Visegrad Fund

Innovative Solutions for Sustainable Development and Inclusive Growth.

V4 countries and Ukraine overview

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Introduction

The modern world faces challenges related to the necessity of sustainable development, improving the quality of life for citizens, and reducing the negative impact of human activities on the environment. Transport, as one of the key sectors of the economy, plays a significant role in shaping modern societies. At the same time, it is a source of numerous challenges, such as greenhouse gas emissions, infrastructure accessibility for all social groups, and the need to integrate various modes of transport in a way that promotes social inclusion and environmental protection.

This monograph attempts to address the challenges associated with transforming transport into a more sustainable and inclusive system. The chapters included focus on different aspects of this process, highlighting the importance of integrated transport hubs, methods for assessing their efficiency, the environmental impact of transport, and strategies for supporting low-carbon development.

The first chapter, *Methodology of Factors That Influence the Formation of Greenhouse Gas*, examines how improving accessibility in transport hubs can contribute to reducing social exclusion. Particular emphasis is placed on the needs of people with reduced mobility and ways to create more inclusive transport infrastructure.

The second chapter, *Improving Accessibility in Integrated Transport Hubs as an Example of Enhancing Social Inclusion*, presents an innovative approach to evaluating the efficiency of integrated transport hubs. This method identifies key factors influencing accessibility and transport integration, supporting decision-making processes in spatial planning.

The third chapter, *Indicator Method for Studying Integrated Transfer Nodes, Enhancing Social Inclusion*, addresses the issue of greenhouse gas emissions associated with transport. It includes a detailed analysis of the factors influencing these emissions, which can serve as a foundation for developing more effective emission reduction strategies in the transport sector.

The fourth chapter, *A Low Carbon Growth of Slovakia*, showcases Slovakia as a country striving to achieve the goals of low-carbon economic growth. It discusses political, social, and technological initiatives that support the sustainable development of the country.

The fifth chapter, *Sustainable Transport*, offers a broad perspective on sustainable transport, emphasizing the need to combine local and global efforts to achieve shared environmental and social goals.

This monograph is addressed to researchers, engineers, policymakers, and anyone interested in sustainable transport development and its impact on society and the environment. The content aims not only to deepen knowledge but also to inspire innovative actions in this field.

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Assessment methodology of factors that influence the formation of greenhouse gas emissions: volumes and structure on the example of Ukraine and the Visegrád countries. Ways to reduce greenhouse gas emissions as a basis for SDG implementation

In the face of increasing threats posed by global warming, understanding the mechanisms shaping greenhouse gas (GHG) emissions has become a critical issue in environmental sciences. These emissions significantly impact climate change, public health, and biodiversity. Consequently, developing effective methods for assessing the factors influencing the volume and structure of GHG emissions is essential for better forecasting their effects and implementing appropriate mitigation measures.

The aim of this chapter is to present an innovative methodology for evaluating the determinants of greenhouse gas emissions. This methodology considers various

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aspects, such as emission sources, industrial sector characteristics, environmental policies, and changes in consumer behavior. In particular, we will focus on identifying the key determinants that have the greatest impact on the quantity and structure of GHG emissions.

The first part of this work discusses the theoretical foundations of greenhouse gas emissions and their environmental impact. We will then present the research methods employed, which include both quantitative and qualitative analyses. In the final section, we will outline the research findings and their implications for environmental policy and emission reduction strategies.

Understanding the factors influencing GHG emissions is crucial not only for scientists and policymakers but also for society as a whole. The developed methodology aims to provide tools for better analyzing and understanding this complex issue, ultimately contributing to more effective decision-making in climate protection.

Aims and objectives of the research

The aim of the research is to develop a methodology for identifying local factors that have the greatest impact on the dynamics of greenhouse gas emission changes and to assess the behavior of these changes in the context of implementing policies to combat global warming.

To achieve this goal, the following objectives were identified:

- to assess global trends in greenhouse gas emissions;
- to assess greenhouse gas emissions in Ukraine and the Visegrad countries;
- to research the impact of the war on the environment;
- assess local greenhouse gas emission indexes and identify the type of sustainability of their behavior;
- to conduct an integrated assessment of greenhouse-forming factors;
- summarize the priority directions for reducing greenhouse gas emissions.

Materials and methods of research

The assessment of factors influencing greenhouse gas emissions is based on a conceptual view of emissions as a combined (aggregate) result of the interrelated impact of economic, social, and environmental factors. In fact, the volumes and structure of greenhouse gas emissions are influenced by both the use of greenhouse gas sources and factors of economic and social development. On the other hand, environmental changes in the country lead to economic changes in the economy, influence social factors in general and the possibility of reducing greenhouse gas emissions in particular. Therefore, the potential for reducing greenhouse gas emissions is a dynamic result of the multifactorial impact of factors of different types. For this purpose, a representative database of statistics was selected, which included a number of traits (characteristics) for assessing economic, environmental and social factors that influence greenhouse gas emissions. The number of characteristics in the assessment was 95. The whole group of factors was divided into 3 local components according to their relevance to the object of assessment: Economic, social and environmental.

