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ANALYSIS OF STATISTICAL INDICATORS OF POLLUTANT EMISSIONS INTO THE ATMOSPHERIC AIR OF IVANO-FRANKIVSK REGION

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Abstract: The article examines the urgent problem of atmospheric air pollution in Ivano-Frankivsk region caused by anthropogenic factors. The main attention is paid to the analysis of the structure and dynamics of pollutant emissions from stationary sources, in particular carbon dioxide, sulfur compounds, solid suspended particles, nitrogen and other substances. The analysis of trends in total pollution for the period from 1990 to 2023 has been presented, taking into account economic, social and environmental factors. It has been found that in 2023, total emissions from stationary sources decreased by 3.02% compared to 2022 and amounted to 147.7 thousand tons. The main pollutant remains carbon dioxide (9.9 million tons), which is the main greenhouse gas and contributes to climate change. The structure of emissions of other pollutants has been investigated: a significant share is made up of sulfur dioxides (65%), solid suspended particles (17%), nitrogen compounds (9%), methane (4%), and non-methane volatile organic compounds (3%). The dynamics of changes in emission levels in the context of economic, environmental and technological factors, including the impact of the COVID-19 pandemic, has been presented. Particular attention is given to analyzing emissions of nitrogen dioxide, sulfur dioxide, particulate matter, and nitrogen oxides, as well as their impact on ecosystems and public health.

The results of the study show a gradual decrease in atmospheric air pollution in the region, which is a consequence of a decrease in carbon dioxide and sulfur dioxide emissions, but emissions of volumes of emissions of solid suspended particles and nitrogen oxides have increased in recent years. Therefore, the development of alternative energy, the introduction of the latest emission treatment technologies, the popularization of environmentally friendly transport, and the strengthening of environmental monitoring remain actual for the region.

Keywords: air pollution, emission structure, emission dynamics, Ivano-Frankivsk region.

1. INTRODUCTION

One of the most pressing issues today is the pollution of the atmosphere's surface layer caused by anthropogenic emissions. Atmospheric air pollution has a negative impact on public health, contributes to the spread of respiratory diseases, allergies, cardiovascular diseases and other pathologies. In addition to affecting health, air pollution disrupts ecological balance, contributes to

the degradation of natural ecosystems, and exacerbates climate change (Soroka et al., 2023; Grigorieva et al., 2023).

Of particular importance is the study of atmospheric air quality in the context of Ukraine's integration into European environmental standards, as well as in the context of climate change (Bakharev, 2016). Identifying the main sources of pollution, assessing their impact, and developing ways to reduce emissions is an urgent task to ensure the country's sustainable development and improve the quality of life of the population (Hohunskyi & Prokopovych, 2016). In addition, the relevance of studying the state of atmospheric air in Ukraine is underscored by the country's international commitments under the Paris Climate Agreement, the Association Agreement with the EU, and other environmental initiatives. This involves gradually reducing greenhouse gas emissions, introducing environmentally friendly technologies, strengthening environmental monitoring, and creating legal mechanisms to ensure environmental safety (Hryhorieva et al., 2023).

According to research data, air quality in many industrial regions of Ukraine remains critically low, requiring the implementation of effective measures to monitor, analyze, and control emissions of harmful substances (National Report on the State of the Environment in Ukraine, 2022).

The atmospheric air of Ivano-Frankivsk region is subject to significant anthropogenic impact from the operation of industrial facilities in the region (Adamenko & Akulshyn O, 2011). On the one hand, the region is characterized as a tourist center, on the other hand, such industrial giants as: Burshtyn Thermal Power Plant Industrial Enterprise, DTEK "Zakhidenergo" Private Joint Stock Company, "Naftokhimik Prykarpattya" Private Joint Stock Company, "Nadvirnaftogas", Ivano-Frankivskcement Private Joint Stock Company, and others (Zinko et al., 2014; Environmental Passport of Ivano-Frankivsk region for 2023, 2024). The main air pollutants by type of economic activity continue to be enterprises supplying electricity, gas, steam, and conditioned air, which account for 89.5% of regional emissions, with the share of mining and quarrying development at 3.5%; processing industry at 3.1%; transport, warehousing, postal and courier activities at 2.1%; agriculture, forestry, and fisheries at 1.4%; and other economic sectors at less than 1% (Regional Report on the State of the Environment in Ivano-Frankivsk Region, 2014). Therefore, assessing the impact of stationary sources of pollution on the state of the atmospheric air and studying the main trends in pollutant emissions in Ivano-Frankivsk region is an urgent research task.

