned a range of adaptation measures to mitigate the impacts on communities and infrastructure. These measures aim to reduce the risk of flooding, protect communities and infrastructure, and promote sustainable development in the face of heavy precipitation events. These measures are planned in the areas of:

Drainage and Water Management: Many cities have taken actions to improve their drainage and water management systems, including:

- Reconstruction and modernization of drainage systems:
- Improving the reliability of water supply and sanitation
- Increasing the capacity of storm sewers
- Implementing sustainable management of rainwater
- Introducing new technologies for consumer water treatment and wastewater treatment

Green Infrastructure and Urban Planning: Cities have also focused on developing green infrastructure and urban planning strategies, including:

- Creating green zones and parks
- Implementing "green" and "blue" infrastructure
- Developing green roofs and vertical landscaping
- Planting trees and flowers
- Designing new buildings and infrastructure with flood-resistant materials

Emergency Response and Preparedness: Cities have taken steps to improve their emergency response and preparedness, including:

- Implementing emergency alert systems
- Developing response plans for hot weather and other natural emergencies
- Conducting public awareness campaigns

- Providing training for emergency responders
- Establishing backup energy sources for critical infrastructure
- Establishing climate change offices and departments to coordinate adaptation efforts.

River and Water Body Management: Some cities have focused on managing rivers and water bodies to prevent flooding, including:

- Restoring rivers to their natural state.
- Improving the hydrological regime of rivers and water bodies
- Protecting surface and subterranean waters
- Implementing measures to prevent waterlogging and flooding

In conclusion, Ukraine is vulnerable to hydrometeorological hazards and natural disasters, particularly seasonal flooding and droughts, which affect the agricultural and human health sectors. Climate change is expected to increase the intensity and frequency of these hazards, with 80% of mapped hazards having a high or medium impact. The most common hazards with high or medium impact are heavy precipitation, floods, and mass movements (47%) and droughts, high temperatures, heat waves, and wildfires (43%). Local authorities have planned 490 adaptation actions to address these hazards, with 57% having a sectorial impact.

The majority of actions are planned to tackle extreme heat (28%) and floods and mass movements (23%) with emphasis on river basin management planning, collection and use of water quality monitoring and other relevant data and applying economic instruments to facilitate investments in water infrastructure.

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List of abbreviations and definitions

Abbreviations	Definitions
AAQD	Ambient Air Quality Directives
AAQMRBLC	Ambient Air Quality Monitoring and Radioactive Background Level Center
AQ	Air quality
AQG	Air quality guideline
AQI	Air quality index
BAT	Best Available Technique
BAU	Business as Usual
BEI	baseline emission inventory
BREF	BAT Reference Documents
BSIMAB	Black Sea Integrated Monitoring and Assessment Programme
CAMS	Copernicus Atmosphere Monitoring Service
CAQI	Common Air Quality Index
CHM	Canopy Height Map
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
CO_2-eq	CO_2-equivalents
CoM	Covenant of Mayors
COP	Conference of the Parties
CCAC	Climate and Clean Air Coalition
CLRTAP	Convention on Long-range Transboundary Air Pollution
CSAP	Climate Change Strategy and 2021-2023 Action Plan
DALYs	Disability-adjusted life years
EC	European Commission
ETS	emission trading system
EU	European Commission
EDGAR	Emissions Database for Global Atmospheric Research
EEA	European Economic Area
EFFIS	European Forest Fire Information System
EIA	Environmental Impact Assessment
ENPI	The European Neighbourhood and Partnership Instrument
EQMD	Environmental Quality Monitoring Department
EU	European Union
EUAA	EU-Georgia Association Agreement
EUTR	European Timber Regulation
FSC	Forest Stewardship Council
GBD	Global Burden of Disease

Abbreviations	Definitions
GDP	Gross domestic product
GFC	Global Forest Cover
GHG	Greenhouse gas
HYSPLIT	Hybrid Single-Particle Lagrangian Integrated Trajectory
IAP	Indices of atmospheric pollution
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IHME	Institute For Health Metrics and Evaluation
IMB NASU	Institute of Marine Biology of the National Academy of Sciences of
IOM	International Organization for Migration
JBSS	Joint Black Sea Surveys
LRTAP	Long-Range Transboundary Air Pollution
LULUCF	Land use, land-use change and forestry
LV	Limit value
MAC	Maximum allowable concentration
$MAC_{m.s.}$	Maximum allowable concentration maximum single
$MAC_{a.d.}$	Maximum allowable concentration average daily
MAI	Mean annual increment
MEL	Maximum Permissible Emissions
MHU	Ministry of health of Ukraine
MIAU	Ministry of Internal Affairs of Ukraine
Mton CO2-eq	Mton of carbon emissions
MPC	Maximum Permissible Concentrations
MSW	Municipal solid waste
NAAQS	National Air Quality Standards
NAMSU	National Academy of Medical Sciences of Ukraine
NASU	The National Academy of Sciences of Ukraine
NCEI	National Centers for Environmental Information
NDC	Nationally Determined Contribution
NEA	National Environment Agency
NMS	National Monitoring Studies
NOAA	National Oceanic and Atmospheric Administration
NSC	National Science Centre
OND-86	«Methodology for calculation of the concentrations of hazardous
OSENU	Odessa State Environmental University
PM_{10}	Particulate matter 10 micrometers or less in diameter
$PM_{2.5}$	Particulate matter 2.5 micrometers or less in diameter
PTEs	Potentially Toxic Elements
RES	renewable energy source
RCDCP	Regional centers disease control and prevention

Abbreviations	Definitions
RGs	Reference Groups
RVA	risk and vulnerability assessment
SAUEZM	State Agency of Ukraine on Exclusion Zone Management
SEAP	sustainable energy action plan
SECAP	sustainable energy climate action plan
SESU	State Emergency Service of Ukraine
THHP	Temiz Hava Hakkı Platformu
Kton	Thousand tonnes
TM	Trace Metals
TSP	Total Suspended Particulates
TurkStat	Turkish Statistical Institute
UkrSCES	Ukrainian Center for Ecology of the Sea
UHMC	Ukrainian Hydrometeorological Center
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency
UXO	Unexploded Ordnance
WRB	World Reference Base
WHO	World Health Organization
WHO AQGs	World Health Organization Air Quality Guidelines

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