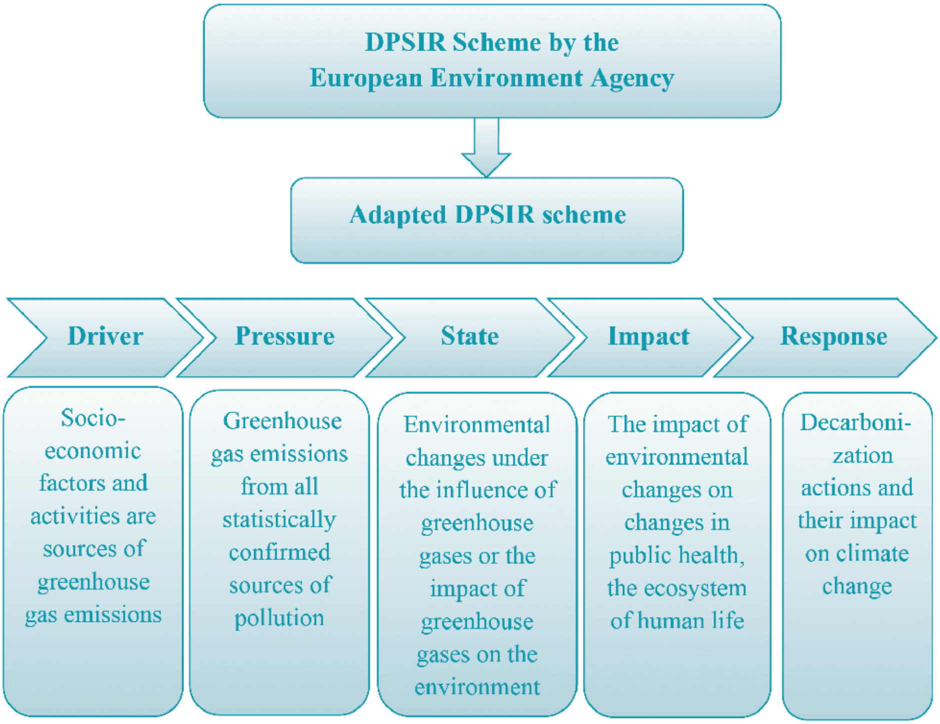
Table 1. Components of an integrated assessment

Local components	Identification of the component
Economic component	An assessment of the impact of the country's economic potential on greenhouse gas emissions
Social component	An assessment of the impact of demographic and social welfare factors on greenhouse gas emissions
Environmental component	An assessment of the level of use of natural processes that produce greenhouse gasses

To evaluate each of the local components is being proposed a system of characteristics that shows the main trends in the factors influencing greenhouse gas emissions, and at the same time allows us to analyze the reasons and results of the carbonate condition. Composite index of integrated assessment allows to determine the level of sustainability and identify the direction of the country's decarbonization policy.

The group of indicators for the assessment is developed in accordance with the environmental assessment scheme proposed by the European Environment Agency: The Driver-Pressure-State-Impact-Response framework, which is based on the assessment of the main components of the greenhouse cycle. The greenhouse cycle is assessed by analyzing the input characteristics that produce greenhouse gas emissions to the results of their impact on the environment and the population.

Figure 1. Steps in assessing the integral index of greenhouse-forming factors



Adapting this framework for greenhouse cycle assessment, the following groups and corresponding indicators for their quantification were selected in the context of this research:

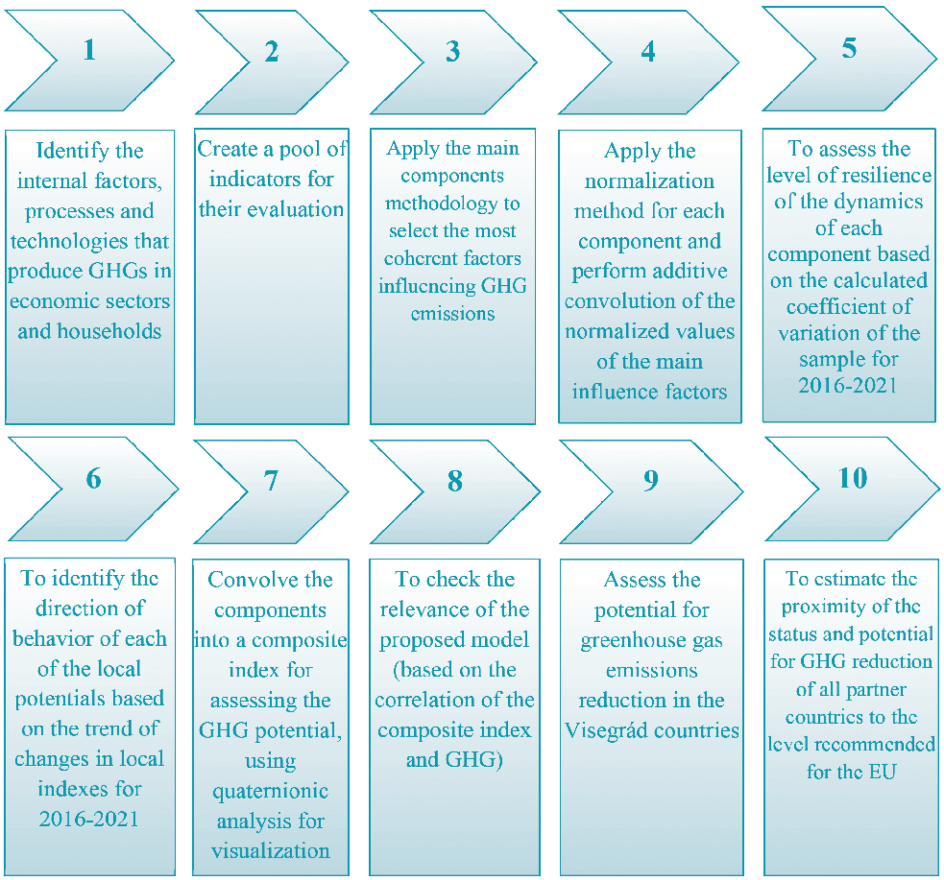
– As for drivers, these are socio-economic factors and activities that serve as sources of greenhouse gas emissions (drivers).
– As for pressure, these are greenhouse gas emissions from all statistically confirmed sources of pollution (Pressure).
– As for state, these refer to environmental changes resulting from the influence of greenhouse gasses or the impact of greenhouse gasses on the environment (State).
– In terms of impact, this refers to the effects of environmental changes on public health and the ecosystems that support human life (Impact).
– As for response, these are decarbonization actions and their effects on climate change (Response).