The purpose of the study is to analyze the structure and dynamics of pollutant emissions from stationary sources in Ivano-Frankivsk region.

To analyze air pollution from stationary sources in Ivano-Frankivsk region, we used official statistics from the State Statistics Service, as well as statistics from the Environmental Passport of Ivano-Frankivsk region and Regional Reports on the State of the Environment in Ivano-Frankivsk region. The statistical collections "Environment of Ukraine" for 2022 and 2010 were also used as a source of statistical reporting.

2. STRUCTURE OF POLLUTANT EMISSIONS INTO THE AIR OF IVANO-FRANKIVSK REGION

According to the Main Department of Statistics in Ivano-Frankivsk region, in 2023, air pollutant emissions from stationary sources amounted to 147.7 thousand tons, which decreased by 3.02% compared to the previous year. The largest contribution to air pollution is made by carbon dioxide, which amounted to 9.9 million tons (1.10% less compared to 2022), the main greenhouse gas that affects climate change (Environmental Passport of Ivano-Frankivsk Region for 2023, 2024).

In addition to carbon dioxide, the following pollutants form the structure of air emissions in Ivano-Frankivsk region: sulfur compounds, substances in the form of solid suspended particles, nitrogen compounds, methane, non-methane volatile organic compounds (Fig. 1).

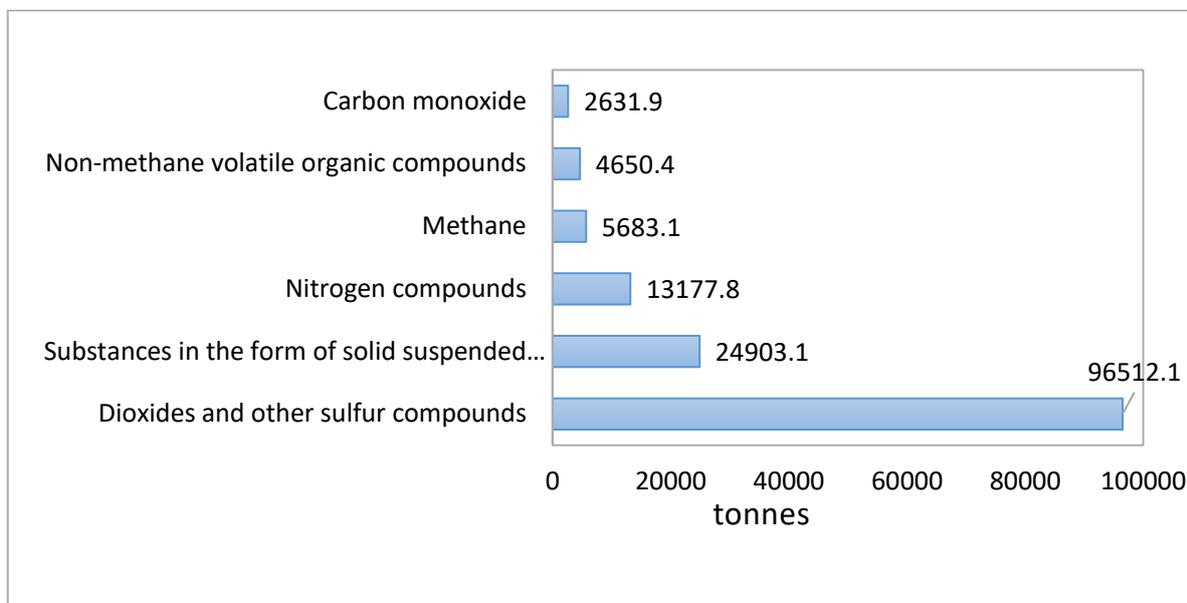


Figure 1. Distribution of pollutant emissions into the atmosphere from stationary sources in 2023, categorized by individual substances

In the structure of air pollutant emissions by stationary sources, after carbon dioxide, dioxides and other sulfur compounds (96512.1 tons) were the second largest contributors to the total emissions, accounting for 65% of the total. On the third place are substances in the form of solid suspended particles – 24903.1 tons, which is 17% of the volume of pollutants released into the atmosphere. Nitrogen compounds take the fourth position – 13177.8 tons (9%). Methane, which is a greenhouse gas, rounds out the top five key pollutants with a share of 4% (5683.1 tons). Emissions of non-methane volatile organic compounds amounted to 4650.4 tons (3% of total emissions). Carbon monoxide emissions were the lowest, amounting to 2631.9 tons (2%) (Regional Report on the State of the Environment in Ivano-Frankivsk Region for 2023, 2024).

