Forecasting factors influence on climatic changes as a part of Sustainable Development Goals 2030

Report with recommendation

Cover design
Wojciech Ciągło Studio DTP, www.dtp-studio.pl

Typesetting
Wojciech Ciągło Studio DTP, www.dtp-studio.pl

ISBN 978-83-67673-52-5

Publisher
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www.wsb.edu.pl

Dąbrowa Górnicza 2024

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Financed by the Visegrad fund Project ID #/Title: 22320037,
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Visegrad Fund

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Introduction

Sustainable development is an economic doctrine that aims to maintain the quality of life at the level of current civilizational development. The concept of sustainable development addresses the issues faced by the modern world. It was established through the activities of the World Commission on Environment and Development, also known as the Brundtland Commission, which was formed in 1983. According to the UN document “Our Common Future” (1987), sustainable development is defined as a form of development where the needs of the present generation can be met without compromising the ability of future generations to meet their own needs. It was recognized that civilization has reached a level of prosperity that can be maintained provided that environmental and climate resources are respected. In social sciences, there is no clear definition of quality of life, which is understood in terms of a compromise between “having more” and “being more.” A key goal of sustainable development is to improve the quality of life, interpreted as “a set of factors determining the objective conditions of life and subjectively perceived well-being.” The complex concept of sustainable development is analyzed in three dimensions: economic, social, and environmental. Economically, it concerns GDP growth, which ensures an adequate amount of goods and services. Socially, it involves meeting basic social needs, improving the quality of life, and reducing unemployment. Environmentally, it pertains to improving the state of the natural environment, preserving natural capital, and protecting biodiversity. Such sustainable production and consumption should be based on ecological responsibility and mutual benefits arising from international integration and the reduction of social inequalities. The lack of such balance leads to the generation of high external costs.

The idea of sustainable development is aptly captured by the statement from the World Commission on Environment and Development’s 1987 report, “Our Common Future”: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Sustainable development is about intergenerational solidarity, finding solutions that ensure continued growth while allowing all social groups to actively participate in developmental processes and benefit from economic growth.

Initially, discussions around sustainable development were limited to the need to reduce the negative impact of economies on the natural environment. Over the years, the concept has gained a fuller understanding, balancing the essence of three factors of development: respect for the environment, social progress, and economic growth. Today, the concept of sustainable development increasingly enters the mainstream discourse on socio-economic development, becoming a horizontal principle reflected in all of the country's development policies.

The 2030 Agenda for Sustainable Development, adopted in 2015 by 193 United Nations member states, is a program of action with unprecedented scope and significance, defining a model of sustainable development on a global scale. According to the 2030 Agenda, modern modernization efforts should focus on eliminating poverty in all its forms while simultaneously achieving a range of economic, social, and environmental goals.

The 2030 Agenda is universal, horizontal, and highly ambitious. It includes 17 Sustainable Development Goals (SDGs) and 169 associated targets, which reflect the three dimensions of sustainable development: economic, social, and environmental.

The new vision of world development outlined in the 2030 Agenda focuses on five major transformational shifts, referred to as the 5P principle (People, Planet, Prosperity, Peace, Partnership):

- **People:** Ensuring no one is left behind by reaching out to excluded groups, creating conditions, and opportunities for all people to enjoy universal human rights and economic achievements.
- **Planet:** Building a development model that fosters economic growth, greater social inclusion, and the rational use of natural resources, leading to improved quality of life and poverty alleviation.
- **Prosperity:** Transforming economies to create jobs and ensure inclusive development, leveraging new technologies and business potential, and providing access to quality education, healthcare, and infrastructure.
- **Peace:** Building peace and effective, just, open, and accountable institutions that guarantee the rule of law, social inclusion, participation, access to justice, and non-discrimination.
- **Partnership:** A new global partnership based on solidarity, cooperation, responsibility, and transparency in the actions taken by all stakeholders at both global and local levels.

Sustainable Development Goals

The Sustainable Development Goals (Figure 1) are ambitious because no country can meet all the requirements and achieve all the goals. They are universal because the requirements and guidelines are the same for every country, whether developed or developing. The SDGs are interconnected in such a way that they form a cohesive whole, making it difficult to implement a single goal in isolation. There are a total of 17 goals, 169 targets, and 230 indicators.

Figure 1. Sustainable Development Goals

Each country is obligated to implement the SDGs at the global, national, or regional level. These goals must be compatible with the specific goals set in each country or region, and their implementation will be appropriate to the capabilities and realities of the given state. Monitoring, verification, and reporting are also crucial. An increasing number of countries are required to report on sustainable development at the level of publicly listed companies or large enterprises.

The Strategy for Responsible Development (Figure 2) places the individual at the center of direct interest, subordinating economic actions to achieving goals related to the level and quality of life of citizens. Expected outcomes, such as reducing social exclusion, poverty, social inequalities, improving healthcare, and the state of the natural environment, as well as enhancing the role of social capital in development, align with the provisions of the 2030 Agenda.

Figure 2. Strategy for Responsible Development

Strategy for Responsible Development

Building a strong industry based on scientific and technological achievements, as well as creating jobs tailored to diverse needs, are just general assumptions of the strategy. Equal access to digital resources and IT tools, clean energy, zero-emission transport, environmental remediation, personal safety, as well as social inclusion and equality, are just some of the elements of the strategy that must be realized. The last decade has been the warmest in the history of meteorological measurements. The average global temperature was about 1°C higher than in the pre-industrial period, with temperatures in Europe increasing by nearly 2°C. At the same time, precipitation is irregularly distributed over time and space and is more intense than in previous years. Due to climate change, we increasingly experience extreme weather events. According to the European Environment Agency, between 2010 and 2020, Poland incurred financial losses exceeding €3 billion (equivalent to €88 per capita) due to these events. Mitigating climate change and protecting the natural environment for future generations are urgent challenges posed by the 2030 Agenda [5].

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Current environmental situation and future action in the area of climate change based on sustainable development in Poland

Poland faces several significant environmental challenges, primarily related to air pollution, greenhouse gas emissions, and the impacts of climate change. The country has long been reliant on coal for energy production, which has led to high levels of CO2 emissions and air pollution. Despite efforts to diversify the energy mix, coal still accounts for about 70% of electricity generation, making Poland one of the most carbon-intensive economies in Europe.

Air Quality: Poland struggles with some of the worst air quality in the European Union, particularly during the winter months. The burning of coal and wood in households for heating, combined with emissions from coal-fired power plants and industrial activities, leads to high concentrations of particulate matter (PM10 and PM2.5) and other pollutants like sulfur dioxide (SO2). These pollutants contribute to severe health problems, including respiratory and cardiovascular diseases, and have a significant impact on public health.

Greenhouse Gas Emissions: Poland's greenhouse gas emissions have decreased since the early 1990s, largely due to economic restructuring and improvements in energy efficiency. However, the pace of reduction has slowed, and the country still faces challenges in meeting its climate targets. Poland's heavy reliance on coal, coupled with slow progress in expanding renewable energy sources, poses a barrier to further reducing emissions.

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Climate Change Impacts: Poland is increasingly experiencing the effects of climate change, including rising temperatures, changes in precipitation patterns, and more frequent extreme weather events such as heatwaves, droughts, and floods. These changes are already affecting agriculture, water resources, and human health. For instance, the agricultural sector, which is vital to Poland's economy, is particularly vulnerable to climate variability, with droughts leading to reduced crop yields and financial losses for farmers.

Future Actions in the Area of Climate Change Based on Sustainable Development

Poland's approach to climate change and sustainable development is guided by both national policies and international commitments, such as the European Green Deal and the Paris Agreement. The country is gradually shifting towards a more sustainable development model, although challenges remain.

Energy Transition: One of the key areas for future action is the transition from coal to cleaner energy sources. Poland has set targets to increase the share of renewables in its energy mix, particularly wind and solar power. The government has also announced plans to phase out coal by 2049, with a focus on expanding renewable energy infrastructure and developing nuclear energy as a low-carbon alternative. Additionally, Poland is investing in energy efficiency measures, particularly in building insulation and industrial processes, to reduce overall energy consumption and emissions.

Climate Policies and Strategies: Poland has developed several strategic documents to address climate change, including the National Energy and Climate Plan (NECP) and the Polish Energy Policy until 2040 (PEP2040). These plans outline the country's goals for reducing greenhouse gas emissions, increasing the use of renewable energy, and enhancing energy security. PEP2040, for example, envisions a significant reduction in coal usage, with renewables expected to account for 32% of electricity production by 2030.

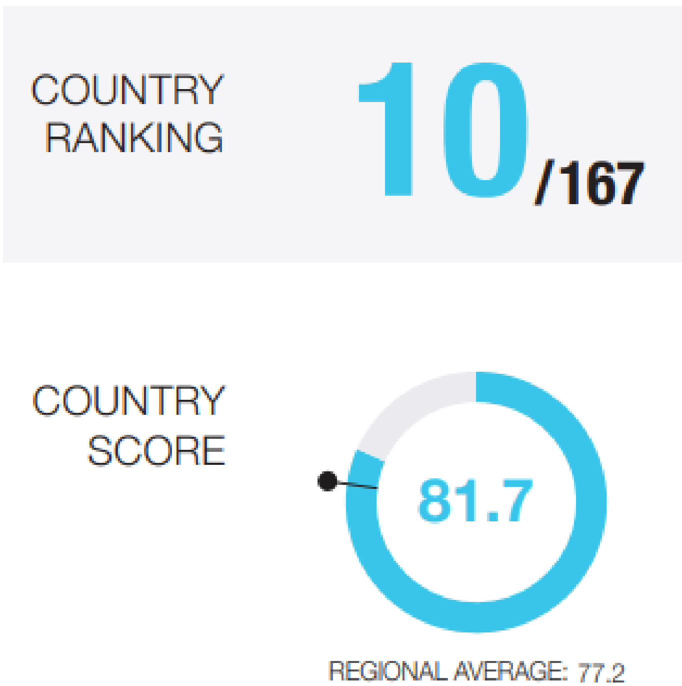
Sustainable Development Goals (SDGs): Poland is committed to the United Nations' 2030 Agenda for Sustainable Development, which includes 17 Sustainable Development Goals (SDGs). Within this framework, Poland is focusing on goals related to clean energy (SDG 7), climate action (SDG 13), and sustainable cities and communities (SDG 11). These efforts are aligned with broader EU policies aimed at achieving climate neutrality by 2050.

Public Awareness and Participation: There is also a growing emphasis on increasing public awareness and participation in climate action. The Polish government, along with various non-governmental organizations (NGOs), is working to educate the public about the importance of sustainable practices and the impacts of climate change. This includes promoting energy-saving behaviors, supporting local renewable energy projects, and encouraging sustainable transportation options.

Adaptation to Climate Change: Poland is also focusing on adapting to the inevitable impacts of climate change. This involves improving water management to address issues like droughts and floods, enhancing infrastructure resilience, and supporting farmers with climate-smart agriculture practices. The government is working on a National Adaptation Strategy, which will outline specific measures to protect key sectors, such as agriculture, water, and health, from the adverse effects of climate change.

Poland is at a critical juncture in its efforts to address environmental challenges and move towards a more sustainable future. While significant progress has been made, particularly in setting ambitious targets and developing strategic plans, the transition away from coal and the broader implementation of sustainable development practices will require continued effort and investment. Achieving these goals will not only benefit the environment but also improve public health, economic stability, and social equity, ensuring a better quality of life for future generations.

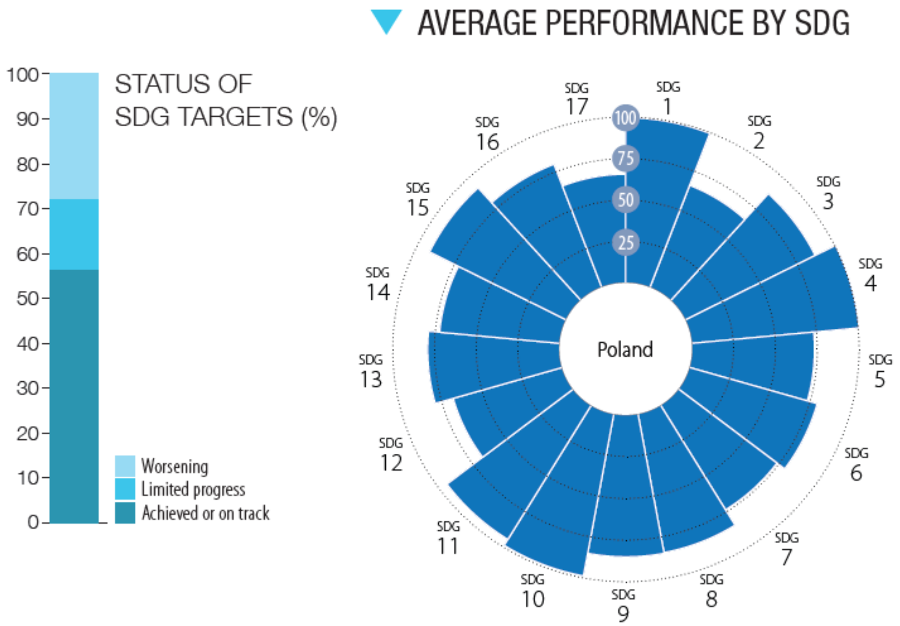
Figure 3. Polish achievements in the sustainable development goals



Source: https://dashboards.sdgindex.org/

Poland was one of 10 countries to achieve more than 80 per cent of the targets in the sustainable development goals according to Agenda 2030. The average achievement of this indicator was about 77% in other countries (Fig. 3).

Figure 4. Average performance by SDG in Poland



Source: https://dashboards.sdgindex.org/

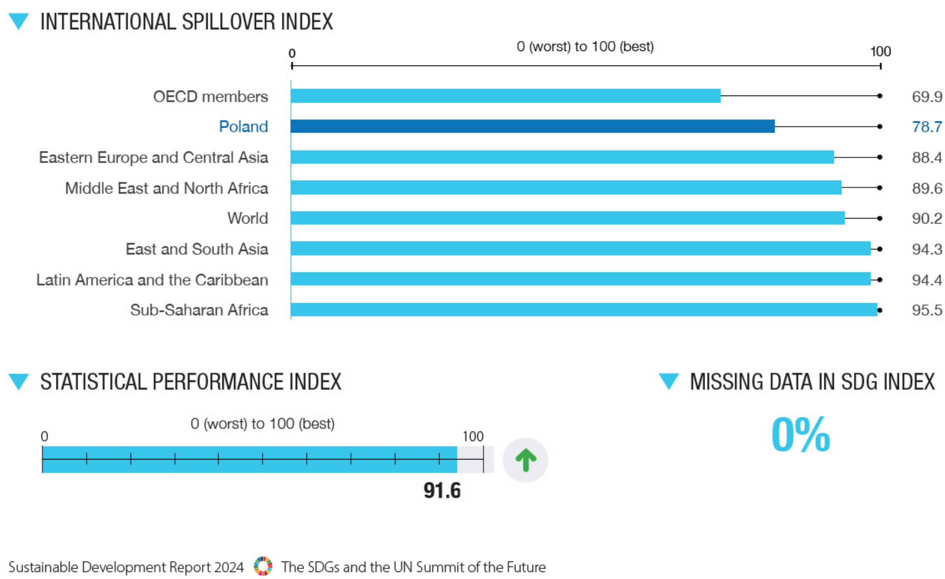
Poland has the highest attainment of the sustainable development goals in goals 1, 4 and 10. Poland has the lowest attainment of goals 2, 12 and 17 (Fig. 4).

Figure 5. SDG dashboards and trends in Poland

Source: https://dashboards.sdgindex.org/

Figure 5 shows the trends in the achievement of the individual targets in Poland. Marked with a green arrow pointing upwards, the sustainable development goals are those whose trends are upward. In the case of Poland, no downward trend was found, marked with a red downward arrow.

Figure 6. SDG indexes in Poland



Source: https://dashboards.sdgindex.org/

The performance and impact indicators of the Sustainable Development Goals presented in Figure 6 show that Poland's contribution to the Sustainable Development Goals is very high compared to countries around the world, above all the OECD member countries. The statistical performance index for Poland is as high as 91.6%, which indicates an increasing trend in the implementation of the sustainable development goals.

Figure 7. Details about 13th SDG in Poland in years 2021–2023

SDG13 – Climate Action				
CO_2 emissions from fossil fuel combustion and cement production (tCO_2/capita)	8.5	2022	● (red)	↓
GHG emissions embodied in imports (tCO_2/capita)	3.5	2021	● (orange)	→
CO_2 emissions embodied in fossil fuel exports (kg/capita)	287.4	2023	● (yellow)	● (grey)
Carbon Pricing score at EUR60/tCO_2 (%, worst 0–100 best)	61.4	2021	● (yellow)	↑

Source: https://dashboards.sdgindex.org/

The chart (Fig. 7.) presents data related to Climate Action (SDG 13) across several key areas, such as CO_2 emissions, greenhouse gas (GHG) emissions associated with imports and exports, and the evaluation of carbon pricing mechanisms. It includes data from the years 2021–2023, detailed in four categories:

CO_2 emissions from fossil fuel combustion and cement production (tCO_2/capita): 8.5 tCO_2 per capita (2022). Decrease (indicated by a red arrow pointing down), suggesting that these emissions have decreased compared to the previous period but remain relatively high.

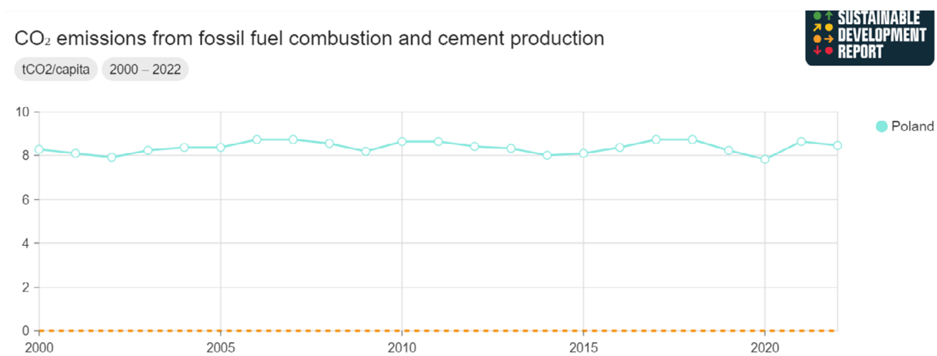
GHG emissions embodied in imports (tCO_2/capita): 3.5 tCO_2 per capita (2021). Stable (indicated by an orange arrow pointing right), meaning there hasn't been a significant change in greenhouse gas emissions related to imports compared to previous years.

CO_2 emissions embodied in fossil fuel exports (kg/capita): 287.4 kg CO_2 per capita (2023). Grey marking (no trend indicated), suggesting this is reference data with no previous figures available for comparison.

Carbon Pricing score at EUR60/tCO_2 (%): 61.4% (2021). Increase (green arrow pointing up), indicating that carbon pricing policies have improved compared to earlier data, approaching the maximum score of 100%.

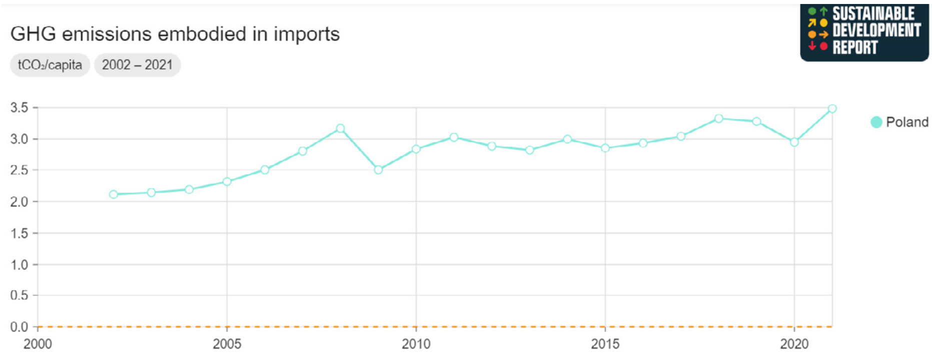
Overall, this data shows both progress and areas that need further action in climate policy, such as high emissions from fossil fuel combustion and moderate improvement in carbon pricing mechanisms.

Figure 8. Details data in Poland



Source: https://dashboards.sdgindex.org/

Figure 9. Details data in Poland



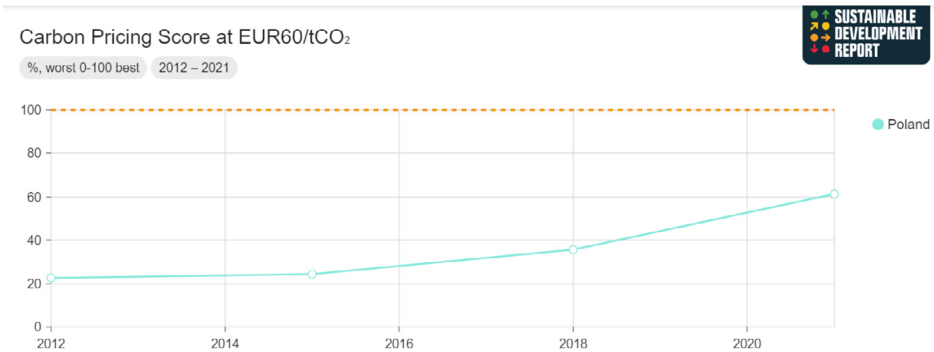
Source: https://dashboards.sdgindex.org/

The following charts (Fig. 8. And Fig. 9.) relate to greenhouse gas emissions in Poland and show two different indicators: CO_2 emissions from fossil fuel combustion and cement production, and greenhouse gas emissions associated with imports. Over the period from 2000 to 2022, emissions remained relatively stable, hovering around 8–9 tCO_2 per person. There are minor changes, with a slight decreasing trend around 2013, after which emissions began to rise again, reaching levels close to previous ones. Despite efforts to protect the environment, CO_2 emissions in Poland have not significantly decreased during this period, indicating challenges in decarbonizing the energy and industrial sectors.

From 2002 to 2021, emissions related to imports increased (Fig. 9.). The most significant rise occurred between 2002 and 2008, where emissions increased from about 2.5 to 3.5 tCO_2 per person. From around 2010 to 2020, emissions stabilized between 3 and 3.2 tCO_2 per capita, with some fluctuations. In 2021, there was a renewed increase in emissions to a level of 3.5 tCO_2 per person, indicating the growing impact of imports on Poland's greenhouse gas emissions balance. Poland imports more and more goods that generate greenhouse gas emissions in producing countries. This highlights the increasing importance of emissions related to global supply chains and the need for responsible importing. Both charts highlight challenges related to reducing greenhouse gas emissions in Poland. Emissions from fossil fuels and cement remain high, and Poland is also experiencing growth in emissions related to imports. This suggests that Poland needs to focus on energy transformation, reducing industrial emissions, and ensuring sustainable imports to meet climate goals.

CO_2 emissions embodied in the exports of coal, gas, and oil (Fig. 10.). Calculated using a 5-year average of fossil fuel exports and converting exports into their equivalent CO_2 emissions. Exports for each fossil fuel are capped at the country's level of production. Emissions from the combustion and oxidation of fossil fuels and from cement production. The indicator excludes emissions from fuels used for international aviation and maritime transport. CO_2 emissions embodied in imported goods and services. The Carbon Pricing Score (CPS) measures the extent to which countries have attained the goal of pricing all energy-related carbon emissions at certain benchmark values for carbon costs, across all sectors, including emissions from the combustion of biomass. The more progress that a country has made towards a specified benchmark value, the higher the CPS. For example, a CPS of 100% against a EUR 60 per tonne of CO_2 benchmark means that the country (or the group of countries) prices all carbon emissions in its (their) territory from energy use at EUR 60 or more.