In the scheme adapted for the greenhouse cycle assessment, factor Drivers is attributed to the economic component, factors Pressure and State to the environmental component, and factor Impact to the social component.

The methodology for assessing the economic, social and environmental impact on greenhouse gas emissions was based on the following sequence of actions within each component:

1. to identify internal factors, processes, and technologies that produce greenhouse gas emissions in economic sectors and by households;
2. to create a group of indicators for their evaluation;
3. to apply stochastic factor analysis to select the most coherent factors of influence on greenhouse gas emissions;
4. to apply the normalization method for each component and perform additive convolution of the normalized values of the main influence factors;
5. to assess the level of resilience of the dynamics of each component based on the calculated coefficient of variation;
6. to identify the direction of behavior of each of the components based on the trend of their changes from;
7. to Convolve the components into a composite index for assessing the GHG potential, using quaternionic analysis for visualization;
8. to check the relevance of the proposed model (based on the correlation of the composite index and GHG);
9. to assess the potential for greenhouse gas emissions reduction in the Visegrád countries;
10. to estimate the proximity of the status and potential for GHG reduction of all partner countries to the level recommended for the EU.

Figure 2. Methodology of integral assessment of the potential for reducing greenhouse gas emissions



The use of the Main Component Analysis method allowed us to identify from the selected group of factors only those that showed close correlations.

To implement the methodology of the research, a group of input components was selected for each of the local groups. The components were selected from those that corresponded to the following criteria: 1) described the dynamics of changes in resources, the use of which is related to greenhouse gas emissions; 2) had group-related characteristics; 3) were officially confirmed; 4) showed close correlations in the local group.

Assessment of global trends in greenhouse gas emissions

Global warming is one of the most acute environmental problems of humanity, which is caused by an increase in the concentration of greenhouse gases in the atmosphere. Among them are carbon dioxide (CO2), nitrogen oxides (NOx), methane (CH4) and fluorocarbons (CFCs). They have a key negative role in enhancing the greenhouse effect and lead to an increase in the average global temperature. According to the National Centre for Atmospheric Science from 1850 to 2022 Global temperatures have increased by over 1.2°C. In the last 143 years of monitoring, the period since 2010 has been the warmest. And the last nine years (from 2014 to 2022) have been the nine warmest years over the whole research period [1]. Temperature changes in Ukraine for the same period of time are slightly different from the global trends, but the overall tendency for increasing temperatures is similar to global trends [2].

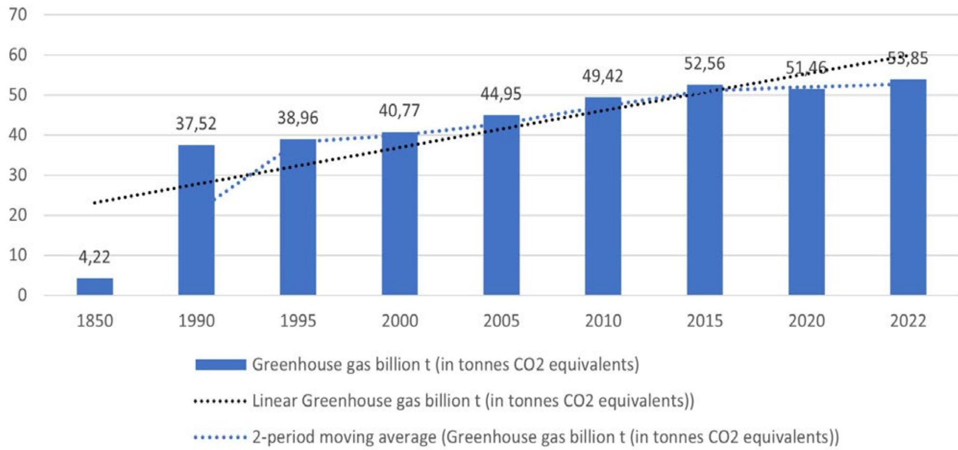
76% of global greenhouse gas emissions are related to the use of fossil fuels especially for energy production and transportation. In 2022, global CO2 emissions from fossil fuels and industry totaled 37.12 gigatons, which was one of the highest levels in human history [3]. Nitrous oxide also has a significant impact on the global warming effect. In 2018, global NO2 emissions were approximately 35 million tons, and by 2023, this figure decreased slightly to 33 million tons. Such changes are explained by economic factors and the impact of the COVID-19 pandemic, which has led to a temporary decrease in industrial activity in many countries [4]. Methane (CH4) is also significant in terms of its impact, its emissions have a stable growth trend and by 2022 its level in the world amounted to 10.49 billion tons of CO2 equivalent [4]. At the same time, research shows that over a 100-year period, one ton of methane causes 28 times the warming effect than one ton of CO2. Therefore, even though its volume in total greenhouse gas emissions by weight is relatively small, methane is responsible for about a quarter of the radiative forcing since 1750 [5, 6].