The structure of emissions of the main pollutants into the air from stationary sources of pollution in Ivano-Frankivsk region in 2023 is shown in Figure 1.

3. DYNAMICS OF AIR POLLUTANT EMISSIONS INTO THE AIR

3.1. General dynamics of pollutant emissions from stationary sources of pollution into the atmosphere of Ivano-Frankivsk region

In the dynamics of pollutant emissions into the air of Ivano-Frankivsk region from 1990 to 2023, several stages can be distinguished that reflected changes in pollution levels and the economic situation in the country and the region (Fig. 2).

The first stage, which covers the period from 1990 to 2000, was characterized by high levels of emissions, in particular in 1990, when they reached 403.3 thousand tons. This reflects intensive industrial production and pollution at a time when the region had not yet felt the impact of economic changes associated with the collapse of the USSR. Emissions in 1995 decreased to 271.7 thousand tons, and in 2000 to 141 thousand tons, which was the result of a reduction in industrial activity due to the economic crisis and structural changes (Statistical Collection of the Environment of Ukraine for 2010, 2011).

The second phase, from 2000 to 2015, was characterized by a gradual but steady decline in emissions. After a sharp decline in the early 2000s, emissions have been steadily declining due to reforms in the energy sector, the use of cleaner technologies, and a reduction in pollution intensity due to the transition to other energy sources and technological upgrades. In 2010, the volume of emissions amounted to 169.2 thousand tons, and in 2015 there was a slight increase again to 223.9

thousand tons, which may be a result of economic growth and intensification of industrial production (Statistical Collection of the Environment of Ukraine for 2015, 2016).

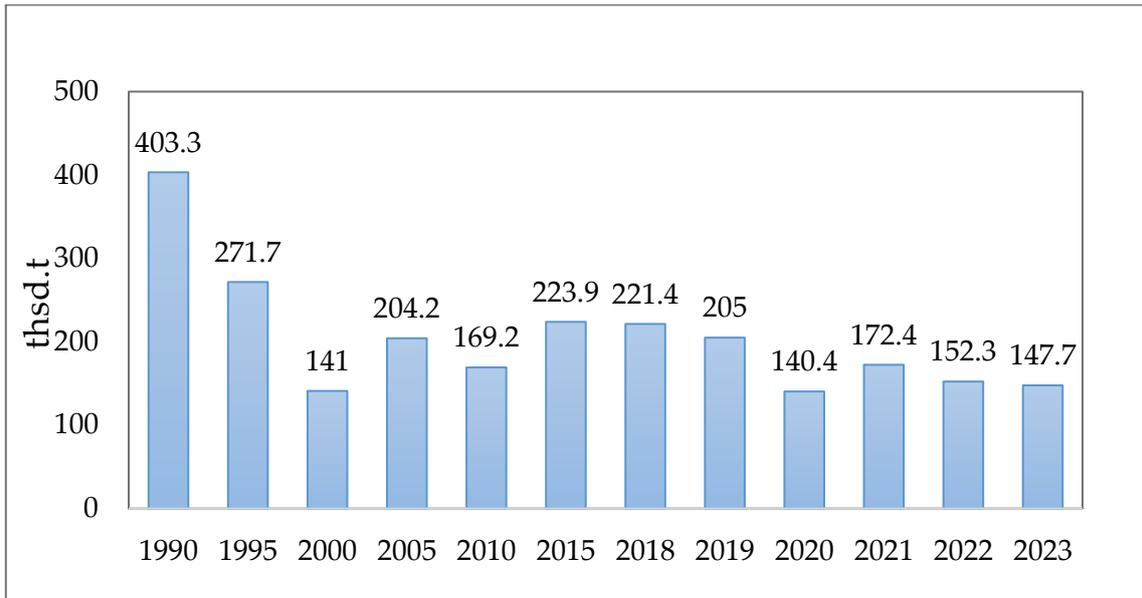


Figure 2. Dynamics of pollutant emissions from stationary sources of pollution into the air of Ivano-Frankivsk region (thousand tons)

The third stage, after 2015, was characterized by volatility of emission levels. After an increase in 2015, emissions declined in 2020 to 140.4 thousand tons (Statistical Digest of the Environment of Ukraine for 2022, 2023), likely due to the economic downturn and lockdown caused by the COVID-19 pandemic. However, after that, there was a slight increase in pollution levels again, indicating a recovery in economic activity and a possible increase in industrial emissions. In 2021, the volume of emissions amounted to 172.4 thousand tons, and in 2022 it decreased again to 152.3 thousand tons (Statistical Collection of the Environment of Ukraine for 2022, 2023).