Figure 10. Carbon pricing Score in Poland



Global actions SDGs – Goal 13 indicators

13.1.1 Number of deaths or affected by disaster per 1 million people

13.1.2 Countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030

13.1.3 Local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies

13.2.1 Number of countries with nationally determined contributions, long-term strategies, national adaptation plans, strategies as reported in adaptation communications and national communications

13.2.2 Total greenhouse gas emissions per year

13.3.1 Extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment

13.b.1 Number of least developed countries and small island developing States with nationally determined contributions long-term strategies, national adaptation plans, strategies as reported in adaptation communications and national communications

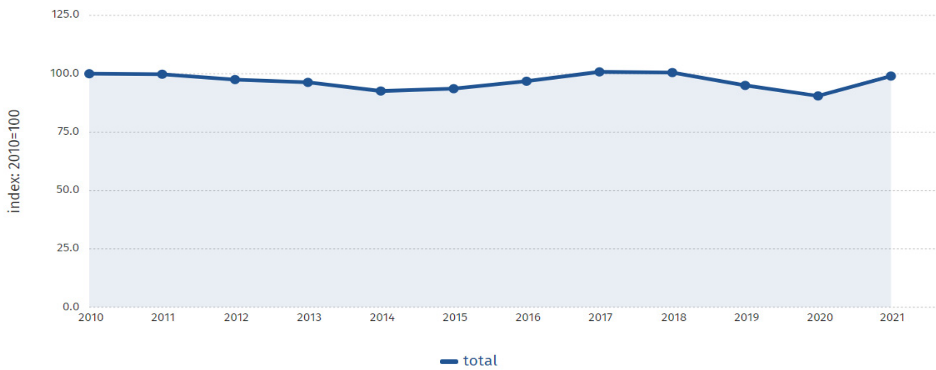
Priorities for Poland in Goal 13

Priorities for Poland	Indicators
Effective reduction of CO_2 concentration in the atmosphere	13.1.a Carbon dioxide (CO2) emissions (2010=100) 13.1.b Greenhouse gas emissions (2010=100)
Introduction of innovative technologies for exploiting available sources of energy, including development of geothermy	13.2.a Renewable energy share in the gross final energy consumption 13.2.b Production of geothermal energy 13.2.c Installed renewable energy capacity
Enhancement of the role of adaptation to climate change as a means of combating climate change equivalent to mitigation	13.3.a Air quality indicator (46 zones of the country where air quality assesment is made) 13.3.b National indicator of average exposure to PM2.5 13.3.c Total emissions of major air pollutants from households 13.3.d Emissions of pollutants from means of road transport
Increasing the country's resilience to the effects of climate change	13.4.a Share of green areas in the total area 13.4.b Capacity of small water retention facilities 13.4.c Length of the coastline protected during a year from the sea erosion and flood
Incorporating actions to combat climate change into national policies, strategies and plans	13.5.a Share of inhabitants of Polish cities covered by the Urban Adaptation Plans
Education and raising awareness in the field of: climate change and ways to minimize its effects, the impact of invasive alien species and the importance and necessity of saving resources, especially water	13.6.a Number of conducted educational campaigns promoting issues related to the problem of invasive alien species entering the natural environment 13.6.b Extent of implemented educational and informational projects

Indicator 13.1.a – Carbon dioxide (CO_2) emissions (2010=100)

Air pollution means the introduction by human, directly or indirectly, into the air of solid, liquid or gaseous substances in such quantities as to endanger human health, adversely affect the climate, living nature, soil or water, or cause other damage to the environment (Fig. 11.).

Figure 11. Carbon emissions in Poland

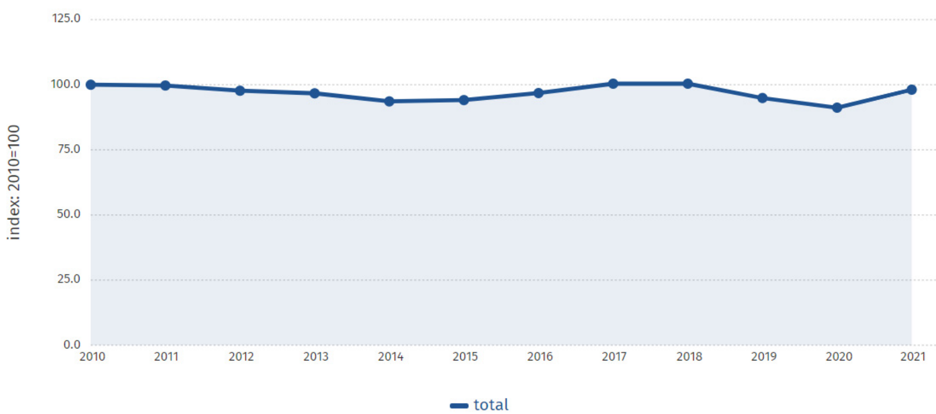


Indicator 13.1.b – Greenhouse gas emissions (2010=100)

Greenhouse gases are components of the Earth›s atmosphere, which due to their physicochemical properties have the ability to retain solar energy within the Earth›s atmosphere, contributing to global warming. Greenhouse gases refer to carbon dioxide (CO_2), methane (NH_4), nitrous oxide (N_2O) and industrial gases: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). Greenhouse gases remain in the atmosphere for several years to thousands of years. They have an impact on the global climate, regardless of where they are emitted (Fig. 12).

The indicator is calculated excluding the balance of CO_2 emissions and removals from the LULUCF sector (land use, land use change and forestry) and including indirect CO_2 emissions.

Figure 12. GHGs emissions in Poland



Conclusion

- Poland's real gross domestic product increased by 46% in the years 2010–2021, and economic growth was accompanied by a more effective use of material resources and water and reduced emissions of greenhouse gases.
- In the year 2020, the COVID-19 pandemic broke out, causing unprecedented limitations of social and economic activity in many countries.
- In Poland, this caused a short-lived, although serious, deterioration in the macroeconomic performance, and may have also affected the extent to which the economy influenced the environment.
- Energy in Poland is produced mainly from fossil fuels.
- Until 2015, the Polish economy had been generating increasing amounts of waste each year, but after that date, its volume started gradually decreasing. Both in 2020 and in 2021, less waste was produced than in 2010.
- In the 2010–2020 period, the volume of air pollution produced by the energy sector was gradually decreasing in Poland, thanks to which in 2020, 30% less particulate matter (PM2.5 and PM10 each) and 10% less greenhouse gases were released into the atmosphere than in 2010.
- The recycling indicator grew from 16% in 2010 to 39% in 2020. However, it is still lower in Poland than in the EU, where on average 48% of municipal waste is reused (in 2010 it was 38%).
- New regulations on selective waste collection and segregation.
- Poland has no operating nuclear power plants.
- A prohibition on the production of internal combustion vehicles from 2035
- Development of charging infrastructure for electric vehicles
- Development of hydrogen technology

Recommendations

Proposal of economic, environmental and social indicators in collection data for new methodology of integral assessment of the potential for reducing greenhouse gas emissions.

Economic Indicators

- Gross value added at basic prices, mln (PLN)
- GDP per capita, (PLN)
- Electric power for goods and services production, kW
- *Energy intensity of GDP, ktoe / (PLN)**
- Natural gas consumption per 1 PLN of gross value added, thousand m^3 per PLN
- Road freight transport, thousand tons, kt
- Transport, storage, postal, and courier activities, mln. PLN
- Manufacturing, mln. PLN

- Mining and quarrying, mln. PLN
- Production and supply of electricity, gas, steam, and air conditioning, mln. PLN
- Waste generation, thousand tons
- Amount of waste incinerated, thousand tons
- Total amount of waste accumulated during operations in specially designated places and facilities, thousand tons
- Natural gas consumption, billion m^3

Environmental Indicators

- Forest area, % of land area
- Nitrogen fertilizer consumption, 1000 t N
- Nitrogen fertilizer consumption per unit of agricultural land, kg N per hectare
- Total organic fertilizer consumption, 1000 t
- Organic fertilizer consumption per unit of agricultural land, kg per hectare
- Share of area treated with organic fertilizers in total agricultural land area, %
- Fertilizer consumption per unit of planted area, kg per hectare
- Use of inorganic fertilizers for maize, kg per hectare
- Use of inorganic fertilizers for industrial crops, kg per hectare
- Use of inorganic fertilizers for fodder crops, kg per hectare
- N2O emission intensity, tons / 1 mln PLN of production
- CO2 emission intensity, tons / 1 mln PLN of production
- CO2 emissions per unit of gross value added, tons / t CO2/PLN
- CO2 emissions per unit of GDP, tons / mln. PLN
- Total greenhouse gas emissions, Mt CO2-eq.
- Emissions per capita, tons / capita
- CO2 emissions from road transport, total, thousand t

Social Indicators

- Income disparity among the population, disposable
- Income per capita, (PLN)
- Population growth, persons
- GDP per capita, (PLN)
- Population distribution by age 15–64 years, persons
- Vegetable consumption per capita, kg/year
- Milk and dairy product consumption per capita, kg/year
- Safety and quality of drinking water by radiation indicators, % of non-standard samples
- Safety and quality of drinking water by organoleptic, physicochemical, sanitary, and toxicological indicators, % of non-standard samples

The collection of data in the Polish holdings needs to be supplemented by individual requests for data of a specific category to institutions designated to collect these collections.

Clarification or determination of the value of a cell when data are missing for the time period or specific year under study (0 or no value).

Wider analysis of data from different datasets or resources and their proper assignment to a group of relevant indicators (economic, environmental, social).

Summary

To improve the data collection process in Polish holdings, it's crucial to supplement existing data by directly requesting specific categories of information from institutions responsible for maintaining these datasets. When data is missing for a particular time period or year, efforts should be made to clarify or assign appropriate values, ensuring consistency (e.g., assigning a value of 0 or indicating no data available). Moreover, conducting a more comprehensive analysis across different datasets is recommended, ensuring that data is accurately classified into relevant groups—economic, environmental, or social indicators—to provide a clearer, more holistic understanding of the trends and patterns. This approach will enhance the reliability and usability of the data for informed decision-making and policy development.

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Implementation of the Waste Management Plan of the Moravian-Silesian Region focused on municipal waste

Introduction

The design part of the study will propose solutions to key problems of municipal waste management.

The identified fundamental problem of municipal waste management is the management of mixed municipal waste. The draft part of the study also respects and respects the waste management hierarchy and will implement the commitments of Directive 2018/851 of the European Parliament and of the Council. Nevertheless, the proposal part will not primarily deal with the management of other groups of municipal waste, the solution and implementation of which is carried out satisfactorily and in the long term, regardless of recommendations or other findings from the study. This category includes, for example, separately collected commodities, including separately collected biodegradable municipal waste (hereinafter referred to as BRKO). For these types of waste, basic recommendations will be defined in the design part, but they will not be a priority target group for solutions and alternatives and comments of the proposal part.

The proposed solution will be based on the current system of municipal waste and similar waste management, it will respect the current and expected requirements for

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waste management, while applying the principles of the circular economy within the economy of the Moravian-Silesian Region (hereinafter referred to as MSK) and its expected changes.

The study is an independent opinion of an expert processor, which is based, among other things, on long-term experience with the preparation of similar conceptual documents. The facts in the study are therefore not the opinion of the Moravian-Silesian Region, but are the basis and guidance for it on how to continue the set trends and obligations in dealing with municipal waste management.

1. Waste management as a part of the economy of the Moravian-Silesian Region

If we conceive of waste as a specific type of raw material and as part of the circular economy, then in a broader context we must talk about a comprehensive concept of the economy of the Moravian-Silesian Region.

The current phase of the region's economy can be characterized as dynamically developing with significant elements of restructuring and transformation.

Brief characteristics of the MSK economy:

- in principle, the privatisation of former state-owned enterprises has been completed – not always successfully and effectively,
- the transformation and stabilization of the economy of the Moravian-Silesian Region is underway,
- promising enterprises of traditional industry are stabilized,
- new industries and new firms are developing,
- new business entities are emerging, especially sole traders and small and medium-sized enterprises, which have great growth prospects,
- some large traditional existing companies, are undergoing a fundamental transformation, or are in insolvency process, or are gradually closing down their activities,
- a fundamental change in the regional economy will occur in connection with the expected termination of hard coal mining in OKD (within 5 to 15 years), which will force systemic changes especially in the energy sector, the heating industry, the metallurgical industry and activities related to the coal industry,
- The situation in the heating industry is specific, there are extensive heating systems in the region, especially in large cities with typical housing estates, especially Ostrava, Karviná, Havířov and Orlová.
- A persistent problem is the worsened, although still improving, air quality and the number of existing and difficult to solve brownfields.

The economy of the Moravian-Silesian Region, but basically the entire Moravian-Silesian Region, is influenced by a number of external factors, which on the one hand bring significant restrictions and complications, but on the other hand are a great opportunity for a comprehensive economic transformation of the region, which should be reflected primarily in the improvement of the environment in the region, an increase in the standard of living of the region's citizens and the elimination of current problems in the region.

1.1. Opportunities for systemic and complex solutions

The following should be mentioned as essential factors and opportunities for a systemic and comprehensive solution to municipal waste management, especially mixed municipal waste:

- Circular Economy Package – brings new perspectives and requirements on waste management, calls for a substantial increase in waste recovery and a radical reduction in the amount of waste sent to landfills,
- a significant reduction in the landfilling of mixed municipal waste (hereinafter referred to as SKO) in the Czech Republic, starting from 2024 (the restriction is given by strict rules) and an expected continuous and significant increase in fees for the disposal of mixed municipal waste in landfills.

As the basic support tools that can decide on the strategic direction of the use of SKO in the Moravian-Silesian Region, it is necessary to mention:

- strategic documents of the Moravian-Silesian Region,
- RESTART – Action Plan of the Economic Restructuring Strategy of the Ústí, Moravian-Silesian and Karlovy Vary Regions,
- Coal Platform for regions in transition – EU measures to reduce the impact of the reduction of coal mining, EU financial assistance is expected in the implementation of projects that will compensate for the consequences of the decline in hard coal mining in the Moravian-Silesian Region.
- EU Winter Energy Package – Clean Energy for All Europeans (mainly to further reduce greenhouse gas emissions, increase efficiency, increase the share of renewables in the energy sector and further reduce CO2);
- the completion of hard coal mining in OKD within 5 to 15 years and the related pressure from the EU to reduce the combustion of fossil fuels.

These support tools are important for dealing with waste management related to waste management and energy, as defined in the analytical part of the study.

The following aspects will be applied in the preparation of the design part of the study:

- the solution must include the entire territory of the Moravian-Silesian Region and at least all SKO and sorted components from the KO or SKO, which cannot be further used materially, considering the development of neighbouring regions,
- The solution must be based on the existing and functional region-wide system of waste management in question, which will be supplemented by proposals for solutions that will meet the current requirements and requirements given by the expected development,

- the solution must be in the context of the Economic Restructuring Strategy of the Moravian-Silesian Region (RESTART) and in the context of other current and expected requirements,
- the proposed solution must be flexible and at the same time sustainable in the long term and in the interest of the citizens, cities and municipalities of the Moravian-Silesian Region,
- the solution must support society-wide interests and the interests and needs of cities and municipalities, especially in the field of raw materials and energy,
- Designed solution must respect Balance Environmental Social and economic factors in a broad sense,
- we will not propose simple "disposal of waste", for example by exporting it abroad, but use it for the benefit of the region,
- we will not propose support for local monopolies, but we will create conditions for the efficient use of waste within the framework of a circular economy,
- the solution must be variant with a recommendation of the most suitable option,
- great attention must be paid to the conditions for the proposal of investors,
- A suitable financing model must be sought, including subsidy opportunities.

1.2. Framework principle of the solution

For better orientation in the design part, the following text describes the framework principles of the solution.

- Territorial dimension:
  The solution must include the entire territory of the Moravian-Silesian Region and all municipal waste and similar waste, taking into account the development of neighbouring regions. The solution has been prepared for the Moravian-Silesian Region as a document that should primarily serve for the region-wide coordination of individual implementation steps leading to the fulfilment of the measures of the "landfill ban" of the SKO so that the resulting solution is as effective, economically, socially and environmentally viable as possible. The proposal seeks to balance the different urban composition of the region and not to disadvantage citizens living outside large residential centres.
- Existing advanced waste management in the Moravian-Silesian Region:
  The current state of waste management in the Moravian-Silesian Region, especially in the field of municipal waste management, can be assessed as very advanced, with the fact that the requirement of a "landfill ban" from 2024 has not yet been fully and comprehensively responded, which is currently causing significant problems, but they are solvable. This study proposes an optimal long-term effective solution, which, in addition to addressing this part of waste management, also corresponds to the ongoing restructuring of the economy of the Moravian-Silesian Region (RESTART) and in the context of other current and expected requirements.

- Long-term sustainability
  There will be an effort to find an integrated and conceptual region-wide solution that respects the requirements and interests of individual waste producers (especially cities and municipalities) on the one hand and takes advantage of specific opportunities in the economic system of the Moravian-Silesian Region on the one hand. The solution is partly flexible and at the same time sustainable in the long term, not only in the interest of the citizens, cities and municipalities of the Moravian-Silesian Region, but also of the entire system of the regional economy. The submitted material is based on society-wide regional interests in the field of waste management as well as in the field of raw materials and energy, and respects the balance of environmental, social and economic factors in a broad sense.
- We do not get rid of waste, but we propose its real and meaningful use
  The negative of the current management of municipal waste and similar waste is the fact that approximately 50% of waste is disposed of without any benefit (landfilling). This situation is no longer sustainable, which is also confirmed by new legislative requirements. In the design part, a solution is proposed that changes this situation and tries to make practically complete use of all usable components, primarily in the economy and for the benefit of the Moravian-Silesian Region.

In general, we recommend further strengthening of separation, if possible as close as possible to the generation of waste, with an emphasis on the separation and material use of biowaste, especially on the production of quality compost and use in biogas plants. The intensity of separation must be based on the potential possibilities of individual types of development and on urban and social assumptions. In areas with increased heating with solid fuels, it is recommended to consider separate ash separation. The main carriers of separation must be individual waste producers (cities and municipalities) with the involvement of citizens and in cooperation with the relevant "collection companies". The aim of strengthening the separation is to reduce the amount of mixed municipal waste generated, even at the cost of increasing discards from the final sorting lines of separately collected commodities, which will be used for the production of alternative fuels. The minimized amount of mixed municipal waste and produced alternative fuels is then designed primarily for energy use in the heating industry, as a substitute especially for black coal.

The flexibility of the entire system is created by a multi-fuel unit that can use up to 40 kt of solid alternative fuels (hereinafter referred to as SAF), produced from discards from sorting lines of separately collected commodities and from the reprocessing of mixed municipal waste using the technological concept of mechanical biological treatment (hereinafter referred to as MBÚ).

The aim of such a roughly described concept is to absolutely minimize unusable municipal waste, which will necessarily have to be deposited in landfills.

The described concept does not bring a revolutionary solution, but is based on well-proven practice not only in the Czech Republic (Prague, Brno, Liberec and now also Pilsen), but also abroad (Switzerland, Vienna, Gothenburg and many others).

- Risks of the proposed concept
  The proposed solution brings a number of risks, some of which can be defined in advance, but some are difficult to estimate and will arise only during implementation.

1.3. End of the introductory part

The submitted study is not a "feasibility study", but a set of possible solutions, based on the Waste Management Plan (hereinafter referred to as POH) of the Moravian-Silesian Region and corresponding to the current situation with a view of at least 25 to 30 years. A very limiting factor is the time pressure given by the "termination of landfilling of waste" by 2026, which can lead to a number of non-conceptual steps that will delay a comprehensive and optimal solution and only make it more expensive or completely impossible.

On behalf of the processors, I must say that as a company and as individuals, we are completely independent of entities that handle waste, we have no corporate interest in participating and in the construction and operation of the proposed systems, and we are neither connected nor connected with any similar company. The aim of the processor's efforts is to design a system that will primarily suit municipalities, cities (which are not motivated by landfilling or other waste management) and citizens, within the intentions of existing and expected rules with maximum economy and efficiency.

2. Possibilities filling Objectives Directive of the European Parliament and of the Council of the EU 2018/851

The Directive was issued on 30.5.2018. The directive contains a number of binding targets for municipal waste management. This is primarily the goal of increasing the separation and recycling of municipal waste (hereinafter referred to as municipal waste).

In order to comply with the objectives of this Directive and to move towards a European circular economy with a high level of resource efficiency, Member States shall take the necessary measures to achieve the following objectives:

- Increase the level of preparation for reuse and recycling of municipal waste to at least 55% by weight by 2025
- Increase the preparation for re-use and recycling of municipal waste to at least 60% by weight by 2030
- Increase the preparation for re-use and recycling of municipal waste to at least 65% by weight by 2035. The target will be subject to revision.

However, there are also deferral options for countries that recycled only 20% of their waste in 2013 or landfilled more than 60% of their KO.

A key factor in this objective is that the weight of recycled waste is measured at the moment when the waste enters recycling.

There are no rules for the calculation, verification and reporting of the weight of materials or substances. The Commission will adopt implementing acts to calculate the targets by 31.3.2019.

Only after the calculation methodology has been determined will it be possible to prepare targeted measures at the national and regional level, which will define the real possibilities of increasing recycling.

One of the decisive factors for compliance with the directive will be the method of accounting for sorted biodiversity, which already forms a decisive part of sorted and materially usable waste and also has the potential for further increase.

It is necessary to realize that the objectives of the directive are not there for themselves, but should serve to improve environmental indicators of waste management. Like many EU measures, the waste management goals are set on the basis of the official so-called environmentalist ideology, and only practice will show whether they have been set in a sufficiently well-founded way, considering the real possibilities of fulfilment.

Therefore, even within the framework of this study, it is possible to consider the medium-term horizons set out in the Directive, i.e. 2025 or 2030 at the latest. In addition, the 2035 targets will still be subject to revision.

The chapters below, on waste prevention and intensification of separation, will serve to meet the objectives of the POH MSK and also in parallel to meet the objectives of Directive 2018/851 of the European Parliament and of the Council of the EU.

Of course, the Directive also contains a number of other objectives and commitments related directly or indirectly to municipal waste management, but from the point of view of the tasks set out in the study assignment, this stated objective can be considered relevant.

The following measures and considerations at higher levels of the waste management hierarchy will have a major impact on the fulfilment of the key objective of the directive for municipal waste management, which will be indirectly reflected in measures to end landfilling of waste management, which is the main task of the design part of the study.

2.1. Proposals and recommendations for waste prevention measures

Support for home composting

In terms of quantity, home composting is by far the most important item in the waste prevention hierarchy. The study does not analyse home composting of citizens who are not covered by public support for home composters. An analysis of the actual state of home composting in the region will have to be determined if home composting can be included in the algorithms of Directive 2018/851 of the European Parliament.

The operation of home composting may be limited by the ever-expanding network of bio-waste collection in the region, where it is easier for some groups of the population to hand over the waste and not take care of it further. This trend is also related to a change in the care of private gardens, where ornamental areas prevail over production areas with a lower need for compost. However, these are mainly older forms of home composting without the use of today's composters available on the market. From the point of view of cities and municipalities, there is still interest in further expansion of this form of BRKO processing.

Recommendation:

- Furthermore, to support home composting as much as possible as the cheapest and most environmentally beneficial way of dealing with biodegradable waste for citizens.
- To analyse and quantify the potential of home composting in the conditions of the Moravian-Silesian Region.
- Strive to include the amount of BRKO from home composting in the calculation of material recycling

Other waste prevention measures

As part of waste prevention, the Moravian-Silesian Region operates many systems that contribute to increasing the amount and types of commodities that do not end up under the Waste Act.

These are mainly systems for the collection of old clothes, and recently so-called RE-Use systems have been introduced within the collection yards, aimed at reusing furniture and other commodities. These commodities are offered for free or for a small fee to people for further use.

From the point of view of the analysis of the RE-Use system converted to weight fractions in the city of Brno, where they are furthest along with this system and where they de facto started with this system in the Czech Republic, this is only an additional amount.

Recommendation:

Continue to gradually introduce waste prevention systems and apply RE-Use systems at larger and suitable collection yard locations.

2.2. Proposal and recommendations for meeting waste sorting targets

Measures to gradually increase the classification of waste components are listed in the POH of the Moravian-Silesian Region, and are part of the approved POH of individual POHs of cities and municipalities, which have a legal obligation to process and evaluate POH. This is a process that is fully under the control of cities and municipalities or collection companies in cooperation with citizens. From the point of view of the study in question, it will only be a recommendation based on the evaluation of the experience of the authorized company EKO-KOM a.s. or other waste management entities.

The main objectives of sorting are primarily to save primary raw materials and energy and to reduce the amount of mixed municipal waste.

Sorting and material recovery targets given by the newly implemented regulations of Directive 2018/851 of the European Parliament and of the Council can also serve as a tool.

2.2.1. Potential classification (paper, glass, plastics, metal)

The development of separate collection and recycling of municipal waste is generally dependent on the decision factor of the actual waste producer, i.e. a citizen or business entity producing waste similar to municipal waste, how to dispose of its waste. Whether to use the separate collection system, or to put it in mixed waste, throw it in the trash can, or in the worst case, throw it in a public space.

The factors influencing the rate of participation in separate collection can be divided into socio-economic factors, technical conditions for separate collection and enforceability of obligations.

The limiting factor for this fundamental decision is the "internal decision" of the producer, which is primarily influenced by the knowledge of what belongs where, the proximity of the infrastructure for separate collection and trust in the entire system and the motivation to separate waste sorting.

According to long-term research on public behaviour, more than 70% of the population actively participates in the separate collection of recoverable waste and it has become a habit and part of culture for them. Within each group of inhabitants, there will be citizens who will not sort waste in principle. The social status of each individual in society and his socio-economic situation play an important role.

Business entities are concerned about their behaviour depending on the enforceability of the obligation to collect sorted waste separately, the price of the service and its possible complexity in terms of space for depositing recoverable waste within individual plants or workplaces.