CFCs, once widely used in refrigeration, air conditioning, and aerosol propellants, are potent greenhouse gasses and contributors to ozone layer depletion. At the high point of their use in production in the late 1980s, global CFCs emissions reached approximately 1.1 million tons per year, which led to significant damage to the ozone layer. As of 2023, as a result of the successful implementation of international agreements and the introduction of alternative technologies that do not contain fluorocarbons, global CFCs emissions are estimated to decrease by 10 to 20 thousand tons per year.

At the same time, the overall trend in greenhouse gas emissions is extremely concerning. NOAA noted that carbon dioxide emissions in 2023 rose to the third-highest level in the 65 years of the organization's records. Consequently, the level of greenhouse gas emissions in 2023 reached a historical maximum and tended to increase at a record pace. The impact of methane on global temperature rise was about 30%, while carbon dioxide had nearly twice the effect [7].

Summarizing global trends in greenhouse gas emissions (Figure 3), we can note that if they continue at the current rate until the end of the 21st century, the temperature could rise by 2.5–4.5°C [8]. This would have catastrophic consequences for the planet and would not align with the goals set by the Paris Agreement [9] and the commitments made by countries to reduce greenhouse gas emissions in order to prevent such temperature increases.

Figure 3. Greenhouse gas emissions (including carbon dioxide, methane, nitrous oxide from all sources), 1850-2022 [4]



* Greenhouse gas emissions include carbon dioxide, methane and nitrous oxide from all sources, including land-use change

This is also emphasized in the latest IPCC report (2023). It presents scenarios of future climate change as a result of greenhouse gas emissions, considering current trends for several generations. Research indicates that accelerating global warming will significantly deepen negative trends and create new risks for the human environment, human health and life (like a snowball effect). With the intensification of these processes, the level of their manageability and conditional "reversibility" of the consequences will decrease.

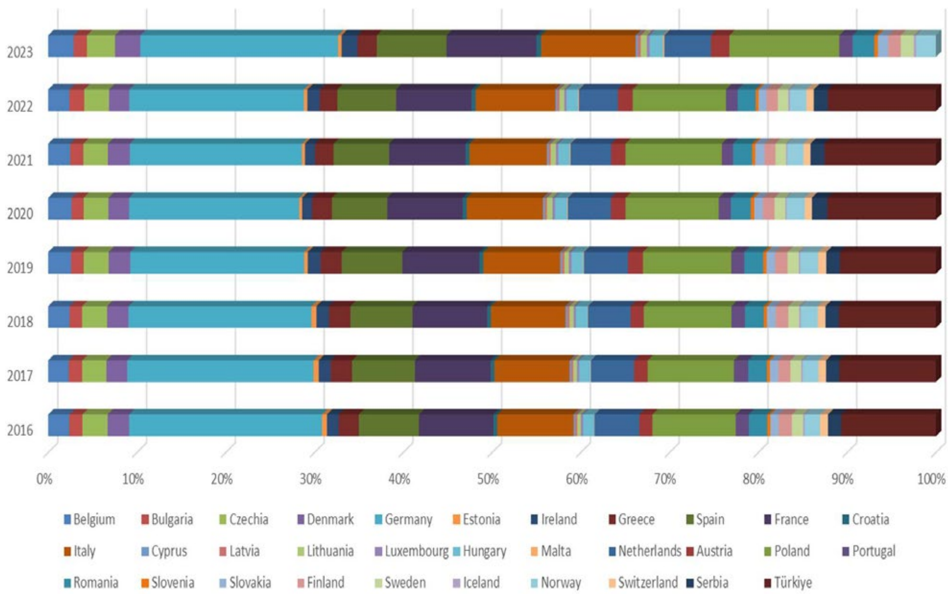
Therefore, the results for much research shows a clear correlation between the level of greenhouse gas emissions and global warming, which confirms the global goal of reducing these emissions as a critical step to reduce the growth of climate change. At the same time, the issue of impact on climate change, taking responsibility for the consequences, and implementing the necessary changes in the process of complying with the commitments to minimize greenhouse gas emissions remains a relevant and debatable issue for a lot of countries.