3.2. Carbon dioxide emissions

The largest amount of carbon dioxide is emitted into the air of Ivano-Frankivsk region. In 2023, stationary sources of pollution accounted for 9.9 million tons (1.10% less than in 2022 and 18% less than in 2021) (Environmental Passport of Ivano-Frankivsk Region for 2023, 2024).

Carbon dioxide is a colorless and odorless gas that is a natural component of the atmosphere. CO₂ is classified as a fourth hazard class substance, which means that it is a low-hazard substance. Carbon dioxide is formed as a result of the combustion of fossil fuels such as coal, oil, natural gas, as well as artificial and synthetic fuels, and biomass such as wood. The danger of increasing the concentration of carbon dioxide in the air lies in its property of being a greenhouse gas, which contributes to the retention of heat on the Earth's surface and thus leads to global warming (Petrovska, 2014; Grigorieva and others, 2023).

An analysis of the dynamics of carbon dioxide (CO₂) emissions from stationary sources of pollution in Ivano-Frankivsk region showed a significant increase in the period from 2010 to 2019, after which fluctuations were observed with a general downward trend (Fig. 3).

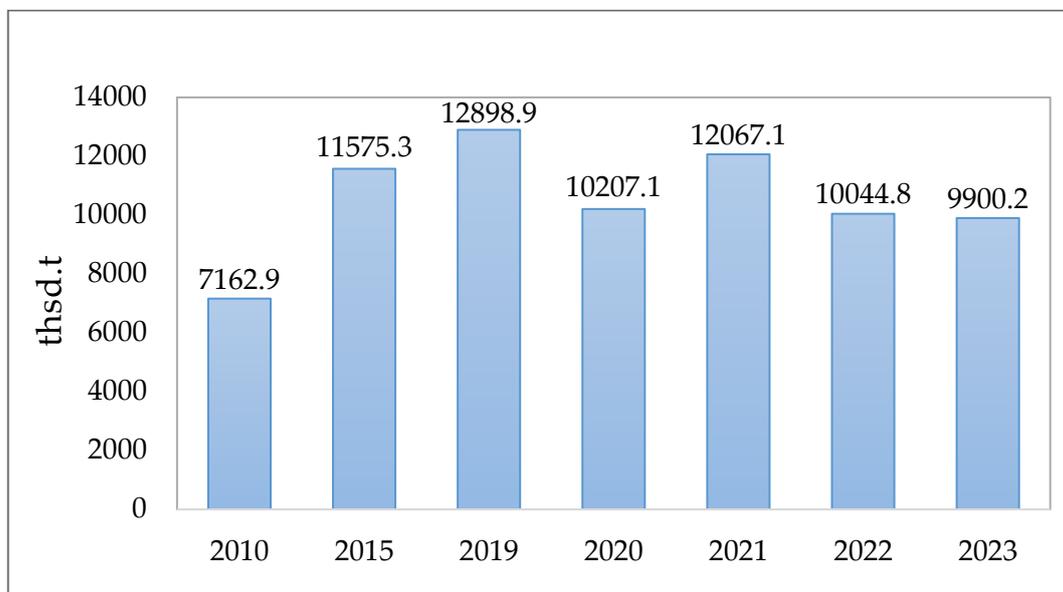


Figure 3. Dynamics of carbon dioxide emissions by stationary sources of pollution into the air of Ivano-Frankivsk region (thousand tons)

In 2010, emissions amounted to 7162.9 thousand tons, but by 2015 they had increased by 38% to 11575.3 thousand tons, which is a significant increase (Statistical Collection of the Environment of Ukraine for 2015, 2016). The highest level was recorded in 2019 – 12898.9 thousand tons, which reflects the maximum intensity of industrial activity for the analyzed period (Statistical collection of the Environment of Ukraine for 2022, 2023).

In 2020, there was a significant decrease in emissions by 21% compared to the previous year, to 10207.1 thousand tons, which was likely due to a decrease in production activity due to the COVID-19 pandemic. In 2021, the level of emissions partially recovered to 12067.1 thousand tons, but after that, in 2022 and 2023, there was a decrease again – to 10044.8 thousand tons and 9900.2 thousand tons respectively (Statistical Collection of the Environment of Ukraine for 2022, 2023).

3.3. Emissions of dioxide and other sulfur compounds

The second place in the structure of emissions in the region was occupied by sulfur dioxide and other sulfur compounds (Environmental Passport of Ivano-Frankivsk region for 2023, 2024).