In terms of the availability of the collection network in the Moravian-Silesian Region, there are 136 inhabitants per average collection nest of containers (paper, plastic, glass), which indicates a very dense network of containers intended for separate collection.

The development of separate collection and recycling of waste is technically limited by the occurrence of recyclable waste, which is currently disposed of outside the system of separate collection of recoverable components of municipal waste.

According to the analyses of the composition of the SKO, it represents the theoretical occurrence of waste of paper, plastics, glass and metals in the analysed buildings. It must be taken into account that it is the weight fraction of commodities contained in the waste, i.e. including the influence of moisture, contamination by other waste etc.

Theoretical occurrence of usable commodities in the waste

Substance group	Housing estates (wt%)	Rural development (wt%)
Paper/cardboard	8,4%	5,9%
Plastics	11,4%	9,5%
Glass	3,5%	3,1%
Metals	2,7%	2,7%
Textile	2,5%	2,4%
Electrical waste	0,9%	0,5%
Bio-waste	17,9%	17,7%

Source: SCO analyses: EKO-KOM a.s.

However, this is a theoretical occurrence. The potential for diversion from waste management to separate collection is only for those wastes that are not further degraded by other secondary pollution and the resulting degradation. These wastes cannot be counted as potential for diversion from waste if the actual waste producer does not have an alternative for his behaviour.

For each commodity, weight percentages of the number of commodities that were degraded for separate collection and material recycling were determined in the manner described below. The differences in the degree of material deterioration between individual buildings were absolutely negligible.

Table of devaluation of individual potentially sortable commodities

Substance group	Housing estates (wt%)	Rural development (wt%)
Paper/cardboard	4,9%	4,9%
Plastics	19,6%	19,7%
Glass	2,7%	2,9%
Metals	4,8%	5,5%

Source: SCO Analyses: EKO-KOM a.s. 2016

As a result, the theoretical potential for separate collection occurring in the case of 100% sorting is calculated in the following table.

Theoretical Screening Potential in the Case of 100% Sorting after Deduction of Polluted Commodities

Substance group	Housing estates (wt%)	Rural development (wt%)
Paper/cardboard	8,0%	5,6%
Plastics	9,2%	7,6%
Glass	3,4%	3,0%
Metals	2,6%	2,6%

Calculation

Theoretically converted to an average production of SKO of 190 kg/inhabitant per year, the amount is about 35–45 kg/inhabitant, with 100% separation of these fractions from SKO. **With the intensification of sorted collection and an increase in the active participation of the population to the limit of 80%, it can be expected from the long-term perspective that usable components will be diverted from SKO in the range of 10–20 kg/inhabitant.**

Substance group	Housing estates (kg/ob and year)	Rural development (kg/ob and year)
Paper/cardboard	15,2	10,7
Plastics	17,4	14,5
Glass	6,5	5,7
Metals	4,9	4,8

Theoretical calculation

When interpreting, it is necessary to take into account the fact mentioned above, that it is a conversion from SKO, which is influenced by factors such as moisture and contamination by other wastes.

To increase the amount of separate collection, it is necessary to analyse the density of the collection network and the use of all available collection systems in individual areas of the region. One of the possible tools is the introduction of so-called individual collection in the development of family houses. Here it is necessary to consider the separate collection as part of the entire system of municipal waste trucks. If individual collection is introduced in the development of family houses and the frequency of waste collection is not adjusted, there will be a significant increase in the costs associated with the collection of usable components.

From the point of view of comprehensive municipal waste management, priorities should be to sort and use materials that are in demand on the market, and their separate collection will help to streamline further management of residual waste. Such materials are mainly glass, metals and paper.

Glass

In the case of the commodity glass, there is a clear direct correlation, that the larger the quantity of glass diverted from the waste, the greater the amount that will be returned to primary glass production. This will create a secondary effect that will occur in the subsequent management of SKO is energy savings during its energy use (it will not take thermal energy) and at the output of the energy process it will not be contained in the slag or undersize fraction that will have to be further handled. As follows from the above analysis, there is still a potential for an increase in sorted glass in households. Compared to the other two commodities, glass is the only commodity that has no limitations in the possibilities of material use today.

Paper

Sorting and subsequent recycling of paper is well set up by several types of systems and there is a chance to use the above potential. The key factor in increasing paper sorting is not the lack of capacity for its use, as in the Czech Republic and its surroundings (Slovakia, Germany) there is sufficient capacity for processing or a collection system that covers both the standard system of collection containers and bag collection as well as additional collection systems in schools or waste materials. The key factor in increasing the increase is to find sufficient motivation among citizens, and therefore education will be of decisive importance.

Plastics

Further possible increases in sorting and especially material use of plastics according to the potential listed in the tables will depend on strategic decisions regarding the possible introduction of take-back of PET bottles, which can fundamentally redefine existing collection systems, especially in the economic area.

2.2.1.1. Examples of good practice in waste sorting in municipalities in the Moravian-Silesian Region

As a good example of increasing effective separate collection, we would like to mention the following municipality in the Moravian-Silesian Region on the recommendation of the authorized company EKO-KOM a.s.:

Trojanovice

In the category of 2500–15,000 inhabitants, the municipality of Trojanovice was the best in sorting among municipalities in the Moravian-Silesian Region in 2017.

The municipality has a sophisticated system of dealing with waste, which in some of its aspects already shows the progressive elements of the Olympic Games under the municipality's own management. The initiation of changes towards efficient municipal management was taken up by the mayor of the municipality.

The municipality of Trojanovice is a shareholder of the association of municipalities ASOMPO, which owns a landfill in Životice, where waste from the municipality is stored.

The municipality has been working for a long time (about 10 years) on the intensification of sorting by several parallel systems, which are evaluated and modified according to their actual efficiency.

Citizens are financially motivated to sort components such as paper, plastics, beverage cartons, which are primarily sorted by bag collection, where citizens themselves take these bags to the collection yard and from the amount of waste handed in, financial compensation is subsequently calculated, which is deducted the following year when determining the fee for waste removal. Citizens can achieve a fee of up to CZK 0 per year by such efficient sorting.

Another sorting system is the classic container system, which also works for cottagers and tourists visiting the Radhošť area.

BRKO is handled within complementary systems. Primarily, the focus of BRKO management is on the level of waste prevention, where 1480 home composters were gradually distributed from the subsidy. Some households are equipped with up to three home composters. Home composters were also distributed to cottagers (there are 600 cottages in the village).

The municipality also owns a community composting plant, which is another system in the waste prevention regime.

Mixed municipal waste is collected at the ASOMPO landfill in Životice, where the waste is weighed. Only the collection itself is carried out by an external collection company. Weighing containers for SKO for citizens is not introduced.

Despite the sophisticated system of dealing with SKO, the condition for reducing the amount of SKO is still not met. In 2015, the production was 468 tonnes, in 2016 496 tonnes and in 2017 503 tonnes. Another amount of SKO results from the final sorting of components at the collection yard (up to 10 tons per year). Also, the specific production of SKO is relatively high and oscillates around 190 kg per citizen. The given state of affairs is caused by various influences that are difficult to influence on the part of the municipality. It is mainly the amount of waste produced by tourists, which is still increasing, by entrepreneurs in the village and its surroundings who abuse the system, and also by the inhabitants of nearby Frenštát pod Radhoštěm, who sometimes dispose of part of the waste in the village of Trojanovice.

2. Recommendations for further action

As part of the implementation of the POH, it is necessary to define priorities that must be coordinated from the position of the Regional Authority of the Moravian-Silesian Region and possibly other important municipalities such as large cities or municipal collection companies.

On the part of the Moravian-Silesian Region, it is possible to support the construction of the IMT only up to the capacity of the energy use of the resulting fractions in the energy sources of the Czech Republic, preferably the Moravian-Silesian Region.

Support for alternative technologies such as plasma gasification for waste can only be declared after submission of references for the processing of waste with unambiguous comparable values with existing technological concepts

The proposed solution for the construction of two WtE units is based on a proven and practice-tested concept that offers profits not only for the long-term stabilization of municipal waste management, but also offers a solution for the part of the energy sector in the heating industry in the central part of the Moravian-Silesian Region, which is easily accessible both by road and in the case of rail transport.

The proposed solution must be accepted and explained, and gradual steps must be prepared to implement the system.

It is necessary to declare support for the construction of a WtE facility at the Dětmarovice Power Plant and to prepare a discussion on the possibilities of building a WtE facility in Ostrava, including the possibilities of alternative financing for the construction, ownership and operation of the facility.

The preparation of a multi-fuel boiler for the energy use of the TAP from the IMF is under the implementation and direction of a private investor, so it is only necessary to monitor the given status and conditions for the implementation of the TAP from the IMF.

An important part of the transition of municipal waste management from landfilling to energy or other alternative forms of recovery is the provision of transport logistics.

Therefore, it is necessary to start preparing the construction of a network of transfer stations in the Moravian-Silesian Region in areas where the construction of capacity facilities for the use of SKO is not expected.

Conclusion

The implementation study for the implementation of the POH of the Moravian-Silesian Region focused on municipal waste followed up on the processed POH and defined and developed the key topic of mixed municipal waste management.

In the design part, the basic level is elaborated on the variant of the management of SKO. The variant consists of two technological concepts, the basis of which is the proven and time-tested and time-tested concept of direct energy use of SKO, for which there are still conditionally suitable conditions in the Moravian-Silesian Region, but which may be lost over the years if this concept is not developed.

Although the primary assignment of the study was to find a solution for municipal waste management, it turned out that an integral part of the solution to the waste management is also the participation of the local energy sector, specifically the heating industry.

The proposed variant of the SKO solution is even in line with the opinions of the non-profit organization Duha, which usually questions similar solutions.

Similar conclusions presented by the feasibility study are also in the document Friends of the Earth

"Really Needed Capacities for Energy Recovery of Waste in the Czech Republic" from August 2016, which was supported by a grant from Iceland, Liechtenstein and Norway under the EEA Grants.

The document proposes the construction of a WtE facility and an MBU in the Moravian-Silesian Region. At the same time, the document confirms the need to prepare a more detailed study to specify the possibilities of construction of these facilities in accordance with the commissioned feasibility study.

The implementation of the proposed solution will certainly not be without problems, as is customary in the specific implementation of similar facilities in the Czech Republic. But it would be a mistake not to try this solution, because in the future this opportunity may not be repeated on the basis of changes in the energy sector, and any other solution may mean a relatively large economic burden for the cities and municipalities of the Moravian-Silesian Region, with the fact that some major environmental benefits may also be lost, such as emission savings in the heating industry or the replacement of primary raw materials.

Alternative options for ending landfilling of waste waste, as stated mainly in the analysis of concepts in the analytical part, are complicated and, above all, economically demanding.

The individual aspects of the proposed solution must be patiently explained to the representatives of cities and municipalities and to the public, for whom the proposed solution is primarily intended and which can solve the management of waste for many decades, regardless of the degree of success of the implementation of the EP Directive.

The design part looks for a solution and further elaborates variants for waste management or other materially unusable municipal waste, which will result after optimization and intensification of sorting and after the implementation of waste prevention measures.

The result of the design part is the recommended optimal variant of the solution, which eliminates, among other things, the expected range of the forecast for the production of the materially unusable part of the waste waste, which, according to the analytical part, ranges from 300kt of the current production to 250kt in 2025 according to the expected decrease due to compliance with the EP directive.

Of course, the proposal part includes recommendations and brief instructions regarding the intensification and optimization of component sorting and waste prevention measures, which correspond to the obligations of the EP Directive.

The zero option is also emphasized, which works with the possibility that an acceptable solution will not be found or will be blocked for many reasons. The zero option emphasizes the economic risks of not solving the problem.

As part **of the WtE variant,** two construction sites in the Moravian-Silesian Region were proposed, which the analysis showed met the parameters that enable economically sustainable operation.

It is the premises of the ČEZ a.s. power plant. Dětmarovice – EDĚ, where it is currently possible to count on a maximum capacity of WtE facility of 140–150kt. In the case of connecting EDĚ to the Havířov and Karviná district heating networks, it is possible to increase the capacity. The Ostrava location has a district heating capacity network, which will theoretically allow the construction of a WtE facility with a capacity of up to 350 kt of solid-state waste per year. From the point of view of the economics of a WtE facility, it is a very advantageous and, in this respect, an exceptional location throughout the Czech Republic.

It should be emphasized that the economy of a WtE facility is primarily dependent on the sale of heat, from which the price for the reception of waste is subsequently derived.

For the construction of a WtE facility, especially at the Ostrava site, the construction time is a major limiting factor, which may exceed the horizon of 2024.

Another proposed variant option is **the solution with the concept of the MBU**. This option is fundamentally limited by the possibility of efficient use of the caloric, energy-usable fraction, which is one of the products of these devices. The limiting factor is therefore the capacity of the equipment capable of using this product, which in this case is the capacity of the upcoming multi-fuel boiler from Veolia Energie in Karviná, which will be able to use up to 40 kt of TAP for energy. The boiler in the Přerov heating plant by Veolia Energie a.s., which is designed for a capacity of up to 114 kt and can theoretically use part of the TAF from regions other than the Olomouc Region, can also be used for energy.

Therefore, in the current situation, it is not possible to find a use for all planned projects for the construction of the MBU (OZO, TS Havířov, Depos, Marius Pedersen, or a project for the energy use of the undersize fraction by the company Ingea)

A limiting factor of the IMT technological concept is also the solution of the management of the energy-unusable so-called undersize fraction due to the strict legislative provisions on the landfilling of this fraction.

The third mono-source option is the option **of building a plasma gasification unit** This option is a pilot project within the EU and, in terms of capacity, currently also worldwide. Therefore, the author of the study includes it only at the express request of the investor, who must bear all investment and operational risks in the event of implementation.

The author of the study recommends a combined variant of the construction of one or two WtE facilities in the Moravian-Silesian Region in Ostrava localities, supplemented by the construction of a unit at the MBU, whose TAF production capacity will correspond to the capacity of the Karviná Heating Plant, where the construction of a multi-fuel boiler capable of using waste-to-energy fuels is planned.

The recommended option applies only to the management of SKO and some other relatively calorie-rich and materially unusable waste, while respecting the priorities of waste management within the hierarchy, where priority is given to waste prevention and sorting and material recycling.

As an essential part of the solution, there is a recommendation for the construction of transfer stations at least in the variant of construction in peripheral areas of the region (Krnov, Opava, Nový Jičín Frenštát pod Radhoštěm). The construction of transfer stations will have to be carried out regardless of the chosen solution. In the case of forced transport outside the Moravian-Silesian Region, it will be necessary to cover the entire territory of the Moravian-Silesian Region with a network of transfer stations.

The study suggests the possibility of rail transport, which can be effective over a distance of 80–100 km, as indicated by the transport of solid waste from the Pardubice Region to SAKO Brno.

The implementation study for the implementation of the POH of the Moravian-Silesian Region focused on municipal waste followed up on the processed and approved POH of the Moravian-Silesian Region and defined and developed the key topic of mixed municipal waste management.

In the design part, the basic level is elaborated on the variant of the management of SKO. The variant consists of two technological concepts, based on the proven and time-tested concept of direct energy use of waste, for which there are still conditionally suitable conditions in the Moravian-Silesian Region, but which may be lost over the years if this concept is not developed.

Although the primary assignment of the study was to find a solution for municipal waste management, it turned out that an integral part of the solution to the waste management is also the participation of local energy, specifically in the field of heating.

The recommended variant of the solution is a synergy for the solution of the part of municipal waste management related to the ban or significant reduction of landfilling and the part of the heating industry, which will have to deal with the diversion from coal combustion in the future and if it wants to maintain its economic and environmental advantage in competition with other types of heating, it will have to find an alternative source, which can be materially unusable municipal waste.

Part of the recommended solution will verify the pilot economic, technological and legislative advantages of the IMF concept in connection with the energy use of SAF in heating plant operations.

The proposed solution primarily pursues the balance of the environmental, economic and social aspects.

From the point of view of the future organization of waste management and especially waste management, which will undergo a fundamental change from simple landfilling to probable energy use, which will require a certain centralization in sales from the point of view of economics and logistics, the study recommends that municipalities consider some form of association, which will ensure a better negotiating position with potential investors in waste recovery facilities and can also serve as a platform for investment, for example, of transfer stations. From the point of view of the form of association, the form of cooperatives seems to be advantageous, as no significant centralization of the system is expected, as was the case, for example, with the KIC project.

The role of the Moravian-Silesian Region in the implementation of the newly designed system will be more organizational and coordinating.

The individual aspects of the proposed solution must be patiently explained to the representatives of cities and municipalities and to the public, for whom the proposed solution is primarily intended and which can solve the management of waste for many decades, regardless of the degree of success of the implementation of the EP Directive.

Responsible representatives of municipalities and cities will have to deal with the implementation of a system that will lead to the fulfilment of the objectives and legislative requirements of waste management, especially the diversion of landfilling of waste. If the solution is postponed or left fully under the control of private collection companies, an increase in waste management costs can be expected with a negative impact on citizens' payments.

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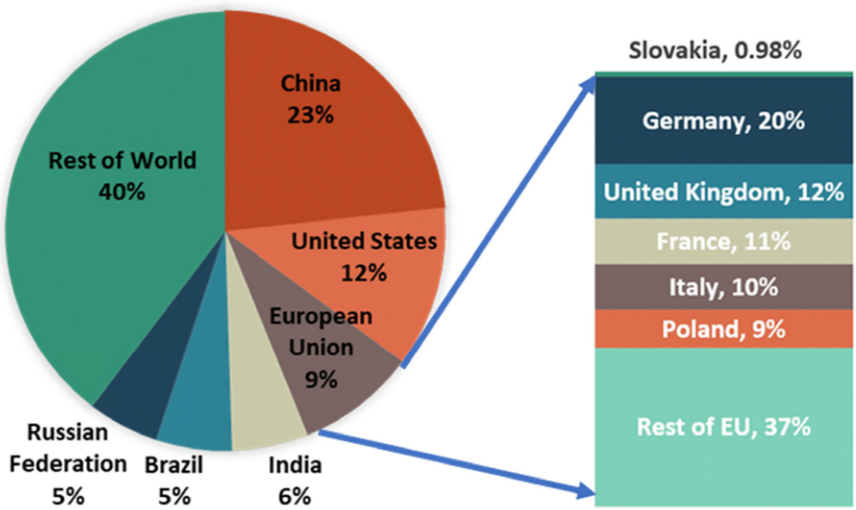
A low carbon growth of Slovakia

1. Introduction

To set the stage for an examination of a low carbon growth path for Slovakia, the country's performance on greenhouse gas emissions, its obligations under the Paris Agreement and as a member of the European Union, and the need for a low carbon growth path are briefly examined. Slovakia is a small country and contributes only marginally to the global carbon footprint, with total GHG emissions of 41 $MtCO_2e$ (million metric tons of carbon dioxide equivalent) in 2016 or less than 0.1 percent of global emissions. The European Union as a whole contributes about eight percent of global emissions (or 4,441 $MtCO_2e$ in 2016), of which Slovakia's emissions constitute less than one percent (Figure 1). Nevertheless, Slovakia has made regional and global commitments to reduce its emissions [1].

Figure 1. Global emissions by selected countries and EU member states' emissions, % of totals [1]



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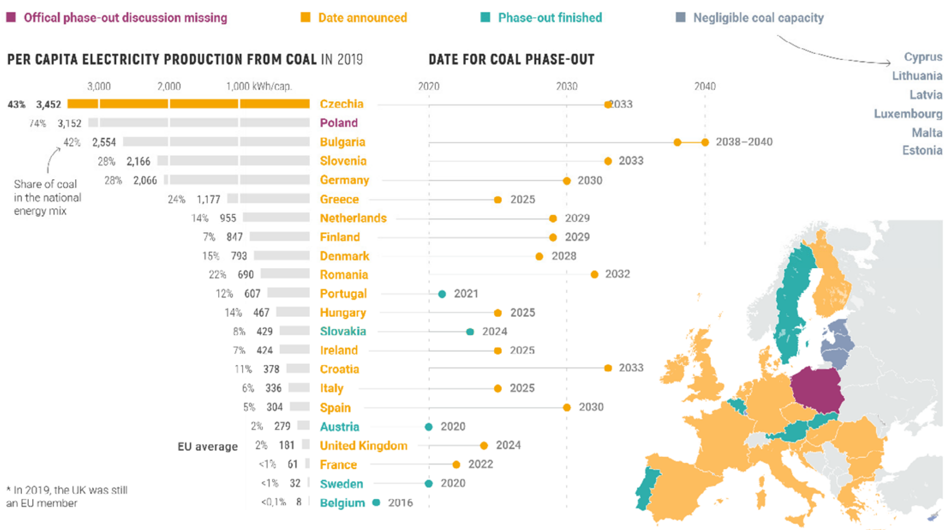
Sustainable development must ensure the current needs of the population without limiting the ability of future generations to meet their own needs. Therefore, it is necessary to change technologies, procedures and habits, both on the side of production and on the side of consumption. The low-carbon strategy aims to select and analyse cost-effective measures regarding the extent of emission reductions. It is necessary to ensure the presentation of measures that will be in line with the goal of achieving climate neutrality, and this monography was created for this purpose.

2. Analysis of the current situation

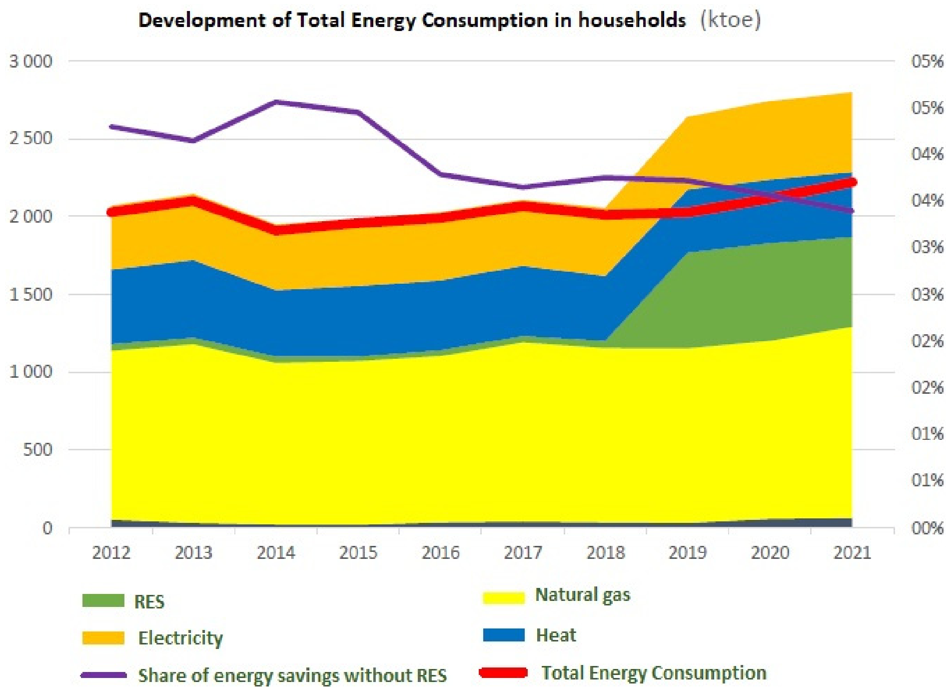
One quarter of the world's CO_2 emissions come from coal-fired power plants. Most EU countries plans to do the coal phase-out. It means the replacement of coal in the energy sector with cleaner sources. Figure 2. shows the comparison of EU countries plans to their electricity production from coal. The amount of electricity produced from coal in each country is provided in kWh per person per year [2]. Slovakia has already met its goal and the last coal-fired power plant was closed at the beginning of 2024.

Figure 2. Coal phase-out plans in the EU countries at the end of January 2022 by Fakta o klimatu, licensed under CC BY 4.0.[2]



The period between 2015 and 2020 in Slovakia was characterized by the highest rate of reconstructions of both family and apartment buildings in the history of the Slovak Republic. During this period, insulation of the buildings, roofs or replacement of windows was carried out in 37% in apartment buildings and 24% in family houses. This was reflected in the decrease of energy consumption and it is represented by the purple line in Figure 3.

Figure 3. Development of total energy consumption in household from 2012 to 2021



It can be noticed the higher share of RES from 2018, what is the beginning of government financial support of renewable energy technologies (Fig.3).

The rate of energy savings potential is closely related to the development of energy intensity. In the period 2001 – 2021, the Slovak Republic reduced its energy demand by more than two and a half times, while from 2015 to 2019 the decrease was only by less than 7%..