Assessment of greenhouse gas emissions in Ukraine and the Visegrad countries

In this research, we focus on European countries, in particular, the Visegrad Four and Ukraine, through the prism of global trends. From this point of view, it is important to note that Ukraine remains one of the countries that cumulatively generate about 80% of greenhouse gas emissions and one of the European countries that demonstrated relative stability of such emissions until the last 4 years (from 2020).

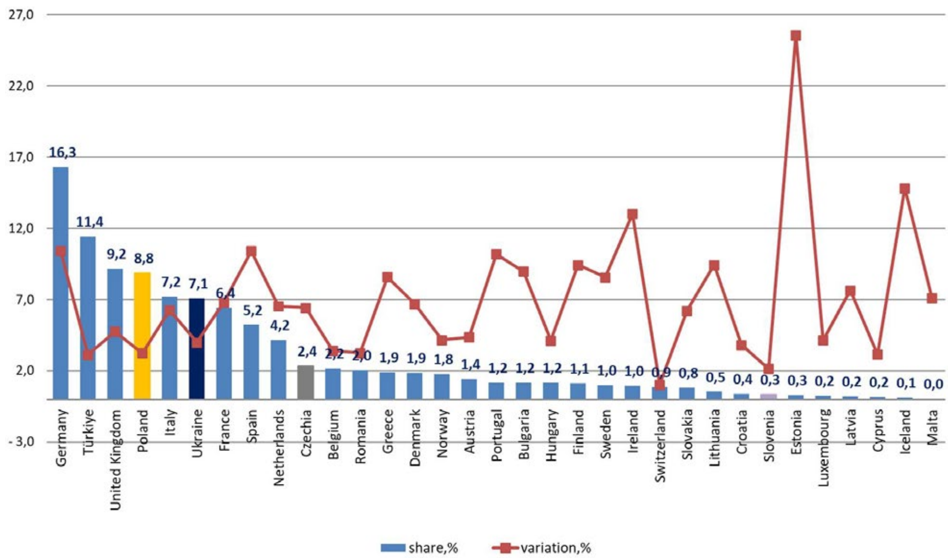
Carbon dioxide emissions are the largest contributor to greenhouse gas emissions. This is a global trend. Accordingly, Ukraine is not an exception in the structure of its region (Europe).The producers of these emissions are comparable both at the global and European levels and at the local level (households and enterprises of all economic activities). Nevertheless, the majority of carbon dioxide emissions into the atmosphere are generated by the economic activities of thermal power plants and processing industry enterprises.

Figure 4. Carbon dioxide – Total – all NACE activities, Tonne (2016-2023) [10]



In 2020, Ukraine produced an average of 7% of the total CO2 emissions of European countries. Despite the tendency to reduce CO2 emissions in Ukraine, their level is still higher than in some European countries.

Figure 5. Share of CO2 Emissions in the Total Volume 2020 (variation 2016–2020) [11]



A comprehensive comparison of CO2 emissions in Ukraine and European countries reveals different characteristics of their quantitative emissions: Ukraine's CO2 emissions are characterized by significant asymmetry, unlike European emissions, which are symmetrical.

The fluctuation of CO2 emissions in European countries and Ukraine from 2012 to 2020 reflects deviations in emissions relative to their average levels in each of these countries, including Ukraine.

At the same time, according to the analysis, Ukraine and Poland are countries with low volatility in carbon dioxide emissions. If we make a comparison in terms of the long-term period, a number of European countries, including the Visegrad Four, demonstrate a decrease in CO2 emissions per $1 of GDP.

The second most important greenhouse gas is methane. It causes significant climate change, and its ability to retain heat in the atmosphere is stronger than that of carbon dioxide. The overall picture of methane emissions from all types of activities in Europe is shown in Figure 6.

According to the results of the research, we can call Ukraine a «leader» among European countries in terms of CH4 emissions. In fact, it holds the top position in the total methane emissions of the EU and Ukraine.

Figure 6. Methane – Total – all NACE activities, Tonne, 2016-2023 [10]