Sulphur dioxide is an inorganic binary gas that is colorless under normal conditions but has a pungent, suffocating odor. It is formed during the combustion of fuels containing sulfur, especially coal and heavy oil fractions, as well as during various production processes, such as the processing of sulfide ores. This substance is classified as a third hazard class, which indicates its moderate hazard level. Sulphur dioxide has a negative impact on materials, oxidizing them and adversely affecting human health. The time during which this ecotoxicant stays in the atmosphere is relatively short: in clean air – 15–20 days, in the presence of high concentrations of ammonia and other substances – several hours. In the presence of oxygen, SO_2 is converted to SO_3 , which, in interaction with water, forms sulfuric acid. The end products of these reactions are distributed as follows: as precipitation on the surface of the lithosphere – 43%, on the surface of the hydrosphere – 13%; absorbed by plants – 12%, surface water – 13% (Petrovska, 2014). Sulphur dioxide is particularly harmful to woody plants, causing chlorosis (yellowing or discoloration of leaves) and dwarfism. In humans, this gas causes respiratory system diseases, including bronchitis. Toxicity can occur even at low concentrations (20–30 mg/m^3), manifesting itself in an unpleasant taste in the mouth, irritation of the mucous membranes of the eyes and respiratory tract, and reduced resistance to respiratory diseases (Soroka et al., 2023).

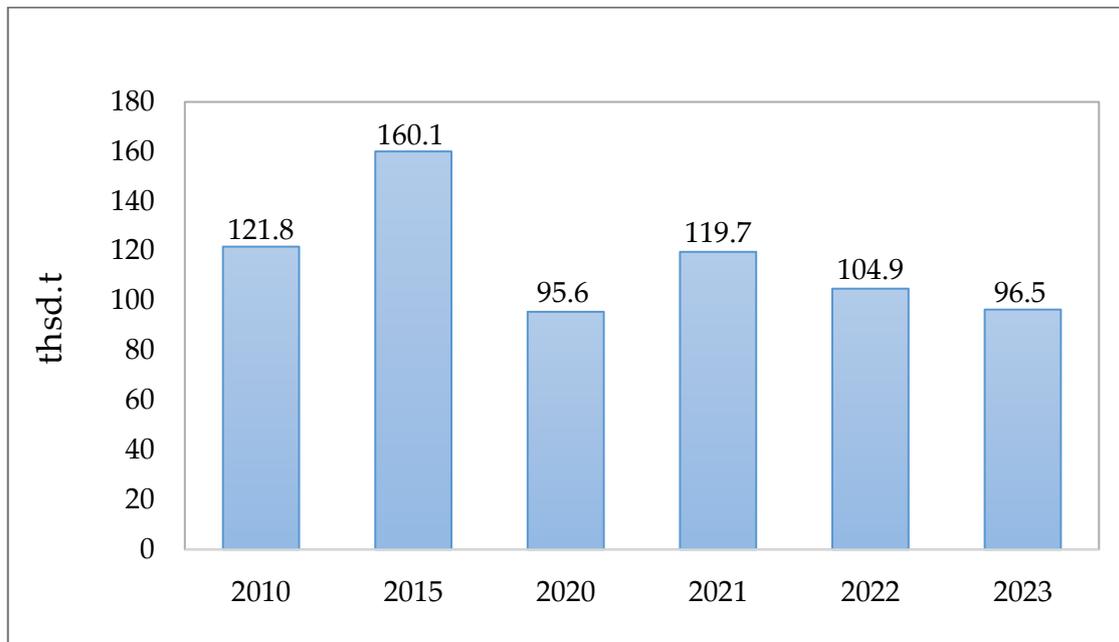


Figure 4. Dynamics of sulfur dioxide emissions into the air in Ivano-Frankivsk region (thousand tons)

The dynamics of sulfur dioxide emissions in Ivano-Frankivsk region is shown in Figure 4. As can be seen from the figure, since 2010 (121.8 thousand tons), emissions have been increasing and peaked in 2015 (160.1 thousand tons) (Statistical collection of the Environment of Ukraine for 2015, 2016). After the peak in 2015, there was a sharp decline to 95.6 thousand tons in 2020, due to the impact of the COVID-19 pandemic and a decrease in industrial activity. In 2021, the figures slightly increased to 119.7 thousand tons, which could be a result of the resumption of production. In 2022 (104.9 thousand tons) and 2023 (96.5 thousand tons), emissions remained relatively low, indicating a decline in industrial production (Statistical Digest of the Environment of Ukraine for 2022, 2023).