2.1. Carbon Budget of Slovakia and measures of decarbonization

Slovakia's greenhouse gas emissions fell by 45 percent by 2016 compared to 1990. Such a decrease was based on the *change of national legislation*, a *change in the structure of the industry*, as well as in *consumer behaviour*. An important role is played by Act No. 137/2010 Coll. on air protection as amended. This Act is supplemented by Act No. 401/1998 Coll. on charges for air pollution, which serves to control and regulate emission limits for basic air polluting substances. Monitoring and keeping records of emissions from stationary sources of air pollution, as well as the system of fees, which is mandatory for operators of large and medium sources of air pollution, positively influenced the reduction of greenhouse gas emissions and contributed to the separation of the emission trajectory in the Slovak Republic since 1997.

Increasing energy efficiency – Measures on the side of energy consumption, according to which energy savings are manifested as a reduction in final energy consumption. These measures are divided by sector (buildings, industry, public sector, transport and appliances). The measure sets minimum requirements regarding the energy efficiency of new and existing buildings, the renovation of buildings, which represent the most important source of possible energy savings until 2030.

Implementation of the Winter package of the EU – The Winter package, as part of the implementation of the energy union, supports the transition to clean energy and takes into account the impact of RES on the production of heat and electricity. For electricity generation, Slovakia depends mostly on nuclear power, far above EU averages. Slovakia generates 54 percent of its electricity from nuclear power, 24 percent from renewables, 15 percent from coal, and six percent from natural gas. Within renewables, almost 18 percent is hydro, about four percent is biomass and about two percent is solar. The European Union on average generates 29 percent of its electricity from renewables, 27 percent from nuclear energy, and 26 percent from coal [1].

The Action Plan for RES established RES targets (also for biomass, support for fast-growing trees, and regulatory measures for technological innovation in wood harvesting, etc.). The Slovak Republic has an obligation to increase the use of renewable energy sources in proportion to gross final energy consumption from 6.7% in 2005 to 14% in 2020, which means sub-goals 14.6% share of RES in heat and cold production, 24% share RES in the production of electricity and a 10% share of RES in the energy demand in transport. The Slovak Republic provides financial grants to households and companies to support the use of following technologies:

- photovoltaic power plants
- thermal collectors
- heat pumps
- wind turbines
- biomass boilers

Over 150 million euros was allocated to support application and installation of RES from 2020. The Table 1. presents estimated and real data of RES for 2021 and 2022. It is clear that real trajectories of RES- Heating and Cooling share are higher compare to estimated data. The real data for electricity and transport are under the plan values.

Table 1. Estimated and Real trajectories of RES [YZ]

	2021		2022		2023		2024	
	E	R	E	R	E	R	E	R
RES- Heating and Cooling share	13,0	**19,5**	14,3	**19,9**	14,6	–	15,2	–
RES- Electricity share	22,4	**21,3**	23,4	**21,9**	23,9	–	24,4	–
RES- Transport share	8,9	**8,8**	9,2	**8,9**	9,5	–	9,7	–
Overall RES share	**14,0**	**17,4**	**15,0**	**17,5**	**15,4**	–	**15,8**	–

E – Estimated trajectories R – Real trajectories

Optimization of district heating – Optimization of district heating will be implemented by installing cogeneration units with combined production of electricity and heat (CHP) in district heating systems. Industrial cogeneration devices produce industrial steam, which can also be used for district heating. Other measures are also taken into account (e.g. improvement of the efficiency of central heat supply systems (CZT), installation of innovative technologies for district heating, improvement of heat supply from combined heat and power plants).

Termination of coal power plants after 2025 – the last two coal-power plants were closed in 2024.

Figures 5 and 6 show the decrease of CO_2 and CH_4 from 2008 to 2021.

Figure 5. Profile of CO_2 concentration from 2008 to 2021

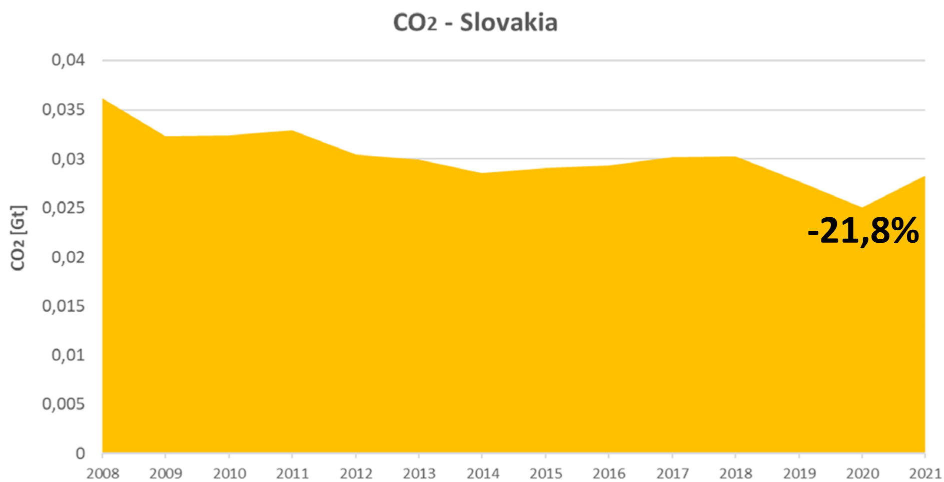
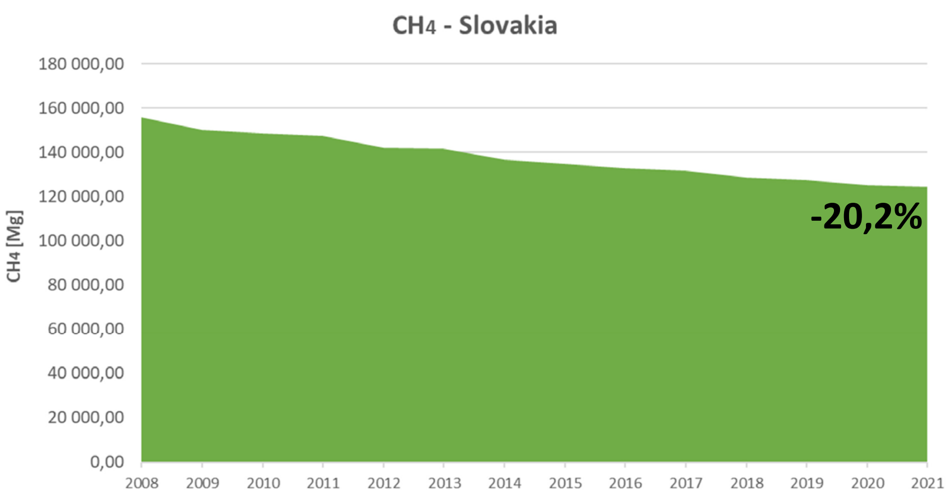


Figure 6. Profile of CH_4 concentration from 2008 to 2021



Support for renewable energy

Supporting and increasing share of RES is one of the main priorities in the energy sector. The directives generally call for greater use of RES and the associated higher security of energy supply, affordable energy, the possibility of introducing innovations and new technologies, reducing greenhouse gas emissions, creating job opportunities and regional development, especially in peripheral areas. In the context of community energy, the term "community for renewable energy" is quite often used, which means a legal entity that is based on the voluntary involvement of natural persons, small and medium-sized enterprises or local authorities in the production, consumption, storage and sale of energy from RES. [3,4] The main purpose is the environmental aspect, economic or social benefits, not financial profit. At the same time, the term "self-consumer of energy from renewable sources" is defined here, which means a customer who produces electricity from RES for own consumption, can sell or store it, but cannot be its main business activity (Directive of the European Parliament and of the Council (EU) of 11 December 2018 on the promotion of the use of energy from renewable energy sources, 2018)

The state itself should support self-consumers of electricity from RES and should create such conditions that they do not have to face discrimination or disproportionate burdens, e.g. charging for their own electricity produced and consumed. Their importance in achieving climate goals and fighting energy poverty should be taken into account. [3,4] Proposals for a revised directive on renewable sources, part of the Fit for 55 energy package, are currently being discussed and applied.

In the context of the legislative framework of community energy in the EU, it is also necessary to take into account the historical development. Despite the long-term existence of citizen initiatives to engage in the production of renewable energy in some EU member states in Germany or Denmark, energy communities entered European legislation only in the last years. For example, in Denmark approximately 50% of wind capacity is owned by residents and distribution systems are owned by communities due to long-term historical development. [4]. Spain and Portugal only started adapting their legislation relatively recently in 2019, but energy communities are enjoying high popularity today. There are currently around 40 of them and typical for the Spanish communities is precisely that the geographical role does not play a role. [3,4]

Consumers should have the opportunity to join energy communities, which can take different forms, such as cooperatives, communities, associations, non-profit organizations, partnerships, etc. The energy community should mainly be oriented towards the production and provision of affordable energy from renewable energy sources, unlike ordinary energy companies whose main goal is to generate profit. (Directive of the European Parliament and of the Council (EU) 2019/944 of 5 June 2019 on common rules for the internal electricity market and on the amendment directive 2012/27/EU, 2019). In addition, community energy enables the production of clean energy, the introduction of new consumer behavior patterns and, thanks to lower rates for the supply of electricity, it can help in the fight against energy poverty. At the same time, it enables the involvement of citizens in the energy market who otherwise would not have sufficient capital to build their own resource. It thus brings added value on a social, environmental and economic level. This approach enables the faster integration of new technologies, the introduction of smart electricity meters or the modernization of the distribution network, which should be built in such a way as to motivate decentralized production (Directive of the European Parliament and of the Council (EU) 2019/944 of 5 June 2019 on common rules for the internal electricity market and amending Directive 2012/27/EU, 2019). [3,4] It is obvious that both directives appeal to the active role of the consumer as a rightful participant in the energy market. However, it is not only a unit, such as a household or a business, but a group of persons, municipalities, small and medium-sized enterprises who can participate in the production, consumption and storage of energy together. Within the framework of community energy, everyone does not have to be connected to only one consumption point, and moreover, energy consumption is not limited only to the production point. The main driving force in the implementation of community projects are primarily energy savings, possible financial profit from selling surpluses to the network, environmental protection and energy self-sufficiency are only in second place. On the contrary, the main barriers were identified as legislative obstacles and complex administration, as well as high technical and financial demands, distrust of people and limits of the transmission and distribution system, such as the impossibility of connecting to the network or the deterioration of operational reliability. [3,4]

The research shows that the most installed source is PV, followed by biomass boilers, on the basis of which it was possible to identify the main motivating factors for the construction of community projects. In the case of PV, the main factor is the financial side of the matter, i.e. savings on energy prices, the possibility of selling electricity to the grid and the generation of financial profit, which is further used in the municipality for local development. [3] In the case of thermal energy production, the main motivating factor is the need to supply the village with heat after the renovation of the old boilers, when the choice was made due to the preference for state subsidies, the environmental friendliness of the fuel. [4,5]

Energy in the city

A significant part of the society looks at the energy sector as passive consumers of energy, produced from high-performance and centralized sources, which are thermal power plants, burning primarily fossil fuels, and nuclear power plants, using enriched uranium. It is a centralized system of energy production, where there are a few energy producers in a given area, which is then distributed to all places in the region, even hundreds of kilometers away, through the electrical system and the heating network. With increasing demand to reduce the impact of global climate change, greater independence from fossil fuel supplies, with greater striving for regional self-sufficiency and in connection with reducing energy poverty, there is growing pressure for an energy transition, when society will not depend only on a few sources of energy production. An integral part of this necessary energy transformation is decentralization or distributed energy production. It is an energy model, where the sources of energy production are located near the point of consumption. [6,7] Community energy brings a new perspective on energy production, when people are not just recipients, but also producers and distributors of energy produced from local renewable sources. The people themselves thus participate in the decentralization, democratization and decarbonization of the energy sector. The primary idea of this energy production from RES is not to generate profit, but to hand over power to people in energy production, protect the environment and fight climate change and energy poverty. [8] From a social point of view, community energy means a transformation, unusual for our society, namely the transfer of responsibility for energy production to the community level. This is a kind of transfer of power from multinational companies operating in the energy industry to the people. Shift from fossil fuel burning sources to RES and clean energy. However, this change must be accepted by the people, by the given community, which must identify with the project and trust it. The key to development is therefore community acceptance of the project, its acceptance and willingness to engage. It is necessary to provide citizens with the necessary information and to pass on knowledge and skills related to the issue, so that they themselves can refine and evaluate their attitudes and needs in their ranking of values and thus avoid possible scepticism and misinformation. If the project is accepted, it is necessary that the community is really empowered to make this change, so that it is politically supported and the legislation of the given country is inclined towards the energy transformation and the related social transformation. [3,4] The energy community must have clearly set goals and visions of the project, otherwise there may be an uneven distribution of forces and conflicts within the community due to unequal expectations. Diversity among members is especially important, when, for example, in the production of energy from PV plants, the most energy is produced during the morning and midday hours. If only householders were members of the energy community, this energy would not be used. As part of the community, local educational institutions, companies or municipal buildings that can use energy in times of surplus and should also be involved. Diversity should prevail even within RES technologies, if the conditions of the given place allow it. [3,4,9] However, if the project is implemented, community energy can bring a whole range of positives and benefits to society. The first is the already mentioned self-sufficiency and independence in energy production and higher stability in the case of a well-set diversity of RES. Furthermore, lower energy prices, added value for the local region and image enhancement, as increasing awareness, related to higher attendance both by the general public and the specialist, despite the fact that it is not primarily intended to generate profit and is not built on a commercial basis. All this can bring new job opportunities directly in the region. And above all, it is one of the few ways that citizens can directly decarbonize the energy sector and fight global climate change. Here we encounter possible barriers to the development, which are, for example lack of trust in RES, their dependence on the weather, spreading misinformation, previous negative experiences, interference with the character of the landscape, stereotypes, closure to new innovations and progress, land grabbing and the high entry costs. [10, 11, 12]

From an economic point of view, this is a costly investment. In this regard, support from the state is needed through various subsidy programs and forms of assistance. It is necessary to add that with the growing demand for some renewable energy production technologies, especially for photovoltaic panels, their price is constantly decreasing and the return on investment period is thus shorter. Joining the energy community can also bring financial benefits, such as lower energy prices and the possibility of selling surpluses to the grid. Communities can also benefit financially thanks to the attendance of RES enthusiasts. This approach has the potential to modify power relations, both at the national and international level. Starting with the decreasing dependence on fossil fuel supplies from countries with non-democratic regimes and are thus a security risk for other states. [13] According to [3,4] there are three types of motivation. Based on this, the goals also differ: profitable – what will bring the most profit – to increase your financial resources, normative – based on a moral decision – how to behave appropriately and hedonistic – what seems to be the best decision at a given moment – with the aim to feel better. [15] Dóci and Vasileaiadou [16] followed up on this and defined hedonistic motivations as decisive in the short term. Therefore, if environmentally responsible behavior brings pleasure and a good feeling, people will follow it. Profits dominate in the medium to long term and mean that in order for people to decide to behave environmentally, such actions must bring them profit. Finally, normative goals people follow if they are aware of environmental problems and want to prevent them. [3,4]

To increase the chances for the success of the project, the examination of the actors involved and communication with other actors can help. Leiren et al. [17] argue that for the success of the technology, the benefits of the technology should be thoroughly communicated and any new technology strategy should also include how credible information will be provided. In this context, Trifonova [18] also claims that technologies using RES require the active participation of residents, which is different from conventional energy technologies. Despite the fact that more and more people are aware of the negative effects it can bring, there are still more pressing problems for them. An example of this is given in a study [3,4] that despite the great support for the fight against climate change, few people were willing to take individual steps to mitigate its effects.

Energy resources

From the point of view of the existence of the human race, the Sun is an inexhaustible resource that offers a huge and not yet fully utilized potential and is generally considered to be the cleanest source of production. In the case of community energy, it is not about the construction of large photovoltaic power plants plants on arable land, but about the installation of PV plants on the roofs of buildings, which under normal conditions would be difficult to use in any other way. It is FVEs that offer the highest possible potential for use, primarily in the production of electricity. Thanks to the mass production of photovoltaic panels, the increasing demand, and not too demanding installation, FVE are becoming more affordable. We can use the energy from the sun in two possible ways, namely for the production of electricity, or for the production of heating energy in the form of thermosolar systems. Despite the fact that today it is possible to install photovoltaic panels on almost every roof, there are also certain limits that should be taken into account in order to guarantee the highest possible efficiency. An important criterion for PV installation is the size of the roof exposure. Sunlight varies according to the slope of the roof, and from the point of view of using the highest possible PV efficiency. Installation of panels is possible and still advantageous even on the west and east sides of roofs. Especially in the summer months, it is possible to use solar energy earlier in the morning and later in the evening. The size of the roof area can then be a limiting factor during installation. Apart from the orientation and the size of the area, the number of hours of sunshine in the individual seasons is an important factor. This value is primarily dependent on latitude, but can be influenced by other factors as well. These include, for example, increased cloudiness, atmospheric pollution or local conditions, such as smog, which can reduce the level of radiation. [13] The most energy is generally produced in the summer months. The overall utilization of PV potential within KE is reflected in the price and availability of photovoltaic panels and other support options, such as various forms of subsidies for construction. [13]

Wind power plants (VPP) are perhaps the most discussed alternative way of obtaining energy. Parts of the public are praised and the other, on the contrary, cast into disfavor. The power of the wind, both on water and on land, has been used since ancient times through windmills for grinding flour, pressing, cutting, pumping water, etc. VPP works by converting the force of the wind into mechanical energy through the spinning of a wind turbine, which is then converted into electrical energy via a generator. VPP experienced the greatest technological boom in the 1980s and 1990s. Unfortunately, people's skepticism towards VPP probably stems from this period. Windmills at this time were quite noisy and often malfunctioned. As a result of the failure rate, a total of 7 of the 23 VPPs built at the time were removed between 1995 and 2000. The boom occurs in the new millennium with the onset of an increase in the purchase prices of wind energy. Today, the EU only accounts for a third of the installation, and wind energy is clearly dominated by China with a 55% share of all installed VPP (ČSVE, 2022). The potential that Europe offers is far from exhausted. In many ways, development is hindered by bureaucracy, complex administration, a lengthy permitting process, space for construction, physical-geographical conditions and environmental and social restrictions. Despite the fact that VPP does not change much from a visual point of view, it is technically possible today to build higher and larger power plants, which makes them more efficient and economically profitable. The ideal climatic conditions for VPP prevail in the highlands, but it is also possible to consider lowland areas that would otherwise not be used for wind energy, which increases the area for possible construction. They represent a higher financial burden on the construction itself compared to the already mentioned PV panels.

The concept of biomass is very broad, and therefore it is necessary to specify it in more detail. According to its properties, it can be divided into dry, which can be burned directly, wet, used for the production of biogas, and special, which include oilseeds, starchy and sugary crops, which are used for the production of biodiesel and alcohol. Biomass can be further divided according to whether it is grown intentionally for energy purposes, in which case it is a so-called energy crop, among which we include fast-growing woody plants, herbaceous plants, grasses, oil plants and starch-sugar plants. The second group consists of waste biomass from plant and animal production, forest waste, biodegradable municipal and industrial waste and sewage.

Biomass, which can be burned directly in boilers, includes materials of plant origin, both intentionally grown plants and residues from plant production and forest waste. Residues used in this way subsequently save costs and the energy needed for their disposal, and on the contrary bring the possibility of recovering energy. Biomass must be treated before the process itself begins, and only then is the necessary energy obtained from it during combustion, while the water content in the biomass plays an important role. With a higher percentage of moisture, an imperfect combustion process occurs, which can create harmful compounds with carcinogenic effects. Biomass has potential primarily in the production of heat at the household level, where wood chips and briquettes are used.

The limiting factor for a greater expansion of biomass burning boilers is the availability of land, which must primarily satisfy the demand for agricultural products. The targeted cultivation of biomass is also associated with the risks of excessive use of fertilizers, especially synthetic nitrogen fertilizers but also organic ones. Improper application can lead to their penetration into groundwater. The transportation of biomass must also be taken into account, when transporting it over long distances is not advantageous from an economic or ecological point of view. As also mentioned above, an important factor is the combustion process, when harmful carcinogenic substances can be formed during incomplete combustion. The main advantage is without a doubt the renewability and practically zero CO2 balance. Furthermore, as already noted, the possibility of using otherwise unused waste biomass for energy production. [14]

An efficient way to use biomass is the production of biogas in biogas stations. The main role in the production process is played by microorganisms, fungi, yeast and the process of anaerobic fermentation. This is a process where organic matter decomposes without the presence of oxygen. This process is completely natural in nature from bogs, lake bottoms to the digestive systems of ruminants or alternative coffee production. Methane bacteria play a key role in the biogas production process. They have not changed much since their creation 3–4 billion years ago, so their life cycle is dependent on an oxygen-free environment. Decomposition takes place in massive tanks, where the biomass is placed and it is heated and mixed without access to air. The biogas is discharged from the fermenter through a membrane gas collector into the storage tank, where it is treated. Subsequently, the treated gas can be used for heat production, combined production of electricity and heat, sale to the gas network or as a drive for transport equipment. [3, 4, 5, 6]

Motivation for renewable energy

If we summarize the identified motivations from the residents from the questionnaire and the main actors, the motivations of cheaper energy and environmental protection dominated. For the further development of community energy in the Slovak Republic, it will be necessary to emphasize precisely these aspects in communication with residents. The findings of this work also confirm the previous survey by SIEA, from which the same dominant motivations emerged. Furthermore, we can state the prevailing support for the concept in the affected apartment buildings, as well as for the increase of RES in the energy mix. However, compared to the motivations for community energy abroad, the social aspect is significantly lacking in our country, and thus, for example, the interest in strengthening relations. [3,4] The literature also shows that residents are more willing to participate in changes if other residents in the community participate and not just their personal beliefs. It is thus possible that if the will to build social relations is absent, this fact will not play a role and it will be more difficult to convince people. The identified perceived barriers on the part of residents are also similar to the results from foreign literature (e.g. [3, 15, 16]). The barriers are diverse, not one dominates, while they result mainly from legislative causes and concerns about lack of funds. However, since not a single resident indicated that they felt well-versed in the issue and only 23.5% of respondents indicated that they had enough information about the concept, these concerns may stem from what is communicated to them by the representatives of the apartment owners or the founder. which also differed. This can also explain the relatively most frequently mentioned concern about technical problems, which was mentioned by all representatives of apartment owners. Trust in the “leading” person can have a great influence on these answers. An interesting result is that respondents who indicated that they had not heard of the concept until now (20.6%) would “definitely” or “rather” support the creation of such a energy community in their place of residence and they also support the increase of RES in energy. This confirms the so-called “value-belief-norm” theory, which claims that people will support a new RES technology, even if they do not know it at all, if they have pro-environmental values. [3,4]

This also indicated that they would be motivated by environmental and financial reasons. However, it is possible that this finding may also mean a possible complication in case of possible problems in the community. Indeed, these respondents indicated the most frequent answer that this concept will only be talked about, but there will be no result from it, which could influence their will. However, the question also arises from this finding, how is it possible that they have not heard about the concept of energy communities, if they are supposed to be in one. [3, 4, 5] The communication strategy within the community is so remarkable and it is necessary to remember that if people do not get enough high-quality information about the concept, they will not build trust in community energy. Increasing the acceptance of community energy is one of the key directions of the future of energy, as publications also mention. It also turned out that those residents who knew about the concept, but were not interested in participating in it despite their support, were more likely to be in the older age categories. The results show that high support for the idea of the project does not automatically mean interest in active participation for its start-up or operation. This is also confirmed by the phenomenon present in the literature, the so-called "value-action gap", which indicates the difference between what a person declares and what he would actually do. In the questionnaire, people also expressed their concerns that would discourage them from joining the project, especially the lack of time and information. This phenomenon is also explained by behavioral economics, which means that people prefer immediate solutions. The theory of planned behavior can also be relevant, when the perception of shortcomings negatively affects the attitude towards innovation the interviews also revealed that cities could become potential key carriers of community energy and that there are not only technical barriers, such as the absence of smart metering systems in households, which was also mentioned in the literature as one of the important prerequisites for development. Also was perceived insufficient incentivization of communities through market benefits is also a questionable obstacle resulting from the socio-technical transition, as some actors identified the disconnection from the distribution systems as problematic and others, mainly representatives of state authorities rejected this claim. It is thus possible that a misinterpretation occurs in the process. [3, 4]

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The Ecological Environment of Ukraine as a Factor in Climate Change within the Context of Achieving SDGs

In the past decade, the world has faced a series of challenges, the protracted resolution of which is driving humanity toward the brink of a global catastrophe. This crisis threatens to leave future generations grappling with the quest for survival in an ever-evolving world.

The current generation, recognizing the rapidly approaching threat, is making concerted efforts to eliminate or mitigate negative factors by addressing their sources. However, the future safety and sustainability of human existence now hinge exclusively on the collective efforts of all nations. Only a coordinated global policy will yield a positive synergistic effect in preventing the emergence of global threats to humanity.

Unfortunately, all the threats of future shifts in the factors that will ensure the livelihoods of future generations of humanity are being formed today and are related only to the activities of current and previous generations. Today, humanity is not only influencing the development of human consciousness, changes in the culture of human

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behaviour, technological modes of production, digitalisation of production processes and services, but also changing the natural ecosystem.