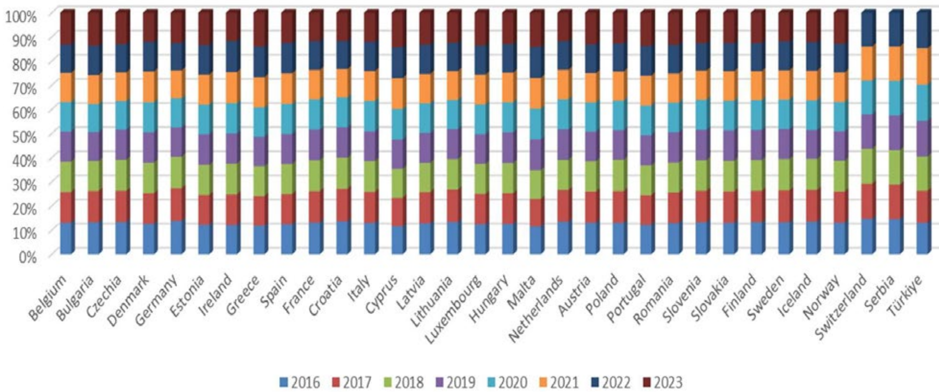
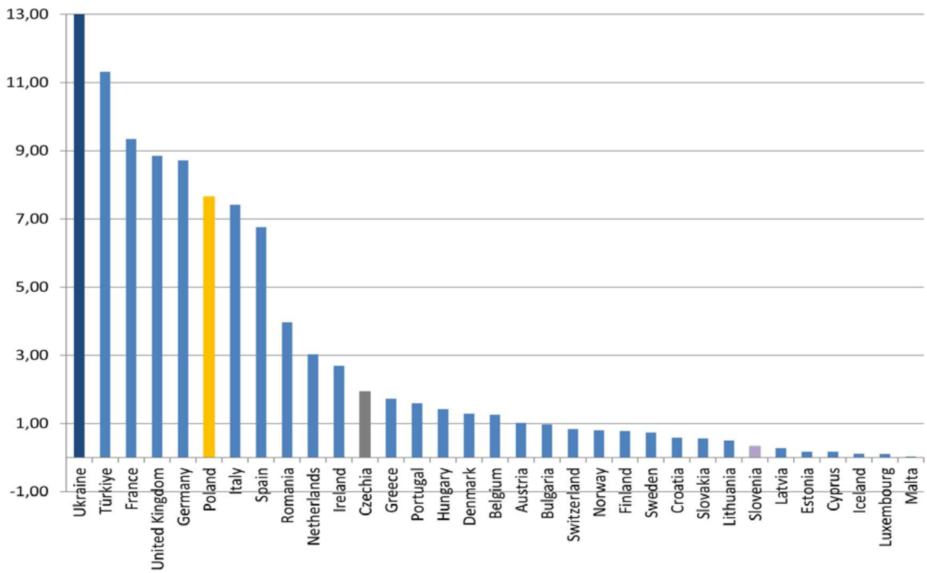
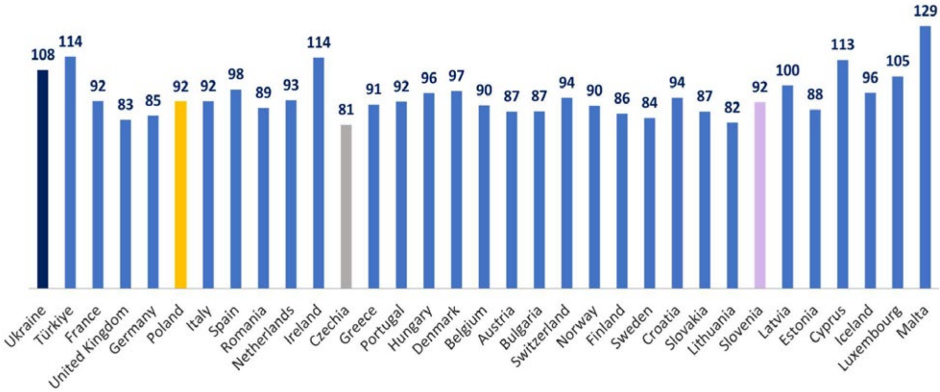


Figure 7. Share of methane emissions into atmospheric air in the total emissions of Europe and Ukraine [11]



The sources of CH4 emissions in Ukraine are almost identical to European and global sources of methane air pollution: the energy sector, coal, oil and gas industries, etc. This is confirmed by the IEA data [12]. The main contributors to methane production in Ukraine are gas supply companies (40%), mining and quarrying industries (28%), and livestock farming (12%). Additionally, the analysis revealed that CH4 emissions in both Ukraine and EU countries over a 10-year period cannot be characterized as steadily declining. In some countries, these emissions have continued to increase.

Figure 8. Trends in the amount of CH4 emissions in the EU and Ukraine (according to Eurostat and the Ukrainian National Statistics Committee) [11]



It is important to note that neither the world nor the EU countries stand aside from the issue of reducing methane emissions. Thus, at COP 2024, the European Commission announced the Methane Emissions Reduction Partnership Roadmap, which outlines a scheme of cooperation between importers and exporters to accelerate the reduction of methane emissions. And the GMP (Global Methane Pledge) participants generally called on the entire international community to continue and accelerate their efforts to reduce methane emissions as soon as possible [13].

The share of nitrogen oxide emissions in 2016-2023 is significant in the total emissions of European countries, as well as other pollutants.

It is characterized by negative growth dynamics. So, 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 and manure management activities. In addition, grain production was found to be the most correlated with nitrous oxide emissions. Nearly 19% of agricultural sector emissions are caused by fermentation of animals. In addition, 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 9. Nitrous oxide – Total – all NACE activities, Tonne, 2016-2023 [10]