3.4. Volumes of emissions of solid suspended particles

Fine dust represents itself as solid particles of different chemical nature, origin and shape that are in the air. This form of pollution is often denoted by the symbols PM_{2.5} PM₁₀, where “PM” means “solid particles” and the numbers indicate the conditional size of the particles in micrometers. Studies confirm the direct negative impact of suspended solid particles in the air on human health in both the short and long term. This impact depends on the size of the particles, their origin, and chemical structure (Adamenko and Arkhipova, 2024).

The dynamics of emissions of particulate matter into the air in Ivano-Frankivsk region showed a significant increase from 2010, when the volume was 17.4 thousand tons, to 2019, when the maximum level of emissions was recorded – 35.2 thousand tons. Particularly notable is the almost twofold increase between 2010 and 2015, when emissions reached 32.9 thousand tons. However, in 2020, the level dropped sharply to 16.8 thousand tons, likely due to the impact of the COVID-19 pandemic and a decrease in industrial activity (Statistical Yearbook of the Environment of Ukraine 2015, 2016; Statistical Yearbook of the Environment of Ukraine 2022, 2023).

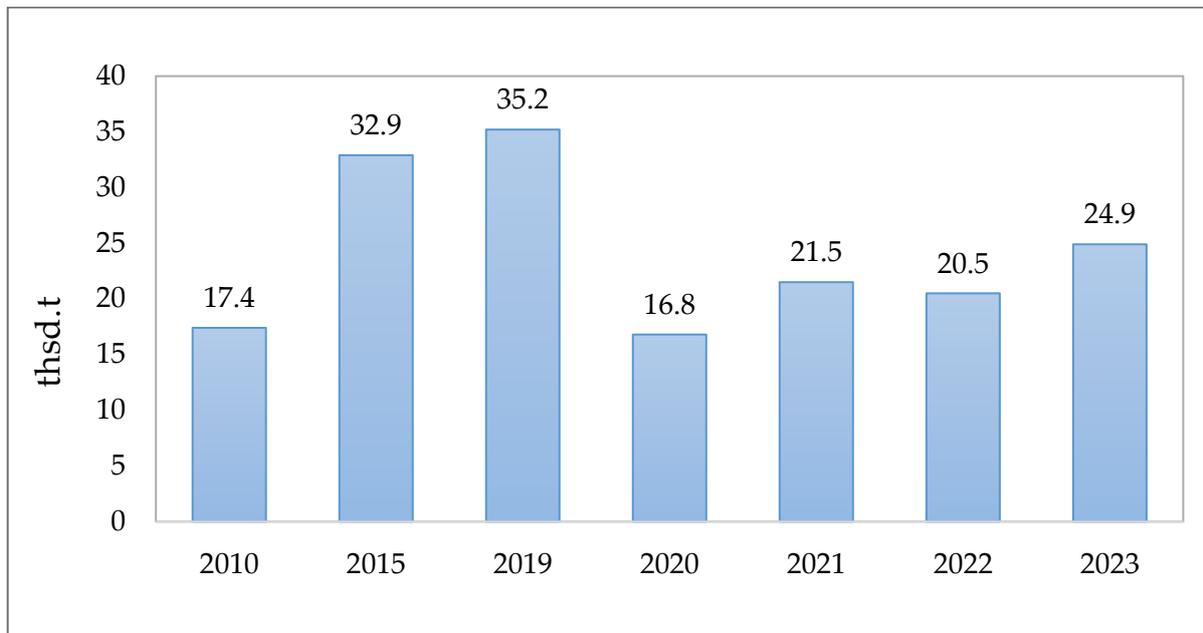


Figure 5. Dynamics of emissions of solid suspended particles into the air in the Ivano-Frankivsk region (thousand tons)

Starting in 2021, emissions have been gradually increasing: in 2021, they amounted to 21.5 thousand tons, in 2022 they slightly decreased to 20.5 thousand tons, and in 2023 they rose again to 24.9 thousand tons. Thus, there is a gradual recovery after a sharp drop in 2020, although the level of emissions remains lower than in 2019 (Fig. 5) (Statistical collection of the Environment of Ukraine for 2022, 2023).

3.5. Emissions of nitrogen compounds

The fourth place in the total amount of emitted pollutants in Ivano-Frankivsk region belongs to nitrogen compounds (Environmental Passport of Ivano-Frankivsk region for 2023, 2024).