Global changes in the human ecosystem are driven by factors that are caused by the fundamental needs of humanity. For example, the need for electricity, heating, fuel, and agricultural products stimulates economic activity related to their satisfaction. The growth of needs increases their supply, and, accordingly, the negative consequences of such production increase.

Greenhouse gases, produced as a byproduct of increasing industrial activity, contribute significantly to adverse climate change. This leads to gradual alterations in the ecosystems of specific geographical regions, changes in agricultural land and crop yields, rising global temperatures, and an elevated risk of floods and cyclones.

The trend of population growth and increased production of goods that support their livelihoods generates forecasts of further growth in global greenhouse gas emissions.

According to the UN World Meteorological Organisation (WMO), the average global temperature has risen by almost one degree Celsius over the past five years.

The reason for this increase is the rapidly growing concentration of greenhouse gases in the Earth's atmosphere. The primary greenhouse gases present include water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ozone (O_3), sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs).

In 2020, carbon dioxide (CO_2) concentrations increased to 149% of pre-industrial levels before 1750, when human activity began to disrupt the Earth's natural balance. The concentration of methane (CH_4) increased to 262% and nitrogen oxide (N_2O) to 123% [1].

Under the Paris Agreement, countries have pledged to jointly work towards limiting the long-term global average surface temperature to below 2°C above pre-industrial levels and to strive to limit the temperature increase to 1.5°C by the end of the century. This is crucial, as each 0.1°C rise in temperature triggers irreversible climate change processes. It provides that all states, regardless of their level of economic development, are obliged to reduce emissions into the atmosphere. Since its entry into force, 195 countries have acceded to it, and 186 countries, including Ukraine, have ratified it.

Our country has announced its intention to achieve climate neutrality by 2060. Ukraine's first Nationally Determined Contribution (NDC) set out its commitments to the global community, which included a target of no more than 60% of 1990 levels of greenhouse gas emissions in CO2 equivalent by 2030. In 2018 (according to the latest greenhouse gas inventory), Ukraine's total emissions amounted to 344.07 million tonnes of CO2 equivalent, which is 38% of the 1990 level. In 2021, the Ministry of Ecology proposed to submit an updated National Determined Contribution with a more ambitious goal: to reduce emissions to 34.8% of 1990 levels. The main emission generators are subject to monitoring: energy, industry, agriculture and waste management. Relevant scenarios have been developed based on the rate of economic development and other parameters.

Ukraine, as a party to the UN Framework Convention on Climate Change, the Kyoto Protocol, and the Paris Agreement, strives to fulfill its obligations under these international agreements. However, state policy on climate change remains fragmented and has traditionally been viewed solely as part of environmental policy. This situation has changed little, despite the existence of strategic regulatory frameworks and identified implementation tools in this area, which require revision. This is particularly necessary in light of European integration processes and the need for alignment with broader European policies.

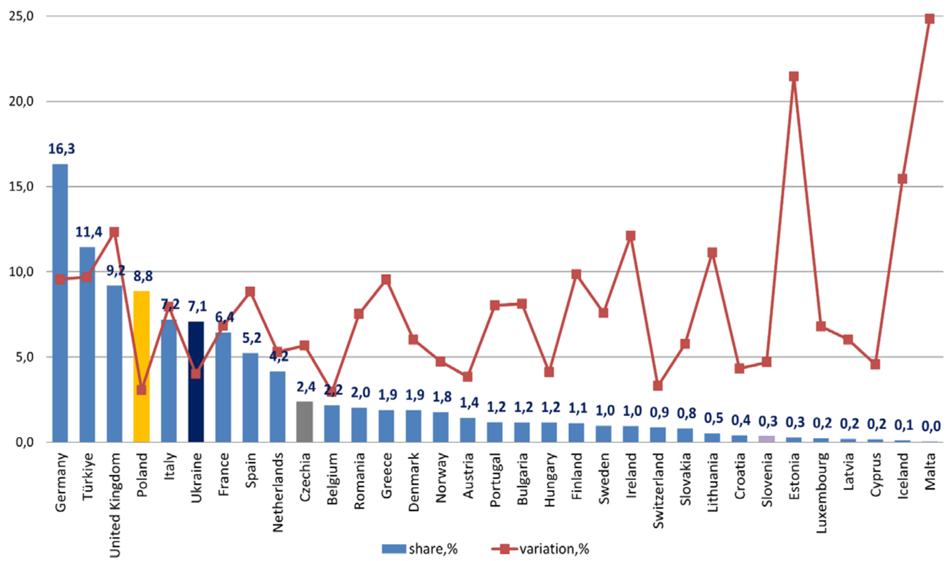
Ukraine, with its considerable industrial, agricultural, and social potential, has experienced a rise in air temperature as a result of its development. Data from the Ukrainian Hydrometeorological Center indicate that over the past thirty years, the average annual air temperature across Ukraine has increased by 1.2°C. It has been established that the rate of temperature rise from 1975 to 2020 in Ukraine ranges from 0.61 to 0.82°C per decade, whereas in neighboring countries it is 0.47 to 0.59°C per decade, and in the Northern Hemisphere and Europe, it is 0.34 and 0.47°C per decade [2]. These data suggest that the rate of temperature increase in Ukraine is significantly higher compared to both global and European averages.

In view of the above relevance of the research on greenhouse gases and climate change, based on the current level of global research and in the context of achieving certain objectives in the field of sustainable development, it should be noted that the issues of analysing the main factors of economic, social and environmental activities, assessing their local and total impact on greenhouse gas emissions in each country of the world remain poorly investigated. However, from the perspective of socio-economic development in the general civilisation context, this issue is also challenging, which is emphasised in the IPCC reports.

That's why the climate change is a pressing global problem that requires action at the local, national, and international levels, in particular in the context of sustainable development. Ukraine has joined the SDGs and started an inclusive process of achieving them. Our country has adapted the SDGs to national realities. As a result, we have developed a national system of objectives, which identifies environmental issues as key) challenges for Ukraine. This challenge sets us the strategic goal of ensuring environmental balance in the context of economic and social objectives. This strategic goal is actualized primarily by the achievement of SDG 13. Let's focus on the main trends in emissions and the factors that determine them.

In 2020, Ukraine accounted for about 7% of total European carbon dioxide emissions and was ranked among the countries that have the greatest impact on the greenhouse effect in Europe. According to the figure, Estonia, Iceland, and Malta showed the largest changes in emissions over the analyzed period. Meanwhile, Ukraine and Poland are countries with low volatility in carbon dioxide emissions (fig.1).

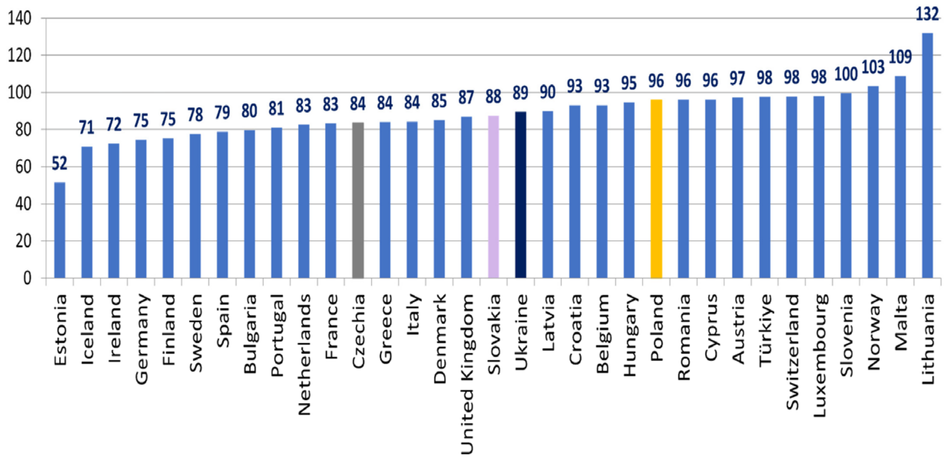
Figure 1. Share of CO2 Emissions in the Total Volume 2020 (variation 2016–2020)



In a long-term analysis, the Visegrad countries demonstrate a reduction in CO2 emissions per USD of GDP. However, despite the significant reduction in emissions, Ukraine had a higher level of CO2 emissions than European countries.

To evaluate the efforts of countries in implementing international agreements on reducing greenhouse gas emissions, tools of dynamic and mathematical statistics were applied, enabling the identification of variability indicators in CO2 emissions. The variation in CO2 emissions in European countries and Ukraine from 2012 to 2020 demonstrates changes in emissions relative to their average levels in each country. The reduction in carbon dioxide emissions in 2020 compared to 2016 is 48% in Estonia, 11% in Ukraine, and 4% in Poland. The application of dynamic analysis methods for emissions enables the identification of specific trends in the observed changes (Fig. 2).

Figure 2. Dynamics of CO2 emissions for 2016–2020, %

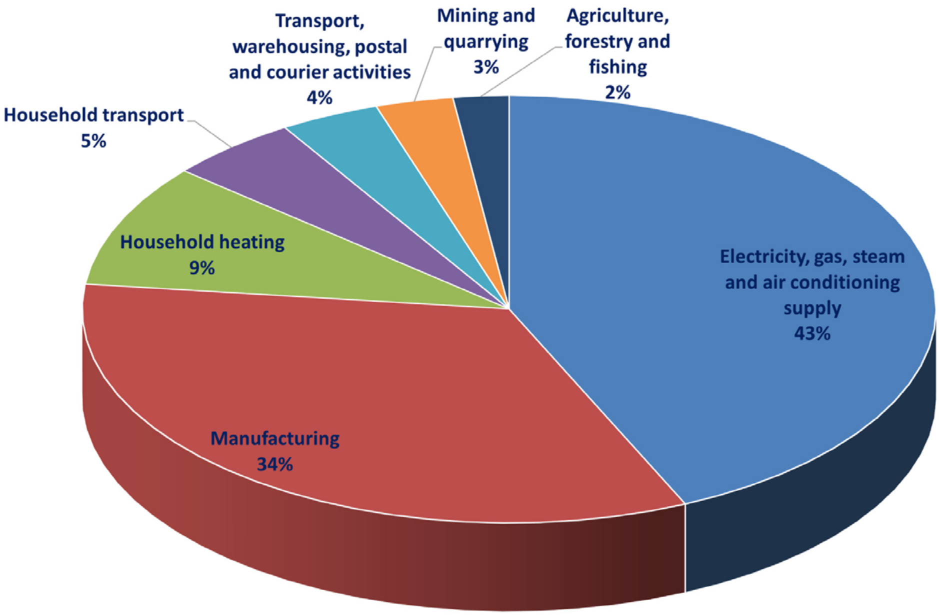


In 2016–2020, total carbon dioxide emissions ranged from 215 to 240 thousand tonnes (Fig. 2) Despite the volatility of CO2 emissions, the share of their producers remained virtually unchanged, as shown in Fig. 1.

It should also be noted that the implementation of the SDGs, in particular in the context of this study, in each of the European countries and Ukraine is proceeding at different rates and with different impacts on solving the overall problem of reducing the negative impact of climate change. This is already evident both in each country and globally. According to The first Ukraine VNR, the integrated assessment of progress in achieving the Goal 13 was ranked as almost unattainable even before russia's full-scale intervention.

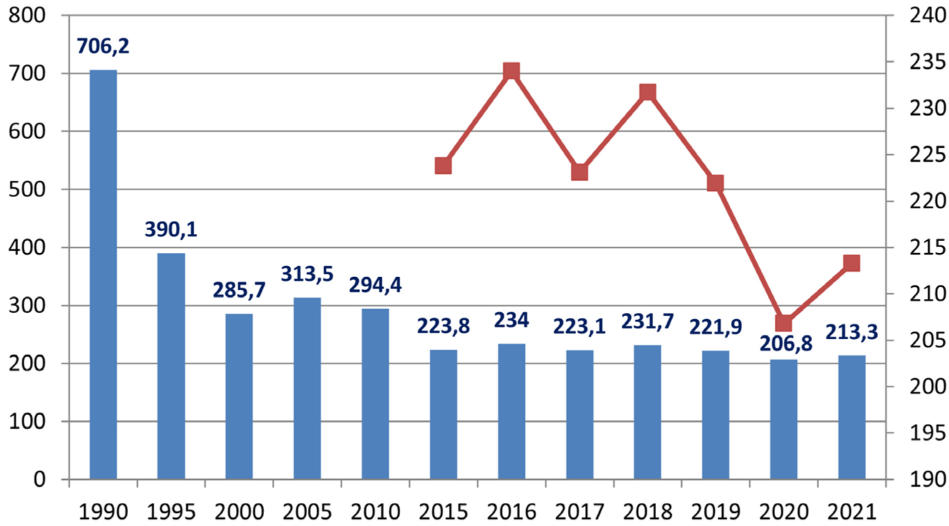
Carbon dioxide emissions account for the largest share of greenhouse gases. Ukraine is no exception. In Ukraine, carbon dioxide is produced by households and all types of economic activity. Carbon dioxide emissions by households are associated with the use of vehicles and operation of individual Heat supply systems. At the same time, the amount of carbon dioxide emitted into the atmosphere as a result of the use of fossil fuels and biomass for heating is about 2 times higher than the amount of this gas emitted from the use of individual transport. The largest amount of carbon dioxide is emitted into the atmosphere as a result of the economic activity of thermal power stations and processing industry enterprises (Fig. 3).

Figure 3. Structure of Methane Emissions by Sectors into the Atmospheric Air in Ukraine 2020



Regarding Ukraine's CO2 emissions management policy, it is important to note that conclusions about its direction can be found in two retrospective periods: long-term and short-term. Thus, in the long-term retrospective of 1990–2020, the CO2 emissions management policy shows indicators of sustainability with minor deviations from previous values (Fig. 4) Thus, strategically, Ukraine is on track to reduce CO2 emissions and reduce its share of the greenhouse effect.

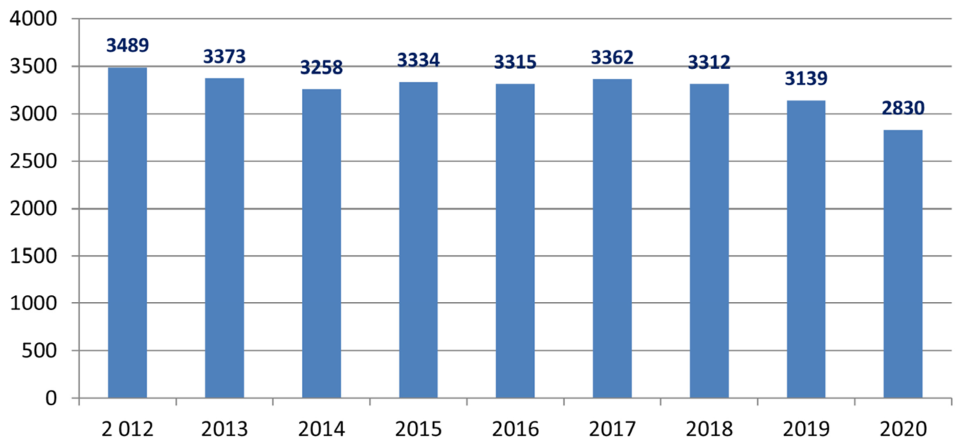
Figure 4. Histogram of CO2 emissions in Ukraine (red – auxiliary axis), million tonnes



This research presents a statistical analysis of the CO2 emissions without analysing the factors influencing the performance indicators.

In European countries, there is a consistent CO2 distribution in the period 2017–2020.

Figure 5. Histogram of CO2 emissions in Europe, million tonnes



Despite the volatility of the quantitative parameters of carbon dioxide emissions, the share of their producers remained virtually unchanged. In the long-term period, we can say that Ukraine is heading towards reducing its carbon dioxide emissions and reducing its share of the greenhouse effect. However, in the short term, there is an asymmetry in the distribution of Carbon dioxide emissions over the past seven years. A comparison of the histogram of CO2 emissions in Ukraine and European countries allows us to conclude that there are different features of their quantitative emissions. Thus, CO2 emissions in Ukraine are characterized by their asymmetry, while in European countries they are consistent.

According to the structure of carbon dioxide emissions shown in Figure 3, the largest producer of carbon dioxide is electricity, gas, steam and air conditioning.

In 2020, Ukraine was one of the largest producers of electricity in Europe. Electricity generation was carried out by various types of generating facilities: thermal, nuclear, hydroelectric, solar, and wind power plants. In the total volume of electricity produced in 2020, 52% was generated by nuclear power plants, and 35% by thermal power plants, which are the primary emitters of CO2 into the atmosphere. Taking into account the consequences of the war, thermal power plants have become the main producers of electricity. In a single day, thermal power plants consume 57.2 thousand tons of coal [3]. The combustion of 1 ton of coal releases 0.102 tons of CO2. The combustion of 1 cubic meter of natural gas (methane) produces approximately 2 kilograms of carbon dioxide [4]. Thus, the daily CO2 emissions of the thermal power plant amount to 57.2 thousand tons * 0.102 = 5,834.4 tons.

Since the largest producer of CO2 is the electricity and steam production sector, a study was conducted to assess the dependence of CO2 emissions on the type of generating enterprises. The application of a simple methodology for calculating pairwise correlation dependencies allowed the creation of a hierarchy of the influence of different types of electricity generation on CO2 emissions. The strength of the relationship between CO2 emissions and the volume of electricity produced by thermal power plants and cogeneration plants is confirmed by correlation coefficients. The close correlation between the sampled indicators suggests that thermal generation is the primary source of CO2 emissions.

Unfortunately, coal, oil, and gas remain the primary resources for electricity generation in most countries around the world. The mere fact that fossil fuels are used for electricity production is not an indicator of a significant impact on the greenhouse effect. The substantial influence arises from the volumes of electricity generated by thermal power plants, which are dictated by the economic needs of countries worldwide.

The source of greenhouse gas emissions includes activities related to the production of thermal energy (steam). The highest correlation between CO2 emissions and steam generation has been identified in the operations of boiler houses ($R^2 = 0.9$), thermal power plants ($R^2 = 0.77$), and combined heat and power plants ($R^2 = 0.73$). In Ukraine, boiler houses produce 60% of thermal energy.

Industrial production is the second-largest source of CO2 emissions among economic activities. In Ukraine, the metallurgical sector has been one of the primary polluters of the atmosphere, including carbon dioxide. The steel industry is classified as an energy-intensive sector with significant greenhouse gas (GHG) emissions: approximately 7% of global GHG emissions are generated during the production of pig iron and steel (2019).

In Ukraine (2020), the steel industry accounted for nearly 14% of the country's annual GHG emissions (or almost 57% of the annual GHG emissions from the country's industrial sector) and is a critical sector in terms of reducing GHG emissions: it is responsible for 88% of the planned overall reduction of GHG emissions in the country's industry by 2030. The formation of carbon dioxide (CO2), the primary type of GHG in the steel industry, occurs throughout the technological chain of metallurgical processes, resulting from the combustion of organic carbon-containing fuels, as well as from the oxidation of carbon and the chemical decomposition of carbon-containing raw materials and energy carriers provided for production processes. Although the phasing out of open-hearth furnaces has contributed to a reduction in the environmental burden from metallurgical enterprises.

According to the German Institute for Energy and Environmental Research Heidelberg, the carbon footprint of many food products in Germany is significantly higher than that of steel. For example, the average specific emissions from converter steel production in the EU are 1.95 tonnes, which is almost the same as honey or half that of milk chocolate.

The impact of each country in Europe and Ukraine in creating general trends in climate change can be assessed using the ABC-XYZ analysis methodology, which is based on the Pareto principle, which in the context of this research allows us to identify a small share of countries whose emissions contribute to 80% of the total emissions of the selection. The division into ABC groups was based on the criterion of emissions volumes, while the division into XYZ groups was based on the criterion of their variation over the period 2012–2020. The combined matrix of distributions made it possible to identify the main greenhouse gas producers and countries whose CO2 emissions are a relatively variable characteristic (Table 1).

Table 1. Grouping of European countries and Ukraine by their share in total emissions and emissions variation for 2012–2020

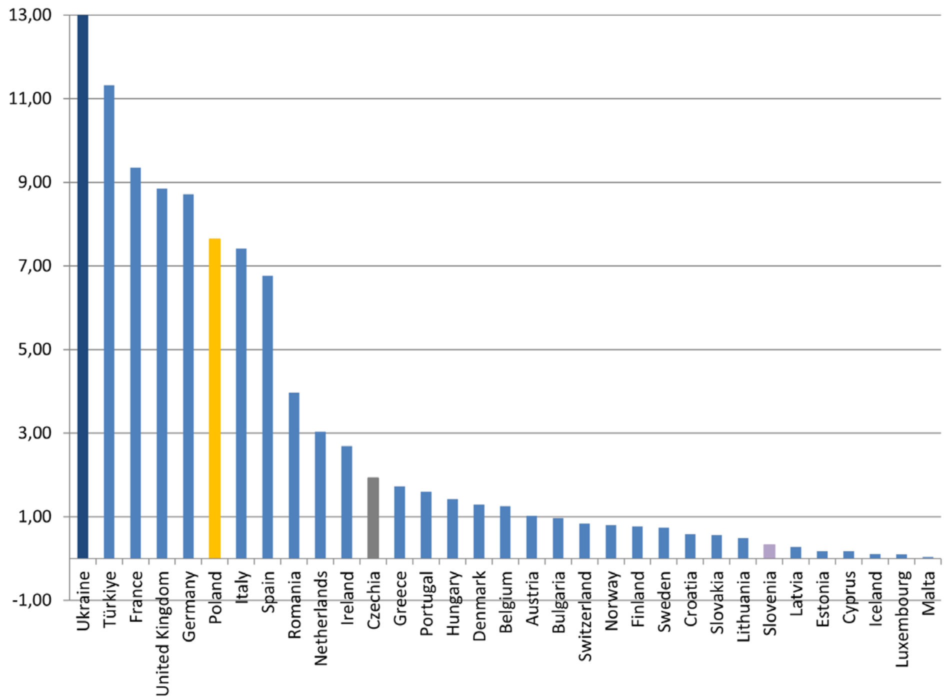
	A (more than 80% of total emissions)	B (15% of total emissions)	C (5% of total emissions)
X (variation to 10%)	**Ukraine** **Poland** Czechia France Spain Netherlands Italy	Portugal Hungary Denmark Belgium Austria Bulgaria Norway Sweden Cyprus Romania	Switzerland Luxembourg Latvia Slovenia Slovakia Croatia
Y (variation 10–25%)	Germany Türkiye United Kingdom	Ireland Greece Finland	Lithuania Iceland Malta Estonia
Z (variation to more 25%)	–	–	–

The matrix visualization of the results reveals the position of each country in the total impact on the greenhouse effect and reveals the level of sustainability of emissions in the selected time horizon (2016–2020).

According to our research, We can summarize that Ukraine is one of the 9 countries that account for 80% of greenhouse gas emissions and one of the 6 countries in the sample that demonstrated relative stability in their emissions until 2020.

Despite the smaller amount of methane produced compared to carbon dioxide, methane has the ability to trap approximately 30 times more heat than carbon dioxide. Approximately 60 percent of methane emissions are caused by human activity. Ukraine is the leader among European countries in terms of methane emissions into the atmosphere, taking the first place in the total methane emissions of the EU and Ukraine.

Figure 6. Share of methane emissions into atmospheric air in the total emissions of Europe and Ukraine

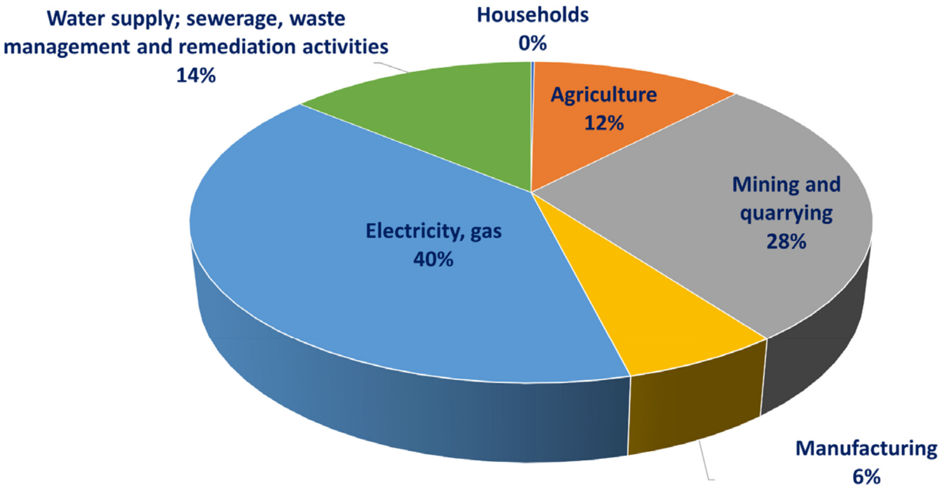


Each type of economic activity has a different impact on the formation of greenhouse gasses (GHGs). Among the primary contributors to methane production in Ukraine are gas supply enterprises (40%), the extraction of minerals and quarrying (28%), and livestock farming (12%).