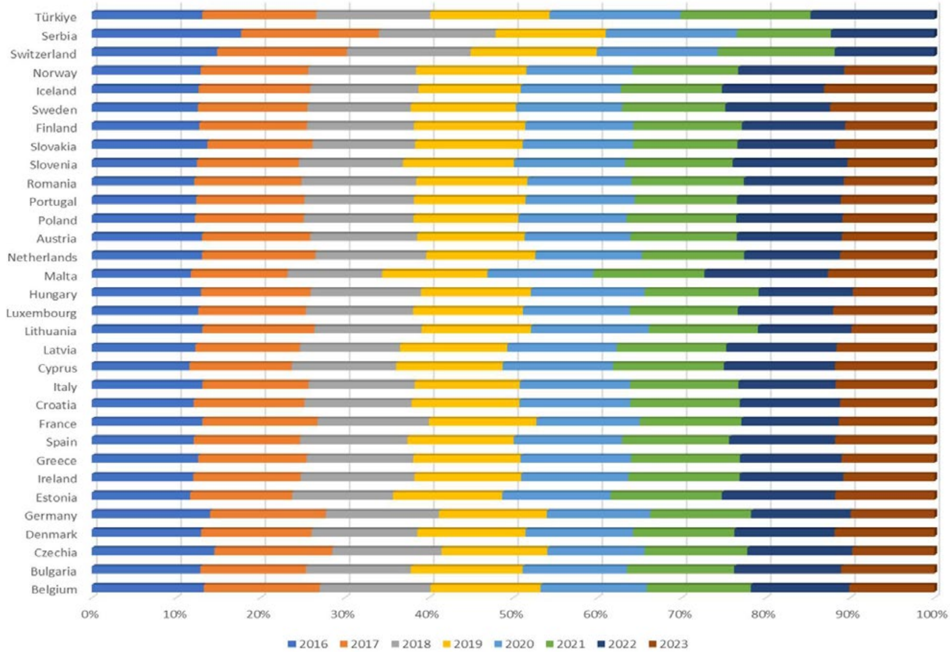
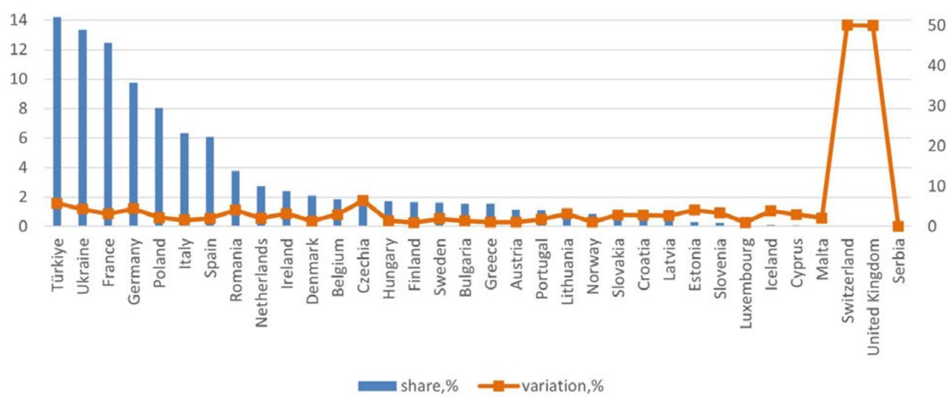


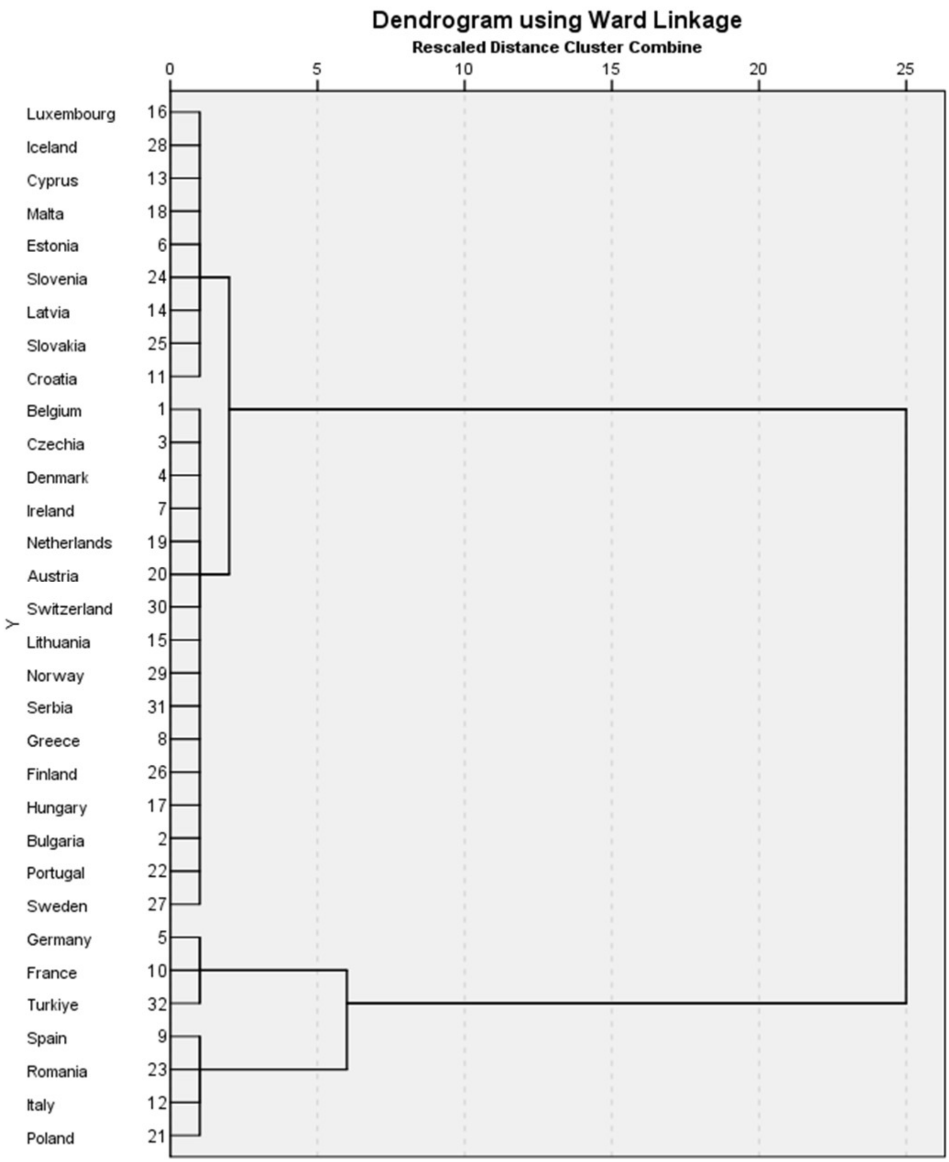
Figure 10. Share of N2O Emissions in the Total Volume 2020 (variation 2016 – 2020) [11]