Nitrogen creates a wide range of different oxides. However, nitrogen dioxide (NO_2) is of particular interest in terms of air pollution and impact on public health. This gas, which has a reddish-brown color and a pungent odor, is one of the most common air pollutants. It is an oxidizing agent, poorly soluble in water, but reacts with it to form nitric (nitrate) acid. Nitrogen dioxide is mainly formed during natural and anthropogenic combustion processes, and its rapid formation mechanisms are closely related to cyanide radicals (Soroka et al., 2023).

In general, this gas is directly linked to global climate change, photochemical smog, ozone formation, and the formation of secondary particulate aerosols $\text{PM}_{2.5}$ in the lower atmosphere. In urban areas, the concentration of nitrogen dioxide can vary significantly both in time and space. For example, with an average annual nitrogen dioxide concentration of 20 to 90 $\mu\text{g}/\text{m}^3$, the maximum hourly level can exceed 1000 $\mu\text{g}/\text{m}^3$ (Soroka et al., 2023).

Nitrogen dioxide and other nitrogen oxides (in the NO_x group) are formed when nitrogen from the atmosphere is burned or heated to high temperatures: nitrogen from the air reacts with oxygen to form various nitrogen oxides. Natural sources of nitrogen dioxide are fires in ecosystems. However, the main pollution of the atmosphere with these substances is associated with human activity: from various domestic and industrial combustion processes to transportation (in particular, internal combustion engines), from mining to the production of heat and electricity, as well as metallurgical production and other areas (Yatsenko et al., 2018).

Air pollution with nitrogen dioxide has direct and indirect consequences for human health. When inhaled, this substance easily penetrates the bloodstream (up to 90%), which can potentially affect all body systems. The long-term effects of nitrogen dioxide on the human body are not yet

fully understood. In general, this pollutant affects lung metabolism, causes inflammation and swelling of tissues, and increases the vulnerability of the respiratory system to bacterial and viral infections. Thus, nitrogen dioxide air pollution increases the risk of premature mortality from infectious and viral lung diseases, especially among the most vulnerable populations, such as infants and children (Soroka et al., 2023).

Nitrogen dioxide enhances the toxic effects of other air pollutants, such as PM, ozone, volatile organic compounds, sulfur anhydride, etc., showing an additive and synergistic effect (Calderón-Garcidueñas et al. (2021).

The analysis of the dynamics of nitrogen oxides emissions into the atmosphere from stationary sources of pollution in Ivano-Frankivsk region showed variability in the period from 2010 to 2023 (Fig. 6).

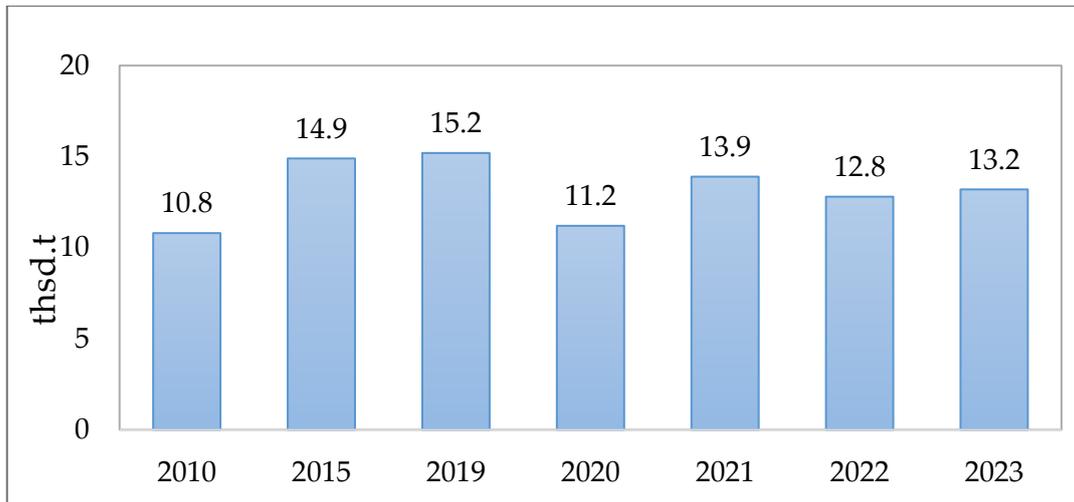


Figure 6. Dynamics of nitrogen oxides emissions into the air in Ivano-Frankivsk region (thousand tons)

In 2010, emissions amounted to 10.8 thousand tons, after which there was a gradual increase to 14.9 thousand tons in 2015 and 15.2 thousand tons in 2019, which was the maximum level for the analyzed period. However, in 2020, emissions decreased to 11.2 thousand tons (Statistical Yearbook of the Environment of Ukraine for 2015, 2016; Statistical Yearbook of the Environment of Ukraine for 2022, 2023), likely due to the impact of restrictions related to the COVID-19 pandemic.