The main leaders in methane production in Ukraine are gas supply enterprises, extraction of minerals and quarry development, and livestock farming. The largest sources of methane emissions in Ukraine are coal mines, as well as the production, transportation, storage, distribution and consumption of oil and natural gas.

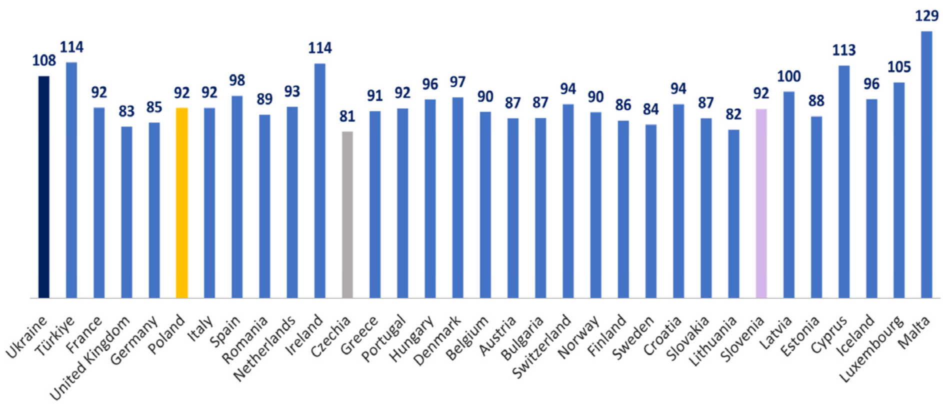
Sources of methane emissions in Ukraine are almost identical to global sources of air pollution. According to the International Energy Agency (IEA), coal-related activities are responsible for the largest part of methane emissions in the energy sector in 2021, which was around 40% of all gas emissions, with coal-related activities at 42 million tonnes, and the oil industry slightly less, at 41 million tonnes. Natural gas processing and transmission activities are in third place in total emissions, with 39 million tonnes [5].

Figure 7. Structure of sources of methane emissions into atmospheric air in Ukraine, % (Greenhouse gases: Nitrogen, Methane)



As for the trends in the implementation of global agreements to reduce methane emissions, it should be noted that, unlike the decarbonisation policy, the volume of CH4 emissions from Ukraine and the EU countries over the 10-year period has not shown a steady downward trend. In some countries, on the contrary, their volume has increased.

Figure 8. Trends in the amount of CH4 emissions in the EU and Ukraine



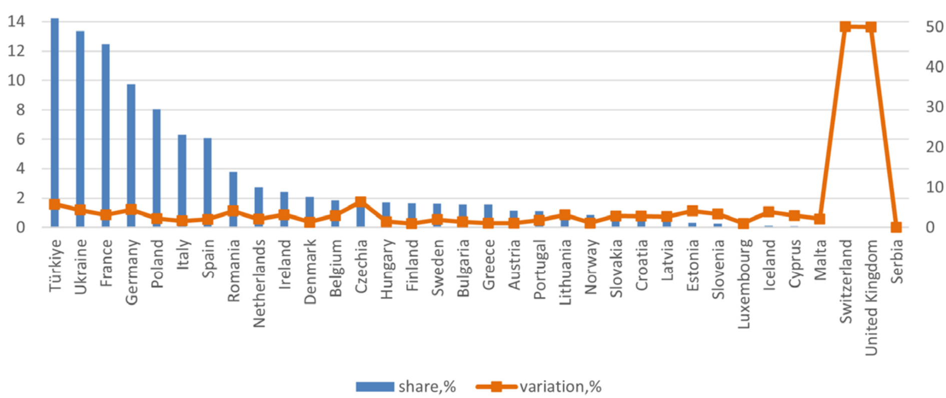
The use of the methodology of grouping EU countries and Ukraine by the criteria of their contribution to total emissions and variation (deviation from the average) allowed the whole group of EU countries to be divided into 3 groups, in which Ukraine is one of the countries with the largest and most constant CH4 emissions (Table 2).

Table 2. Grouping of European countries and Ukraine by their share in the total volume and variation of CH4 emissions for 2012–2020

	A (more than 80% of total emissions)	B (15% of total emissions)	C (5% of total emissions)
X (variation to 10%)	**Ukraine** Türkiye France United Kingdom Germany **Poland** Italy Spain Romania Netherlands	Ireland Czechia Greece Portugal Hungary Denmark Belgium Austria Bulgaria Switzerland	Norway Finland Sweden Croatia Slovakia Lithuania Slovenia Latvia Estonia Cyprus Iceland Luxembourg Malta
Y (variation 10–25%)	–	–	–
Z (variation to more 25%)	–	–	–

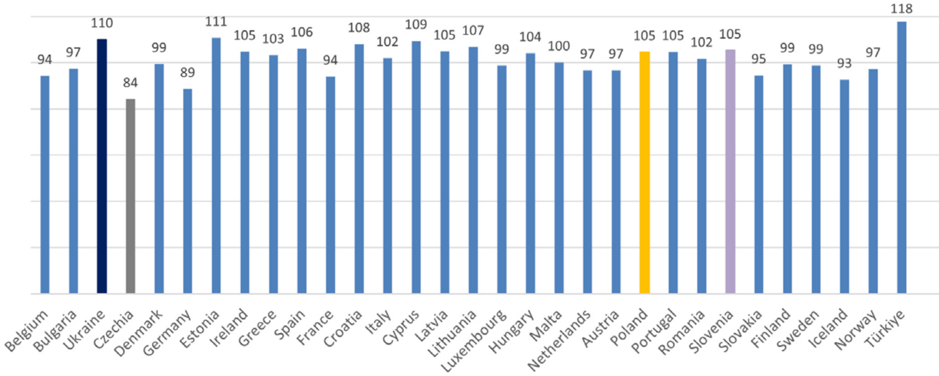
Nitrous oxide is a much stronger greenhouse gas than carbon dioxide in terms of its warming potential. Over a 100-year timescale, and without considering climate feedbacks, one tonne of nitrous oxide would generate 265 times the amount of warming as one tonne of carbon dioxide. The average 'lifetime' of nitrous oxide in the atmosphere is around 121 years. This is typically shorter than carbon dioxide, but longer than methane. The share of nitrogen oxide emissions in 2020 is significant in the total emissions of European countries, as well as other pollutants.

Figure 9. Share of N2O Emissions in the Total Volume 2020 (variation 2016–2020) [6]



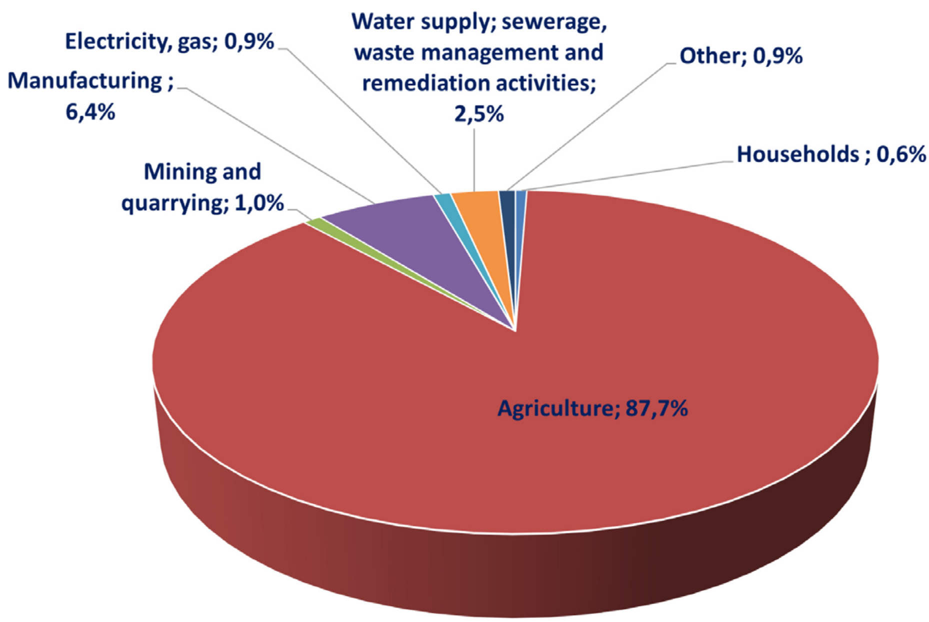
It is characterized by negative growth dynamics.

Figure 10. Rate of Change in N2O Emissions from 2016 to 2020, % [6]



Agriculture is the largest source of nitrous oxide emissions in Ukraine, accounting for 87.7% in 2020 and 87.9% of total nitrous oxide emissions in 2021. Emissions in this sector come from agricultural soils. In addition, grain production was found to be the most correlated with nitrous oxide emissions. According to the data, the volume of nitrogen fertilizers in Ukraine has increased 8.5 times over the past 20 years, which, in turn, increases nitrous oxide emissions.

Figure 11. Sources of nitrous oxide emissions in Ukraine



19% of agricultural sector emissions are caused by intestinal fermentation in animals. Activities such as manure management, liming, and urine use together account for less than 4% of emissions. A retrospective analysis of CH_4 emissions and production of the main categories of the Livestock sector shows the highest correlation of emissions with the number of cattle.

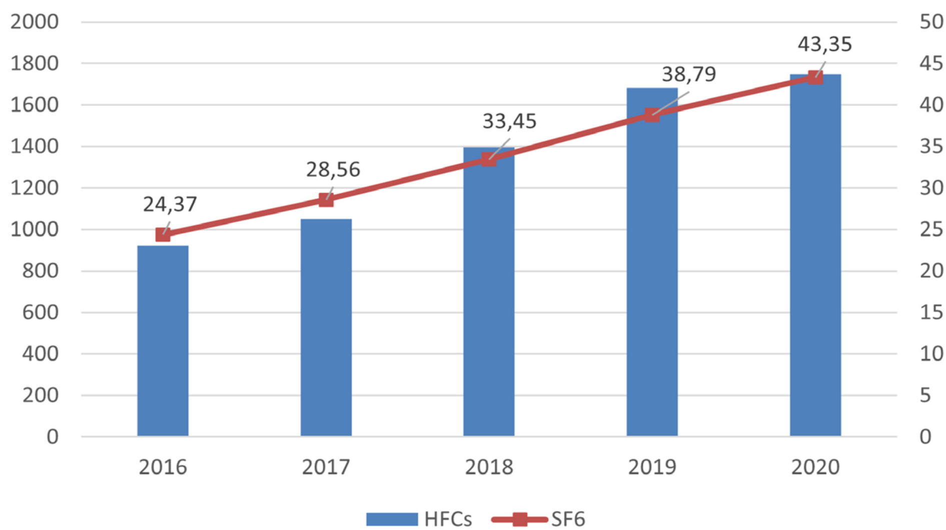
To overcome the exogenous barriers to yield development, determined by natural climatic conditions and the properties of sown areas, the sector aims to increase the level of nitrogen fertilizers and the use of protective equipment. It is the increased use of nitrogen fertilizers that increases N_2O emissions.

Dynamics of production of fertilizers and nitrogen compounds at domestic chemical companies, a thousand tonnes [7]. Over the past 20 years, the volume of nitrogen fertilizer application in Ukraine has increased 8.5 times [8].

The second largest sector by nitrogen oxide emissions is IPPU sector – 5.7 % of the totals in 2021. The key sources of emissions in this sector are production of nitric and adipic acid, as well as use of nitrous oxide for medical purposes. In the Energy sector emissions of N_2O had a 3.5 % of share in total emissions of the gas. Moreover, N_2O emissions occur in the Waste sector (2.5 %).

We would also like to emphasize the emissions of f-gases. The emissions of these gases are relatively small compared to the carbon dioxide, but they can remain in the atmosphere for hundreds of years, "locking" warmth inside the atmosphere. In particular, hydrofluorocarbon refrigerants are considered to be several thousand times worse than carbon dioxide. HFCs emissions are associated with production and maintenance of refrigerators, air conditioners, use of fire extinguishing systems, foams and aerosols. The figure shows the growing dynamics of these emissions of HFCs and PFCs in Ukraine in 2016–2020.

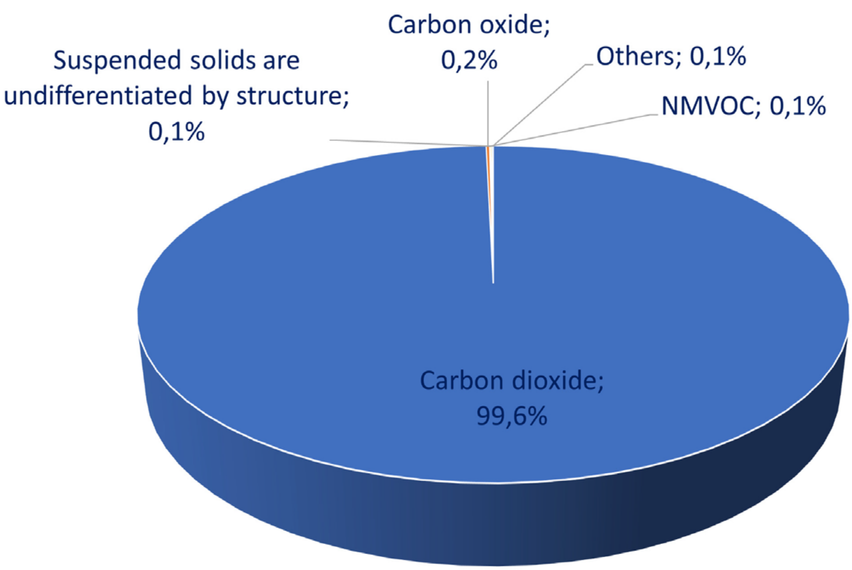
Figure 12. Emissions of HFCs and PFCs in Ukraine in 2016–2020 [9]



The increase of the emissions in 2021 are associated with growth in HFCs imports in some categories, as well as with HFCs that stayed in operated equipment. Since HFCs and PFCs are not produced in Ukraine, potential emissions of these gasses are determined only by their imports and exports. Emissions in Ukraine are not much significant in terms of volumes in comparison with total GHG emissions (0.6% of the total emissions in 2021).

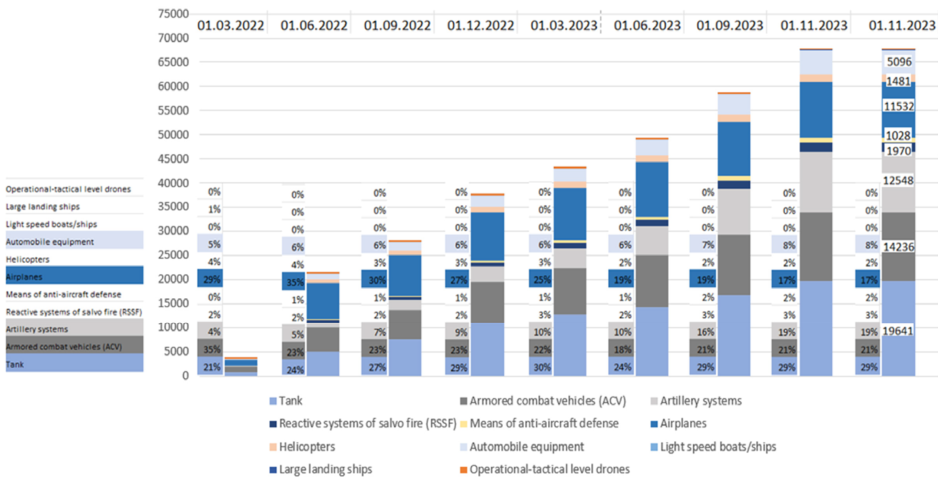
Today, there are unusual and very dangerous environmental pollution factors in Ukraine. Russia's invasion of Ukraine on February 24, 2022, took place along the whole common border and partially from the territory of Belarus. In this way, particularly all climate zones of Ukraine were covered by military actions, which has led to catastrophic environmental impacts, the results of which can only be assessed after the complete de-occupation of the territories of Ukraine. The Ministry of Environmental Protection and Natural Resources of Ukraine has created a methodology for calculating emissions of pollutants from different types of destroyed Russian military equipment. Official data on the destroyed military equipment of Ukraine is not available, because it has been the confidential information. According to this methodology, 99% of the pollutants that are released into the air, water and land from destroyed military equipment are CO2.

Figure 13. Total CO2 emissions from destroying each type of military equipment in tons



According to approximate estimates, the total CO2 emissions from the destroyed Russian equipment as of November 1, 2023, are about 80 thousand tons. In the structure of CO2 emissions, the largest part is contributed by: tanks – 29%, armored combat vehicles – 21%; artillery systems – 18%; aircrafts – 17%. In addition, according to approximate estimates, by February 2023, the total emissions from the usage of munition were about 1.6 million tons of CO2 equivalent. Each explosion of munition is followed by the emission of a complex chemical that settles in the soil and reduces plant growth for years, as well as the population of soil animals and bacteria.

Figure 14. CO2 emissions caused by the war in Ukraine



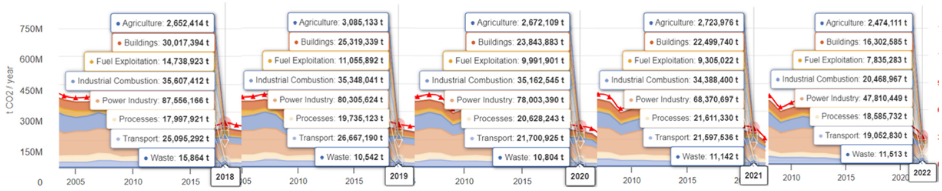
As of October 2022, hundreds of oil storage facilities have been damaged by Russian shelling, with widespread fires and oil emissions into the environment. Flooding of mines leads to pollution of wells and open water sources in the surrounding areas with highly mineralized mine water.

The Ministry of Environmental Protection and Natural Resources of Ukraine has created a website that collects data on environmental damage based on reports from local authorities and civilians who can report damage through a special app. It is called "Ecozagroza" it is like Ecological Threatening.

With the exception of war, In Ukraine, the largest CO2 emissions are generated by the metallurgical sector. As part of its decarbonization strategy, Ukraine's metallurgical sector has begun to gradually change its production approaches with the implementation of electric melting facilities. By the way, Ukraine was currently one of the largest electricity producers in Europe. In addition, 52% of the total electricity generated in 2020 was produced by nuclear power plants and 35% by thermal power plants, which are the main suppliers of CO2 to the atmosphere. Due to the war, thermal power plants became the main producer of electricity.

It is also important to note that the growth of the construction sector has led to an increase in CO2 emissions. In Ukraine, new buildings often use individual heating and their own boiler rooms, which leads to increased CO2 emissions. The reduction in CO2 emissions since 2015 can be explained, on the one hand, by the implementation of decarbonization strategy, and, on the other hand, by the occupation of regions in 2014 by russia, which contain a significant number of industrial facilities that produce a major amount of greenhouse gasses. However, since the beginning of Russia's full-scale invasion of Ukraine, the volume of pollutant emissions has significantly increased.

Figure 15. CO2 emissions from different sectors of Ukraine's economy in tons



According to data from the United Nations, Russia's war against Ukraine could disrupt the achievement of climate change reduction goals. Therefore, the window of opportunity for limiting the temperature rise to 1.5°C by 2100 is getting narrower. Greenhouse gasses, generated in Ukraine, will contribute to global warming. In addition, the military industry is growing, which is very energy-intensive and additionally emits greenhouse gasses.

In general, greenhouse gas emissions in Ukraine align with the structure and trends observed in Europe and globally. For instance, 24% of global CO_2 emissions are attributed to industrial production, 16% to transportation, 17.5% to energy use in buildings and other sectors, 18.4% to agriculture, and 3.2% to waste management. The largest emissions of greenhouse gases are generated from the combustion of associated gas in oil and gas production, as well as from gas combustion in the power sector [10].

All of the above is the basis for the conclusion that the processes and technologies of decarbonising economic activity are integrated. Thus, it can be concluded that a study of the impact of greenhouse gases on climate change, based on Ukrainian data, will mostly reflect their global average trends.

As noted above, the greenhouse gas emissions are generated by the industrial sector of the economy, agriculture, and transport. However, the negative impact of greenhouse gas emissions generated by industrial factors can be partially reduced by the area and quality of their absorption by the planet's ecosystem.

Healthy forests and oceans act as carbon sinks. Given that an average plantation will absorb 6 tonnes of CO2 per hectare per year and release 3 tonnes of oxygen [11] and an average of 400 trees grow on 1 hectare [12], 1 hectare of forest absorbs an average of 400*6=2400 tonnes of CO2 per year.

Considering Ukraine's forest area of 9.6 million hectares, carbon absorption could reach a maximum of 57.6 million tonnes per year, on condition that all forests are of medium age. In 2020, economic activity in Ukraine generated 232 million tonnes of CO2. Therefore, the level of CO2 absorption by forests is 25% of the carbon produced. Based on the different age structure of forest plantations and the balance between the area of forest renewal and the area of forest losses, the actual level of CO2 absorption by forests may be significantly lower than the estimated level. As a result, about 174.4 million tonnes of carbon is generated annually in the atmosphere. And this balance will show a tendency to grow fast unless humanity changes its behaviour regarding greenhouse gas emissions and intensifies its efforts to prevent their generation.

Households and enterprises are the primary sources of greenhouse gas emissions. According to the National Statistics Committee of Ukraine, households accounted for 14.05% of the total carbon dioxide emissions in 2020. Statistical sources of household greenhouse gas emissions include transportation and heating. Non-statistical sources are the seasonal burning of plant residues and the heating of private homes. While the burning of residues is a localized, infrequent event with significant one-time CO2 emissions, heating private homes involves a prolonged 4–6 month process with relatively small, daily carbon emissions.

These emissions are significant environmental pollutants, contributing to increased greenhouse gas concentrations in the Earth's atmosphere and exacerbating public health issues.

Comparative characteristics of the condition of urban and rural population of Ukraine with cancer were carried out by medical scientists I.B. Shchepotin, Z.P. Fedorenko, A.V. Gaisenko, L.O. Gulak, A.Y. Ryzhov, E.L. Gorokh, O.V. Sumkina, L.B. Kutsenko [13] and showed that rural and urban population of Ukraine have different rates of cancer incidence. Despite the fact that the research was based on statistics from 1969–2007, its results have been confirmed by later generations of scientists. Regardless of the time of the research, scientists agree that cancer rates in urban populations are higher than in rural areas.

Despite the influence of a wide range of urbanization factors on the morbidity rate of urban populations, air quality remains a key component contributing to the rise in disease levels. Lower concentrations of stationary pollution sources, a higher number of green spaces per 100 rural inhabitants, the free movement and faster circulation of air masses all contribute to reducing the rate and concentration of harmful emissions in rural areas.

In the structure of CO2 emissions in Ukraine, the share of emissions from household and economic transport activities ranges between 8–10%. Considering the value chain involved in the production and life cycle of a vehicle, all participants responsible for CO2 emissions can be conditionally divided into several personalized groups.

Table 3. Grouping of participants responsible for CO2 emissions

Formation subjects	Groups of participants
Proposals	producers of automobile engines and other components
	car producers
Demand	sers of cars and lorries
Related offer	fuel sellers
	vehicle service and technical assistance
	producers of spare components
	entities that recycle separate parts of a car

Based on the basic laws of economics, in particular the law of supply and demand, we will research the impact of car supply on the dynamics of CO2 emissions. For this reason, based on the structure of the car value added chain, we will divide all its participants into a group according to their influence on the supply and demand for cars.

The entities involved in the supply chain of direct and related automobile offerings, while not being direct consumers of fossil fuels, are consumers of electricity. The method of electricity generation influences CO2 emissions. Their production capacities determine the amount of electricity consumption.

The entities that generate demand for automobiles, such as individuals and legal entities (particularly transport companies), consume the available supply of automobiles. The source of CO2 emissions during vehicle operation is the combustion of fuel by engines.

It is worth noting that in 2021, Ukrainian gas stations sold 5 million tons of petroleum products, including 2.3 million tons of A95 gasoline, 0.66 million tons of A92 gasoline, and 2.1 million tons of diesel fuel [14].

When burning 1000 litres of petrol, total CO_2 emissions will be ≈ 2.355 tonnes [15].

To calculate CO2 emissions, we used the Methodology for Calculating Air Pollutant and Greenhouse Gas Emissions from Vehicles Proposed by the State Statistics Committee [16].