After 2020, emissions began to recover: in 2021, they reached 13.9 thousand tons. In 2022, there was a slight decrease to 12.8 thousand tons, and in 2023, a slight increase to 13.2 thousand tons (Statistical Digest of the Environment of Ukraine for 2022, 2023).

4. CONCLUSIONS

Thus, in the structure of air emissions in Ivano-Frankivsk region in 2023, the following pollutants dominated: carbon dioxide (9.9 million tons), sulfur dioxides and other compounds (96512.1 tons), substances in the form of solid suspended particles (24903.1 tons), nitrogen compounds (13177.8 tons).

Three stages can be distinguished in the dynamics of pollutant emissions from stationary sources in Ivano-Frankivsk region from 1990 to 2023. Each stage of the emissions dynamics indicates a close connection between social and economic changes in the region and the country, the introduction of environmentally friendly technologies, and the level of pollution. In particular, during the 1990s, when emissions were highest, this process reflected intensive industrialization and high energy consumption from traditional sources such as coal and oil. The economic downturn after the collapse of the USSR led to a reduction in production and emissions, which contributed to a significant improvement in the environmental situation in the region.

The introduction of cleaner technologies in industry, particularly in the energy sector, has been an important factor in reducing pollution. However, periods of economic growth, such as in the mid-2010s, have led to some increase in emissions due to the recovery of industrial production, increased transportation and other energy consumers using traditional energy sources.

The COVID-19 pandemic in 2020 was an important factor in the significant decline in emissions, as economic activity temporarily halted due to lockdowns, leading to a reduction in emissions from industrial plants and transportation. This shows how much the level of pollution depends on economic activity and the structure of the economy.

Recent years (2021-2023) have seen a recovery in economic activity after the pandemic, which has led to some increase in emissions, but they are still significantly lower than in the 1990s. This emphasizes the importance of implementing sustainable environmental practices to ensure that pollution continues to decrease as economic activity increases. Therefore, the future requires the continued development and application of innovative and energy-efficient technologies, as well as an increased role of environmental awareness in the management of industrial processes and the transportation system to achieve sustainable development in the region.

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Мельниченко Р.Б., Микитин Т.В., Мельниченко Г.М., Козарук Р.В., Мельниченко В.Б. Аналіз статистичних показників викидів забруднюючих речовин в атмосферне повітря Івано-Франківської області. *Журнал Прикарпатського університету імені Василя Стефаника. Біологія*, **11** (2024), С.136–С.145.

Анотація. У статті досліджується актуальна проблема забруднення атмосферного повітря в Івано-Франківській області, зумовлена антропогенними чинниками. Основна увага приділена аналізу структури та динаміки обсягів викидів забруднюючих речовин від стаціонарних джерел, зокрема діоксиду вуглецю, сполук сірки, твердих суспендованих частинок, азоту та інших речовин. Представлено аналіз тенденцій сумарного забруднення за період з 1990 до 2023 року, враховуючи економічні, соціальні та екологічні чинники. Виявлено, що у 2023 році загальний обсяг викидів від стаціонарних джерел зменшився на 3,02% порівняно з 2022 роком і склав 147,7 тис. тонн. Основним забруднювачем залишається діоксид вуглецю (9,9 млн тонн), що є основним парниковим газом і сприяє зміні клімату. Досліджено структуру викидів інших забруднюючих речовин: значну частку складають діоксиди сірки (65%), тверді суспендовані частинки (17%), сполуки азоту (9%), метан (4%), а також неметанові леткі органічні сполуки (3%). Наведено динаміку змін рівнів викидів у контексті економічних, екологічних та технологічних факторів, включно з впливом пандемії COVID-19. Особливу увагу приділено аналізу викидів діоксиду азоту, діоксиду сірки, твердих суспендованих частинок, оксидів азоту їхньому впливу на екосистеми та здоров'я населення. Результати дослідження свідчать про поступове зменшення забруднення атмосферного повітря в області, що є наслідком зниження обсягів викидів діоксиду вуглецю, та діоксиду сірки, проте обсяги викидів твердих суспендованих частинок, оксидів азоту за останні роки зросли. Тому для області залишається актуальним питання розвитку альтернативної енергетики, впровадження новітніх технологій очищення викидів, популяризація екологічно чистого транспорту та посилення екологічного моніторингу.

Ключові слова: забруднення атмосферного повітря, структура викидів, динаміка викидів, Івано-Франківська область.