Based on the methodology of the State Statistics Committee and fuel sales volumes, the average CO2 emissions were 9 421 680 tonnes for an annual consumption of 3 million tonnes of petrol

When burning 2.1 million tonnes of diesel fuel, the emissions are 6 684 300 tonnes. Thus, 16 105 980 tonnes of emissions were generated from the fuel sold at petrol stations in 2021. In total, the combustion of petrol and diesel fuel generates about 22 million tonnes, which is approximately 10% of total CO_2 emissions in Ukraine. In 2016–2021, there was an increase in both the number of cars purchased and fuel sales [17]. A negative trend related to transport is increasing use of it. The volume of retail sales of motor oil products through the petrol station network (mln tonnes) is shown in the table 4.

Table 4. The volume of retail sales of motor oil products through the petrol station network (mln tonnes)

	2018	2019	2020	2021	Growth for 2021–2018
Sales volumes	2,82	3,9	4,46	5,0	2,18
CO2 emissions	8,98	12,41	14,20	16,1	7,12

According to the State Statistics Committee of Ukraine [18]. *Excluding direct purchases, which are about 50% of sales through the petrol station network.

According to the table, in 2018–2021, the increase in CO2 emissions from the increase in the volume of fuel sold in the petrol station network was 7.12 million tonnes. Looking at the absorption capacity of the forest and the time it needed to become a middle-aged, to absorb only the increase in CO2 20–30 years ago, an additional 1 166 666 hectares of new plantations had to be planted over 4 years (7 120 000/(6 tonnes) ha), or 291 666 hectares annually (7 120 000/(6 tonnes*4 years). According to the statistics of the State Statistics Service of Ukraine, the area of forest regeneration does not meet the required needs for carbon emission offsetting sources.

The extra amount remains in the atmosphere, blocking the sun's heating and leading to a rise in temperature. Therefore, the results of the analysis showed an increase in greenhouse gas emissions and a lack of sufficient sources for their absorption, which is the main cause of climate change. As noted above, greenhouse gas sources are different in nature, with different directions and strengths of impact. In order to systematise a variety of different information on the type of greenhouse gas emission source, there is a primary need to group them by the nature of their origin into economic, environmental and social factors. The group of economic factors was formed from the sources of emissions arising from economic activity. Group of social factors – includes a set of demographic and social factors that affect greenhouse gas emissions. Environmental factors group – formed from natural sources that produce greenhouse gases.

This grouping established the methodological basis for a two-tier aggregation of all the factors studied into three groups of local indices (economic, social, environmental) and their subsequent consolidation into an integral index of factor influence on greenhouse gas emissions.

In a more detailed form, the methodology for assessing the impact on greenhouse gas (GHG) emissions consisted of the following stages:

1. Internal factors, processes, and technologies that produce GHG emissions in economic sectors and households were identified.
2. A sample of indicators for their assessment was developed.
3. A stochastic factor analysis method was applied to select the most coherent factors influencing GHG emissions.
4. A minimax normalization method was used to calculate each local index, followed by additive aggregation of the normalized values of the key influencing factors.
5. The stability of the dynamics of each local index was assessed based on the coefficient of variation of the sample for the years 2016–2021.
6. The direction of behavior for each index was identified based on the trends in their changes over the years 2016–2021.
7. The local indices were aggregated into a composite index to assess the impact of emission sources on the state of GHG emissions.
8. The adequacy of the presented model was verified (based on the correlation between the composite index and GHG emissions).
9. Forecasts were made for the behavior of the local and composite indices.
10. The potential for GHG reduction in the Visegrad Group countries was assessed.
11. An assessment was conducted to evaluate the alignment of the current status and the potential for greenhouse gas (GHG) emissions reduction of all partner countries with the levels recommended for the European Union.

As a result of implementing stages 1- 4 of the proposed methodology, a close correlation was identified between 14 indicators of greenhouse gas (GHG) emission sources out of a studied sample of 76 economic indicators, using the principal component method. Two groups of factors were distinguished: Factor 1, with a 78.9% contribution to the overall change in GHG conditions, and Factor 2, with an 11.6% contribution (as shown in the table). Factor 1 included features related to economic development, while Factor 2 consisted of factors related to the use of fossil fuels.

Table 5. Factor indicators for assessing economic sources of GHG emissions

Factor	Indicator
Economic development	Gross value added at basic prices, mln.UAH
	GDP per capita, U.S. Dollars per capita
	Electric apacity of goods and services production, kW
	Energy intensity of GDP, ktoe / thsd. international dollars
	Usage of natural gas per 1 UAH of gross value added, thousand m3 per UAH 1
	Transportation of goods by road transport, thousand tons, kt
	Transport, warehousing, postal and courier activities, mln. UAH
	Manufacturing, mln. UAH
	Mining and quarrying, mln. UAH
	Electricity, gas, steam and air conditioning supply, mln. UAH
	Waste generation, thsd.t
	Volume of incinerated waste, thsd.t
	Total amount of waste accumulated during operation in specially designated places and facilities, thsd.t
Use of fossil fuel	Use of natural gas, billion m^3

The quantitative values of the selected factor attributes are presented in the table.

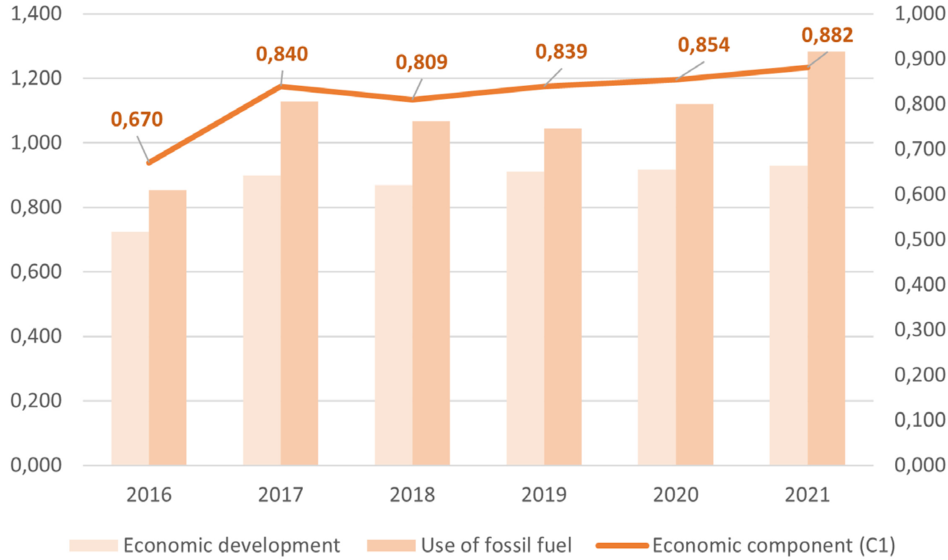
Table 6. Quantitative data of selected factor indicators for assessing economic sources of GHG emissions

	2016	2017	2018	2019	2020	2021
Gross value added at basic prices, mln.UAH	2023228	2516906	3017896	3421628	3626725	4684726
GDP per capita, U.S. Dollars per capita	55,78	70,07	84,00	94,38	100,76	131,07
Electric apacity of goods and services production, kW	0,011307768	0,007692656	0,006805342	0,005785296	0,005288127	0,00413851
Energy intensity of GDP, ktoe / thsd. international dollars	0,192	0,177	0,179	0,166	0,167	0,167
Usage of natural gas per 1 UAH of gross value added, thousand m3 per UAH 1	31,8202	31,4596	33,4386	30,5932	32,3002	28,7402
Transportation of goods by road transport, thousand tons, kt	117256	126471,96	134398,22	190041,19	151920,35	180029,52
Transport, warehousing, postal and courier activities, mln. UAH	341938	420484	503326	582500	594010	669354
Manufacturing, mln. UAH	1465931027	1824500593	2113765782	2082883251	2146728545	2908709919

	2016	2017	2018	2019	2020	2021
Mining and quarrying, mln. UAH	275776490,1	364364376,5	420842363,4	414080082,2	377862680,2	614350601,1
Electricity, gas, steam and air conditioning supply, mln. UAH	573682621	638527555	726330512,9	748823156,4	955830268	1415923268
Waste generation, thsd.t	295870,1	366054	352333,9	441516,5	462373,5	462373,5
Volume of incinerated waste, thsd.t	1106,1	1064,3	1028,6	1059	1008	1008
Total amount of waste accumulated during operation in specially designated places and facilities, thsd.t	12393923,1	12442168,6	12972428,5	15398649,4	15635259,6	15635259,6
Use of natural gas, billion m^3	31,8202	31,4596	33,4386	30,5932	32,3002	28,7402

The application of the minimax method for normalizing the sample indicators allowed them to be converted into a dimensionless form, facilitating their additive aggregation for the calculation of local indices. As a result of the above actions, the composite indices of each of the identified factor groups and the local index of the economic component of the factors that are sources of greenhouse gas emissions are shown in Fig 16.

Figure 16. Dynamics of the composite local index of economic factors of impact on GHG emissions



According to the figure, the composite local index of the impact of economic components on greenhouse gas emissions has shown a sustainable trend of growth since 2018, which is indicative of an increase in the concentration of GHGs in the atmosphere as a result of growing economic activity in the country. However, it is important to emphasize the difference in the growth in the influence of the selected factor groups on the growth of the composite local index of the influence of all economic factors. Thus, according to the factor analysis, the greatest impact on GHG emissions is made by activities related to the use of fossil fuels, the combustion of which emits CO2.

Based on the detected dynamics and identified impacts, the statistical evidence confirms that the activities related to the use of fossil fuels (oil and gas) have the greatest impact on the greenhouse impact. Therefore, the potential to reduce GHG emissions is associated with a complex of regulatory, organizational actions and economic incentives focused on increasing opportunities for the use of energy alternatives to fossil fuels.

In the environmental assessment group, the evaluation of the coherence between greenhouse gas (GHG) emission volumes was conducted using a sample of 38 indicators. As a result of the analysis, a correlation was identified among 18 factor characteristics, which were grouped into three categories (Table 7).

Table 7. Factor indicators for assessing environmental sources of GHG emissions

Factor	Indicator
Intensity of fertilizer usage and greenhouse gas emissions	Use of nitrogen fertilizers, 1000 т N
	Use of nitrogen fertilizers per unit of agricultural land, kg N per 1 hectare
	Total use of organic fertilizers, 1000 t
	Use of organic fertilizers per unit of agricultural land, kg per 1 hectare
	Share of area treated with organic fertilizers in total agricultural land, %
	Use of fertilizers per unit of planted area, kg per 1 hectare
	Use of inorganic fertilizers under maize, kg per 1 hectare
	Use of inorganic fertilizers under industrial crops, kg per 1 hectare
	Use of inorganic fertilizers under forage crops, kg per 1 hectare
	Emissions intensity N2O, tonnes / 1 million UAH of production
	Emissions intensity CO2, tonnes / 1 million UAH of production
	CO2 emissions per unit of gross value added, tonnes / t CO2/UAH
	CO2 emissions per unit of GDP, tonnes / mln.UAH
	Use of nitrogen fertilizers, 1000 т N
Aggregated Contributors to Climate Change	Total Greenhouse gass emissions, Mt CO2-eq.
	Emissions per capita, tonnes / per capita

Table 8. Quantitative data of selected factor indicators for assessing environmental sources of GHG emissions

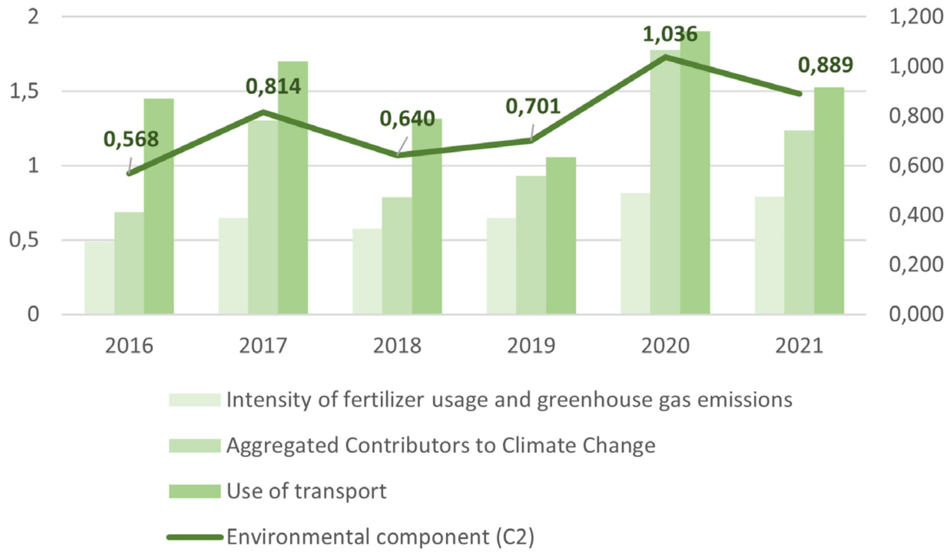
	2016	2017	2018	2019	2020	2021
Forest area, % of land area	16,6824906	16,6942862	16,7034864	16,7138419	16,7241974	16,734553
Use of nitrogen fertilizers, 1000 т N	1197,4	1365,3	1532,7	1601,7	1916,7	1970
Use of nitrogen fertilizers per unit of agricultural land, kg N per 1 hectare	57,8	66	74	77,4	93	95,6
Total use of organic fertilizers, 1000 t	9162,9	9273,9	11648,9	11382,5	11414	11962,9
Use of organic fertilizers per unit of agricultural land, kg per 1 hectare	442,7	448	562,7	549,9	554,1	580,7
Share of area treated with organic fertilizers in total agricultural land, %	2,4	2,4	3,9	3,9	4,9	4,9
Use of fertilizers per unit of planted area, kg per 1 hectare	294	276	350	358	331	320
Use of inorganic fertilizers under maize, kg per 1 hectare	726	745	834	798	785	799
Use of inorganic fertilizers under industrial crops, kg per 1 hectare	369	392	525	476	481	502

	2016	2017	2018	2019	2020	2021
Use of inorganic fertilizers under forage crops, kg per 1 hectare	3052	3013	3206	3357	3600	4498
Emissions intensity N20, tonnes / 1 million UAH of production	0,022322702	0,017345864	0,016043348	0,014230692	0,013510762	0,0135
Emissions intensity C02, tonnes / 1 million UAH of production	0,036476674	0,027645096	0,024650881	0,021613258	0,019279722	0,0193
C02 emissions per unit of gross value added, tonnes / t C02/UAH	0,000178922	0,000133775	0,000120846	0,000104482	8,75721E-05	7,35582E-05
C02 emissions per unit of GDP, tonnes / mln.UAH	0,000151759	0,00011284	0,000102427	8,98602E-05	7,52245E-05	6,32195E-05
Total Greenhouse gass emissions, Mt C02-eq.	362	336,7	364,7	357,5	317,6	344,6
Emissions per capita, tonnes / per capita	8,465756949	7,906632695	8,604174924	8,480969416	7,579518118	8,285964355
C02 emissions from road transport, total, thsd.t	23,3	24	24,1	25,9	22,8	22,8

The Composite Environmental Index of the impact of environmental factors on greenhouse gas emissions showed instability in its dynamics, due to the volatility of indicators in the factor groups that showed the highest internal correlation dependencies. Therefore, emissions from transportation by households and businesses have the greatest impact on the composite environmental index. A decrease in social and business activity in 2019 related to strict restrictions on the movement of the population led to a dramatic reduction in CO2 emissions, which had a positive impact on the environmental index.

A comparison of the pandemic's impact on the economic and environmental components of greenhouse gas emissions in the atmosphere has led to the conclusion that their dependence is different. In furthermore, the significant role of traditional vehicle fuels in the formation of the greenhouse effect in the earth's atmosphere has been confirmed. Therefore, the decarbonization policy should be connected with the production strategy of automobile manufacturers aimed at a gradual transformation to the production of electric vehicles and additional environmental responsibility for the production of vehicles that use traditional fuels.

Figure 17. Dynamics of the composite local index of environmental factors of impact on GHG emissions



In the complex of social factors, 15 indicators characterizing the behavior of an individual in society were researched. The closeness of the correlation was found among 2 groups of factor indicators.

Table 9. Factor indicators for assessing social sources of GHG emissions

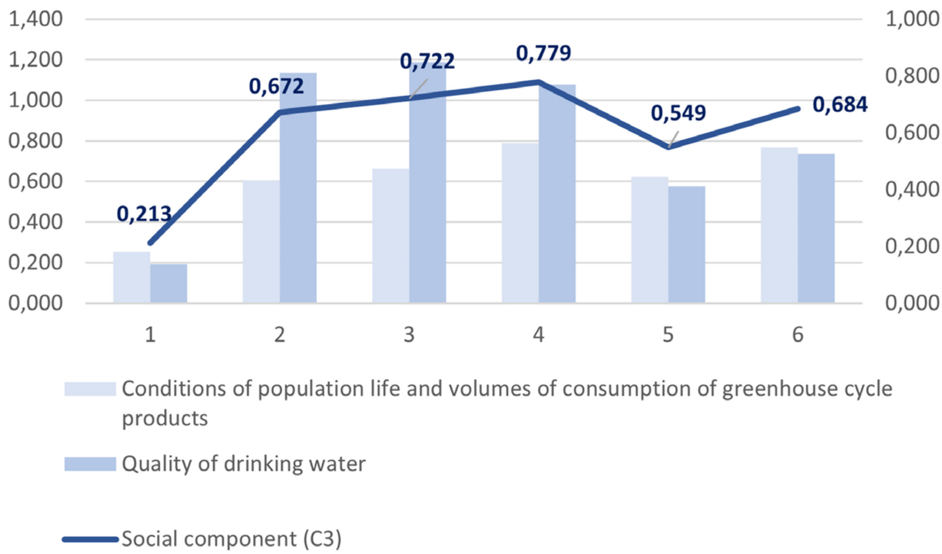
Factor	Indicator
Conditions of population life and volumes of consumption of greenhouse cycle products	Differentiation of population income, once
	Income per capita, UAH
	Population growth, person
	GDP per capita, U.S. Dollars
	Population distribution by age of 15–64 years, person
	Vegetable consumption per capita, kg/year
	Consumption of milk and dairy products per capita, kg/year
Quality of drinking water	Safety and quality of drinking water by radiation indicators, % of non-standard samples
	Safety and quality of drinking water by organoleptic, physicochemical, sanitary and toxicological indicators, % of non-standard samples

Table 10. Quantitative data of selected factor indicators for assessing social sources of GHG emissions

	2016	2017	2018	2019	2020	2021
Differentiation of population income, once	1,9	1,9	2	2,1	2	2,1
Income per capita, UAH	41440,49	62278,11	76645,57	89351,92	97267,29	116944,1
Population growth, person	-175974	-198139	-233202	-250785	-314062	-421019
GDP per capita, U.S. Dollars	2187,728	2638,325	3096,563	3661,458	3751,737	4827,846
Population distribution by age of 15–64 years, person	29327724	29011835	28719006	28468034	28199524	27927758
Vegetable consumption per capita, kg/year	209,5	200	197,7	200,5	201,9	201,5
Consumption of milk and dairy products per capita, kg/year	163,7	159,7	163,9	164,7	164	165,9
Safety and quality of drinking water by radiation indicators, % of non-standard samples	1,1	4,3	4	4,5	0,8	2
Safety and quality of drinking water by organoleptic, physicochemical, sanitary and toxicological indicators, % of non-standard samples	13,7	16,2	18,5	17,2	16,8	18,2

In the group of social factors affecting greenhouse gas emissions, there is a tendency to reduce the impact of the population on the environment. One of the factor groups that has a significant impact on greenhouse gas emissions is the group of drinking water quality, as deterioration of drinking water quality leads to an increase in its infiltration and evaporation in summer, which increases the level of steam in the atmosphere (Fig. 18).

Figure 18. Dynamics of the composite local index of social factors of impact on GHG emissions



The application of mathematical statistics methods to research the behavior of local indices allows us to identify the type of sustainability and the direction of factors in terms of their impact on greenhouse gas emissions (Table 11).

Table 11. Type of behavior the factors affecting GHG emissions

Local indices	Index coefficient of variation	Type of sustainability	Type of behavior
Economic	0,35	resistant	Aiming for a slight increase in emissions
Environmental	0,33	resistant	Uneven dynamics
Social	0,23	moderately resistant	Aimed for reducing emissions from households

The calculation the coefficient of variation in each local index allowed us to identify the level of volatility of the indicators that were used in their calculation and, on this basis, to identify the direction of the government efforts, activities of economic participants and the population in implementing the decarbonization policy.

Considering the significance of the coefficient of variation in identifying a country's sustainability in fulfilling its commitments to reducing greenhouse gas (GHG) emissions, it is important to note that it does not characterized by stability. This characteristic highlights the need for intensified legal, organizational, and economic efforts towards environmentally sustainable production. The dynamics of changes in local indices have shown a slight increase in activities related to GHG emissions, which further supports the aforementioned conclusion.

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Greenhouse gas emissions and reduction options in Hungary

Introduction

One of the most pressing sustainability challenges the world faces today is climate change, largely driven by human-generated greenhouse gas (GHG) emissions. The consequences of these emissions are global in scope, yet their impact and mitigation strategies vary significantly by region. Understanding the sources of GHG emissions and formulating effective strategies for reduction are crucial to combat climate change, and it is in the center of the efforts in the European Union. This study examines the greenhouse gas emissions in Hungary, their sources, and potential mitigation strategies. The relationship between economic development, political transitions, social attributes, and environmental concerns renders Hungary a good case study for investigating the challenges and opportunities in addressing sustainability challenges.

Hungary is one of the founding members of the Visegrád Group (V4) that was established in 1991. This regional partnership includes four Central European countries – the Czech Republic, Hungary, Poland, and Slovakia – that have shared historical, political, and economic experiences. Historically, Hungary's economy was predominantly agricultural, particularly in the Great Plain region. This gradually changed after the Industrial revolution, but vastly accelerated during the Soviet era when Hungary became part of the Council for Mutual Economic Assistance (Comecon), leading to rapid industrialization under Soviet influence. As a result, the country became an important station for the implementation of Soviet political and economic ideologies that also defined the country's current environmental challenges and efforts to transition towards more sustainable practices.

The political changes of 1990 marked a significant turning point in Hungary's development. Following the collapse of the Soviet Union, Hungary rapidly oriented

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itself towards Western Europe, joining NATO in 1999 and the European Union in 2004. These geopolitical shifts were accompanied by an economic transformation, with Hungary moving away from heavy industry towards the service sector. As an EU member state, Hungary is to align with numerous environmental strategies and standards. This alignment has been a driving force behind many of Hungary's sustainability initiatives and has provided a framework for the country's environmental policies. For instance, the EU established a target to increase the use of renewable energy sources to at least 20% of total final energy consumption. This target has been a significant catalyst for change in Hungary's energy sector, prompting the country to invest in and develop renewable energy sources. Most countries, including the V4 nations, successfully met this target well in advance, with the exception of Poland, which, on the other hand, was the only one in the V4 group to achieve reduction in the total consumption (Taušová et al., 2021).

With the substantial industrial changes, Hungary's environmental impact began to decrease as early as 1990, thanks to the various international financial aids and technological modernization that facilitated improvements in education, innovation, and infrastructure (Lamb et al., 2022). This early reduction in impact is noteworthy, as it suggests that Hungary's transition from a Soviet-era economic structure, lagging developmental stage and reliance on energy-intensive industries (Chovancová & Tej, 2020; Gáspár et al., 2023) needed to change into a market-oriented one which had immediate positive effects on the country's environmental performance. However, energy dependency on imports of primary energy sources and the slower adoption of cleaner technologies – in which the region is still lagging behind the Western European countries – remain a significant challenge (Chovancová & Tej, 2020), particularly in the energy sector, which is one of the largest contributors to GHG emissions in the region (Mohammed et al., 2021).

The EU is ambitious with climate policies, such as the "Fit for 55" strategy aimed at reducing net GHG emissions by 55% by 2030, but Hungary is considered one of the less ambitious member states of both the EU and the V4 when it comes to setting sustainability goals (Brożyna et al., 2023). Non-compliance with the EU targets could lead to financial penalties, as well as severe environmental and social impacts, including increased natural disasters, food and water shortages, and public health crises (Brożyna et al., 2023). Thus, achieving these climate targets is critical for Hungary and the V4 countries to not only meet EU standards but also to mitigate the more severe consequences of climate change.

In addition to these long-term challenges, recent geopolitical and global health crises, such as the Covid-19 pandemic, the Russo-Ukrainian war, and the ongoing energy crisis, have all significantly impacted Hungary's economy and its ability to pursue environmental goals. These events have highlighted the interconnectedness of economic, political, and environmental issues, such as rising energy prices, educational inequalities, and political polarization, and the need for resilient and adaptable sustainability strategies as well (Gáspár et al., 2023).

In light of these factors, this study aims to provide a comprehensive analysis of greenhouse gas emissions in Hungary, their origins, and possible mitigation strategies. The analysis is based on secondary data collection, and the application of basic and multivariate statistical methods. After presenting the results, the conclusions shortly describe how Hungary and the V4 region can advance towards a more sustainable development.

Methodology and Data

The data collection methodology in this study was based on the DPSIR framework. The DPSIR model, developed by the European Environment Agency in 1999, provides a structured approach to evaluating environmental issues by categorizing influencing factors into five components: driving forces (underlying social and economic drivers), pressures (direct effects on the environment), states (current environmental conditions), impacts (consequences of changes), and responses (actions taken to address the issues) (Liviu et al., 2021). In this research, the DPSIR framework was used to identify relevant indicators for assessing the environmental, social, and economic factors driving greenhouse gas (GHG) emissions in Hungary.

The DPSIR model has been applied across various contexts and adapted for specific research goals. For example, Alexakis (2021) examined the potential enhancements in water quality and utilization within the aquifers of the Troizina basin in Greece, concluding that educational initiatives and network monitoring could significantly contribute to the attainment of relevant sustainable development objectives (3: good health and well-being, 6: clean water and sanitation). Labianca et al. (2021) developed an "engineered DPSIR" (eDPSIR) for semi-quantitative analysis in selecting remediation strategies for contaminated coastal areas in Southern Italy.

Nevertheless, the fundamental objective of DPSIR is to enhance the consciousness of decision-makers. Carnohan et al. (2023) argued that specific supportive methodologies and activities can significantly augment the visibility of results for policymakers: engaging diverse stakeholder groups, incorporating a variety of perspectives, demonstrating flexibility, employing data visualization techniques, and providing clear and standardized definitions. The involvement of a broad spectrum of stakeholders – encompassing both experts and non-experts – has also been recognized as crucial in the advancement of sustainable development in other research studies (see Gáspár et al., 2023 and Márton et al., 2022 for example).

In this study, DPSIR facilitated the identification of indicators necessary for quantifying the environmental, social, and economic determinants of greenhouse gas (GHG) emissions. Cao and Bian (2021) collected a set of indices within their DPSIR-based cloud model that could effectively assess ecological performance, albeit their findings were somewhat country-specific. Statistical data for Hungary was compiled, adhering to the indicator selection guidelines established by the V4 research team to ensure consistency and comparability with findings from other V4 countries.

Eventually, the chosen indicators covered a wide range of factors influencing GHG emissions, with some overlapping with those used in previous studies, such as Nitrogen oxide emissions, forest coverage, water quality (Cao – Bian, 2021), waste management, population (Liviu et al., 2021), transportation, and fertilizer application (Walling & Vaneeckhaute, 2020), among others.

Secondary data were collected from national and international statistical sources, providing a comprehensive dataset for Hungary. The selection process emphasized coherence with existing studies to facilitate cross-country comparisons and regional analysis. Descriptive statistical techniques were used to summarize the characteristics of the selected indicators, providing an overview of central tendencies, variability, and data distribution. Linear trends were also employed on key indicators to highlight observable tendencies. Finally, to reduce the dimensionality of the dataset and simplify the analysis, principal component (factor) analysis (PCA) was employed to condense the size of the input sample, thereby facilitating a more streamlined modeling of GHG emissions through their determinants. The findings from these analyses are presented in the following sections, describing the trends and key factors influencing GHG emissions in Hungary.

Results

Basic statistics

The analysis of long-term greenhouse gas (GHG) emissions trends within the V4 Group demonstrates a generally positive direction, with substantial reductions across these nations. Notably, Hungary achieved a significant 42% reduction in GHG emissions compared to 1990 levels. This progress is primarily due to advancements in the power sector, industrial improvements, and better land-use practices, even though increases in emissions from the transportation sector soften the picture. Nevertheless, Hungary's performance in emission reduction has outpaced the V4 and EU averages (Table 1).

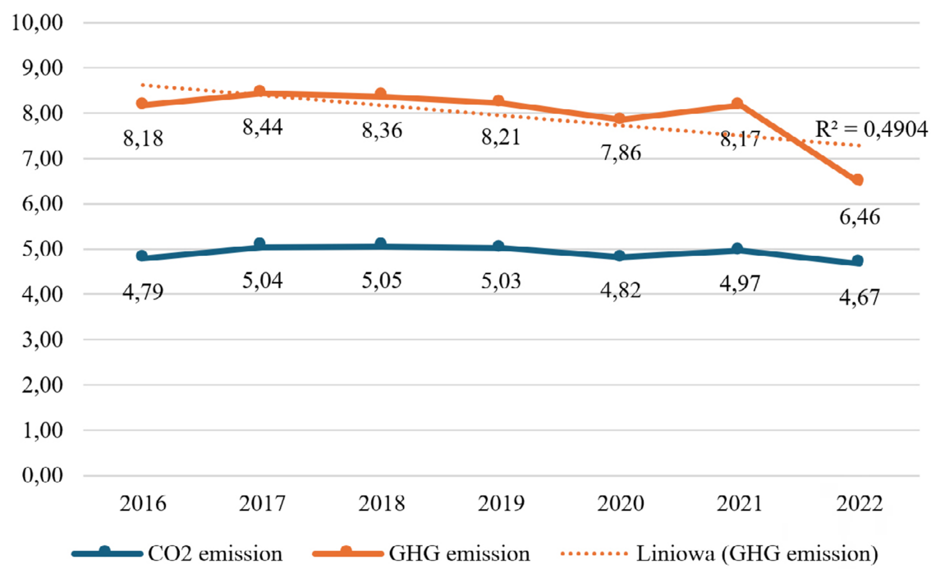
Table 1. Change of greenhouse gas emissions in selected regions and sectors

	Total net GHG emissions change (%) 1990–2022	Total net GHG emissions change (%) 2019-2022	Sector performance change (%) 2015–2022							GHG intensity of GDP (2022) (gCO_2-eq)	GHG emissions per capita (2022) (tCO_2-eq)
			Power	Industry	Transport	Buildings	Agriculture	Waste	LULUCF		
Hungary	-42%	-11%	-6%	-2%	5%	-1%	-1%	0%	-2%	472	5.5
V4 average	-38%	-8%	-6%	-2%	4%	-0.75%	-0.25%	0%	1%	519	8.1
EU27	-32%	-6%	-7%	-2%	0%	-2%	0%	0%	2%	229	7.0

Source: Author, based on data from Climate Action Progress Report 2023, EC (2023)

The downward trend in Hungary's GHG emissions is evident despite the relatively stagnant levels of carbon dioxide (CO_2) emissions, which remained just below 5 tons per capita from 2016 to 2022 (Figure 1). This stagnation suggests that the most significant progress in emission reduction has occurred in other types GHGs (e.g., methane and nitrous oxide), while the reduction in CO_2 has not been as pronounced.

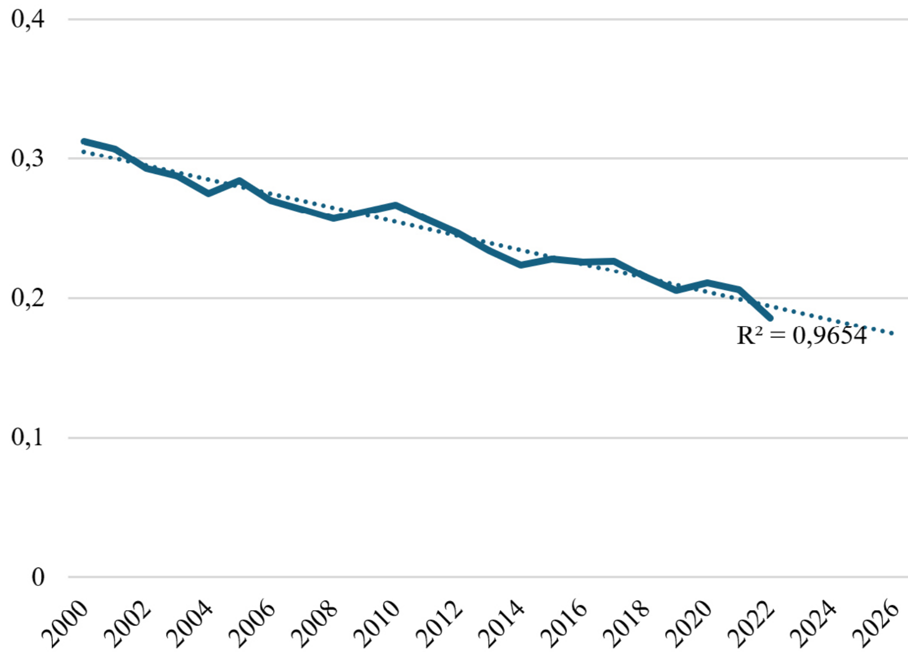
Figure 1. GHG and CO2 emissions per capita, 2016-2022, tons



Source: author, based on KSH (2024) data

The development of the energy sector in Hungary has been key in the emission reduction. The expansion of photovoltaic (PV) solar plants and the increased use of nuclear energy have led to improvements in energy intensity, reflecting a more efficient use of energy in economic activities (Figure 2).

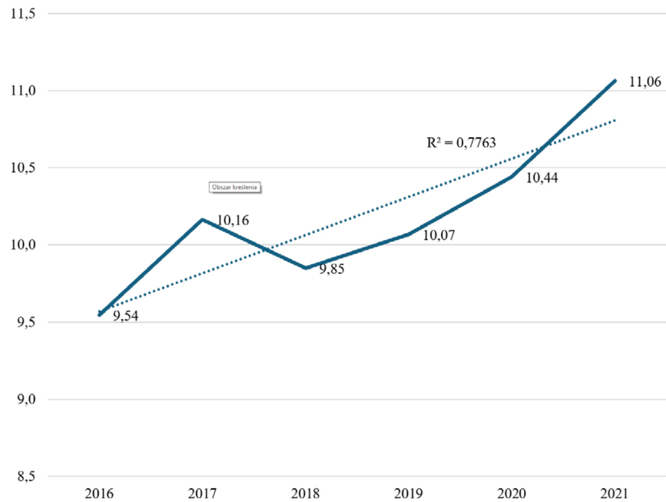
Figure 2. Energy intensity in Hungary, 2000-2022, Mtoe/EUR



Source: Author, based on data from KSH (2024)

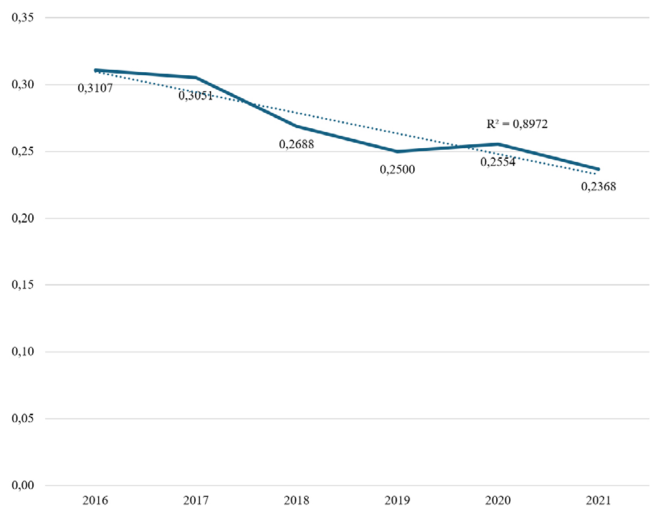
Similarly, despite a notable increase in natural gas consumption, the economic progression has led to a higher level of value-added, thereby leading to an augmentation in economic efficiency in this context (Figure 3 and 4). Starting in 2022, natural gas consumption began to decrease significantly because of the energy crisis resulting from the Russo–Ukrainian war. The conflict, along with its repercussions on the European energy market, prompted member states, including Hungary, to adopt immediate energy-saving policies and fostered more conscious energy consumption behaviors.

3. Figure. Natural gas consumption, billion m³



Source: author, based on KSH (2024) data

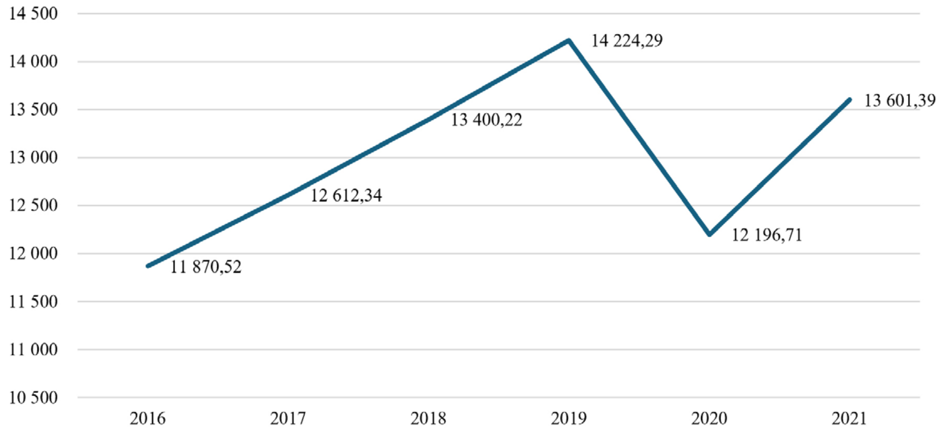
4. Figure. Natural gas consumption per value added m3 / HUF 1



Source: author, based on KSH (2024) data

The transportation sector has presented a unique challenge in terms of GHG emission reduction. Unlike the EU, where transportation-related emissions have remained stable over the past decade, the V4 countries, including Hungary, have experienced an increase in emissions from this sector. This upward trend is associated with a growing rate of motorization and the relatively slow adoption of eco-friendly transportation options, such as electric vehicles.

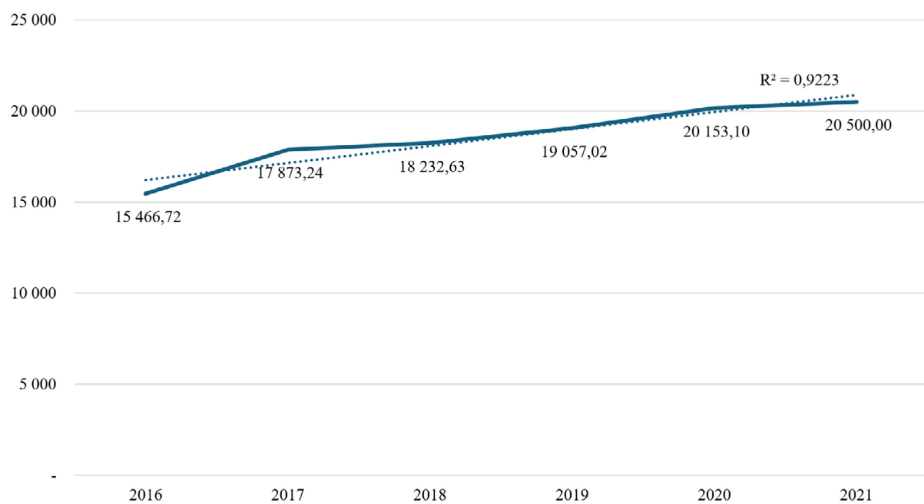
Figure 5. CO_2 emissions in road transport, 2016-2021, thousand tons



Source: author, based on KSH (2024) data

In terms of waste management, while GHG emissions associated with waste generation and disposal have remained relatively constant, there has been a significant increase in the volume of waste generated in Hungary, which rose by 32.5% between 2016 and 2021 (Figure 6). Waste incineration, which moderately correlates with GHG emissions (correlation coefficient of 0.71), plays a dual role in Hungary's environmental performance: on the one hand, it reduces landfill waste and provides an energy source; on the other hand, it contributes to emissions. However, improvements in recycling and other waste management practices have mitigated local emission effects.

Figure 6. Waste generation, 2016-2021, thousand tons



Source: author, based on KSH (2024) data

The analysis of descriptive statistics, with a focus on correlation and covariance, offers insights into the relationships between the drivers of GHG emissions. The analysis supports the results of the findings by Chovancová et al. (2021), indicating a lack of significant interrelations between economic growth and environmental indicators, including energy consumption and CO_2 emissions. In many cases, correlations between presumed drivers (e.g., energy consumption, industrial output) and GHG emissions were weak or moderate, and the covariance between these variables was almost negligible. This suggests that economic growth alone does not predict environmental outcomes in a straightforward manner.

However, some derived indicators revealed stronger relationships. For example, GDP per capita and value-added output showed significant correlations with a range of environmental variables, highlighting their relevance in understanding the interaction between economic development and environmental performance. Conversely, variables such as the supply of electricity, gas, steam, and air conditioning, as well as forest coverage, showed weak correlations (less than 0.5) with the majority of other factors. This implies that these elements individually have limited direct influence on the overall trends in GHG emissions.

Factor analysis

It was an aim of this research to develop a composite indicator that reduces the number of variables, facilitating a more efficient analysis of complex data sets. To achieve this, factor analysis was integrated into the research design, by applying Principal Component Analysis (PCA). Factor analysis enables dimension reduction by identifying the underlying structure within a set of variables, thus streamlining the dataset while retaining essential information. However, several methodological challenges emerged, as the initial set of indicators could not be incorporated into a single factor analysis due to statistical constraints, specifically the presence of negative eigenvalues. Consequently, a selection of variables was made to enable dimension reduction, and factor analysis was conducted in three steps with only a subset of variables based on the corresponding sustainability pillars: economic, environmental, and social.

Economic Component

Following several iterations of trial and error, the factor analysis involved Gross Value Added, Transport and Warehousing, Mining and Quarrying, and Waste Generation in the economic dimension. The Kaiser-Meyer-Olkin (KMO) test confirmed good sampling adequacy, while the Bartlett's test for sphericity indicated that the variables were suitable for factor analysis (Table 2). The analysis of communalities and total variance explained showed that approximately 93% of the original information was retained in the principal component, affirming the effectiveness of the factor reduction process (Table 3). The component matrix demonstrated a strong correlation between the original variables and the new component, suggesting that the component could effectively replace the original measures without significant loss of information (Table 4).

Table 2. KMO and Bartlett's Test for PCA – economic dimension

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		,787
Bartlett's Test of Sphericity	Approx. Chi-Square	19,357
	df	6
	Sig.	,004

Source: Author

Table 3. Total Variance Explained for PCA – economic dimension

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3,724	93,105	93,105	3,724	93,105	93,105
2	,198	4,942	98,047			
3	,047	1,171	99,218			
4	,031	,782	100,000			
Extraction Method: Principal Component Analysis.						

Source: Author

Table 4. Component Score Coefficient Matrix for PCA – economic dimension

	Component 1
Gross_value_added	,264
Transport_warehousing	,262
Mining_quarrying	,259
Waste_generation	,252

Source: Author

Considering the content of the resulting factor, which encompasses elements from both the primary and tertiary industry sectors in addition to waste management, it may be designated as the "non-manufacturing sectors" or "extractive, transport, and waste sectors" industrial factor. However, it is important to note that emissions from the energy industry – a key part of the secondary sector in Hungary – should be considered as well, due to its significant environmental impact.

Environmental Component

In relation to the environmental component, variables such as Use of Nitrogen Fertilizers, Emissions per Capita, and Emissions Intensity were merged into a single factor. Although the KMO test indicated a somewhat lower level of sampling adequacy compared to the economic component, it remained within an acceptable range. The Bartlett's test showed a relatively high significance level, indicating unequal variances among the indicators (Table 5). Despite these limitations, factor analysis was still viable for this set of variables.

Table 5. KMO and Bartlett's Test for PCA – environmental dimension

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		,620
Bartlett's Test of Sphericity	Approx. Chi-Square	4,798
	df	3
	Sig.	,187

Source: Author

The communalities and total variance explained indicated that the environmental component captured approximately 76% of the original data's variance, which was lower than the economic factor but still acceptable (Table 6). The component matrix confirmed a strong correlation between the original environmental indicators and the newly formed component (Table 7). This factor effectively represents the "impact intensity" factor, reflecting the pressure exerted by human activities on the environment.

Table 6. Total Variance Explained for PCA – environmental dimension

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2,290	76,322	76,322	2,290	76,322	76,322
2	,529	17,629	93,951			
3	,181	6,049	100,000			
Extraction Method: Principal Component Analysis.						

Source: Author

Table 7. Component Score Coefficient Matrix for PCA – environmental dimension

	Component 1
Use_of_N_f_per_unit	,411
Emission_per_Cap	,377
Emissions_int_CO2	,355

Source: Author

Social Component Analysis

The social dimension encompassed almost all the social-related variables, including GDP per Capita, S80/S20 Ratio,[2] Income per Capita, Population Growth, and Population Distribution. The KMO test indicated acceptable adequacy for this set of variables (Table 8). The analysis of communalities and total variance explained showed that the social factor preserved nearly 93% of the original information, indicating a high level of data retention in the principal component (Table 9). The component score coefficient matrix revealed distinct correlations: GDP per Capita and Income per Capita were negatively correlated with the new component, while the S80/S20 Ratio, Population Growth, and Population Distribution showed positive correlations (Table 10). This suggests that the new factor captures elements of social welfare and distribution dynamics, hence it was termed the “social welfare and distribution” factor.

Table 8. KMO and Bartlett’s Test for PCA – social dimension

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		,740
Bartlett’s Test of Sphericity	Approx. Chi-Square	29,773
	df	10
	Sig.	<,001

Source: Author

2 S80/S20 ratio is an index of inequality, calculated as the ratio of the total incomes of the highest and lowest 20% of the population.

Table 9. Total Variance Explained for PCA – social dimension

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4,642	92,834	92,834	4,642	92,834	92,834
2	,187	3,735	96,569			
3	,137	2,748	99,317			
4	,032	,648	99,965			
5	,002	,035	100,000			
Extraction Method: Principal Component Analysis.						

Source: Author

Table 10. Component Score Coefficient Matrix for PCA – social dimension

	Component 1
GDP_per_Cap	-,209
S80_S20_ratio	,199
Income_per_Cap	-,214
Population_growth	,204
Population_distribution	,212

Source: Author

Finally, by utilizing the results from the correlation matrix and the principal components identified through factor analysis, the key drivers of greenhouse gas emissions in Hungary (and potential targets for policy measures) have been determined as follows: the “extractive, transport, and waste sectors” factor, the “impact intensity” factor, and the “social welfare and distribution” factor. Additionally, the indicator for waste incineration volume, which shows a noticeable positive correlation of 0.71 with greenhouse gas emissions, should be considered for policymakers despite not being included in the principal component.

Conclusion

As a founding member of the Visegrád Group, Hungary is undertaking a green energy transition aimed at achieving its greenhouse gas (GHG) reduction objectives. Although the country's targets are comparatively less ambitious than those of the other V4 nations, numerous favorable trends can be discerned within the sustainability-related metrics. Hungary is making substantial progress in reducing emissions across various sectors, including energy, industry, agriculture, and land use, achieving or even exceeding the European Union averages – a noteworthy accomplishment in the post-Soviet landscape.

Nonetheless, progress in certain sectors remains inadequate and necessitates further political intervention, particularly in transportation and waste prevention and management. Economic and energy crises have led to heightened economic consciousness among the population, while technological innovations have facilitated increased efficiency. These developments are reflected in the observed improvements in GHG emissions, energy intensity, and consumption relative to value added.

The environmental impact of a nation's economy and society can be assessed using numerous indicators, even when focusing solely on GHG emissions. In this study, a number of measures were considered, but basic statistical analyses did not identify key indicators due to the absence of significant correlations. However, factor analysis was applied, and principal components were derived from the most influential indicators, resulting in the identification of three primary factors, each representing a distinct pillar of sustainability: economic, environmental, and social.

While these three factors effectively reduced the complexity of the analysis and minimized data requirements, incorporating additional indicators is necessary to fully capture the multifaceted nature of sustainability. The "extractive, transport, and waste sectors" factor highlights the most urgent economic issues for decisionmakers to address for effective GHG emission reductions. The environmental "impact intensity" factor emphasizes the significance of emissions, emission intensity, and the use of GHG-intensive materials. The "social welfare and distribution" factor indicates that enhancing wealth and social equity can further improve sustainability outcomes.

The findings offer important insights for policymakers. It is evident that efforts must be directed towards reducing, and eventually reversing, the increase in emissions from the power sector. It is clear that the increase of emissions from the power industry should be reduced and eventually turned. Extended funds (both in time and volume) in alternative energy sources, above all renewables, but also nuclear power can be a possible solution. Extraction, transportation and waste management would also need top-down support of all forms: financial, directional, legal, even educational. The rethinking of certain taxational regulations and practices could also contribute to a better performance in the most pollutant sectors, supporting the use of more ecology-conscious technologies and the employment in green industries (Ghazouani et al., 2021), while it can ease the inequalities between groups of the society to more evenly distribute the more sustainable technologies in the wider population.

Undoubtedly, Hungary and the V4 nations lag behind their more developed Western European counterparts in terms of sustainable development and GHG emission reductions; however, progress towards closing this gap is indeed attainable. Economic and social features need specific solutions, but there is also room for co-operation between countries with common interests, and the V4 community makes a good possibility to strengthen together both economy- and environmental-wise.

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