We would also like to emphasize the emissions of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF6), and nitrogen trifluoride (NF3). The emissions of these gasses 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.

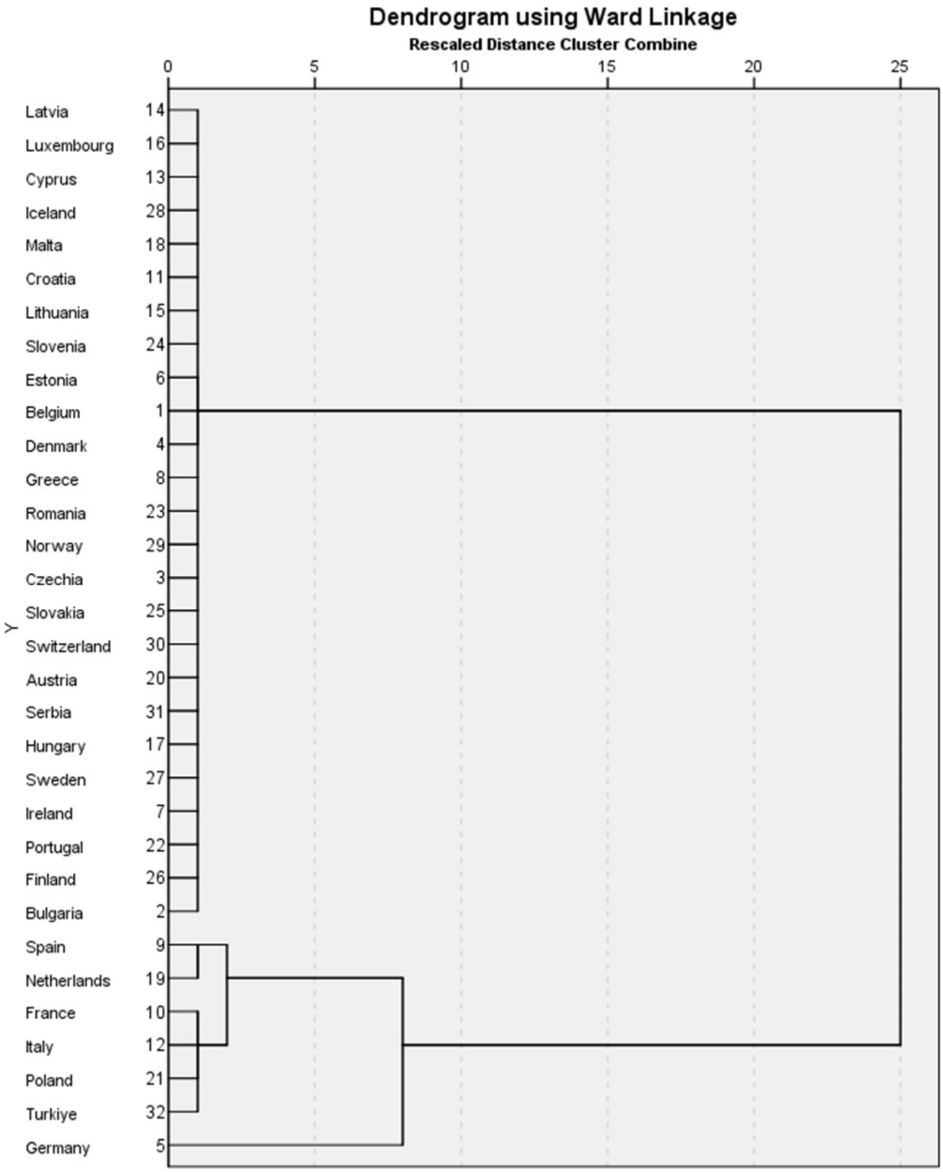
The research included a cluster analysis for the three main greenhouse gas emissions. Its results showed that, in general, for nitrous oxide, methane and CO2, all selected European countries were divided into 2 clusters. In this case, if we discuss the countries of the Visegrad Group, only Poland was included in the 2nd cluster, while the Czech Republic, Hungary and Slovakia were included in the first cluster. Nitrous oxide: we can observe that 25 countries make up the first cluster, and 7 – the second.

Figure 11. Cluster analysis for Nitrous oxide



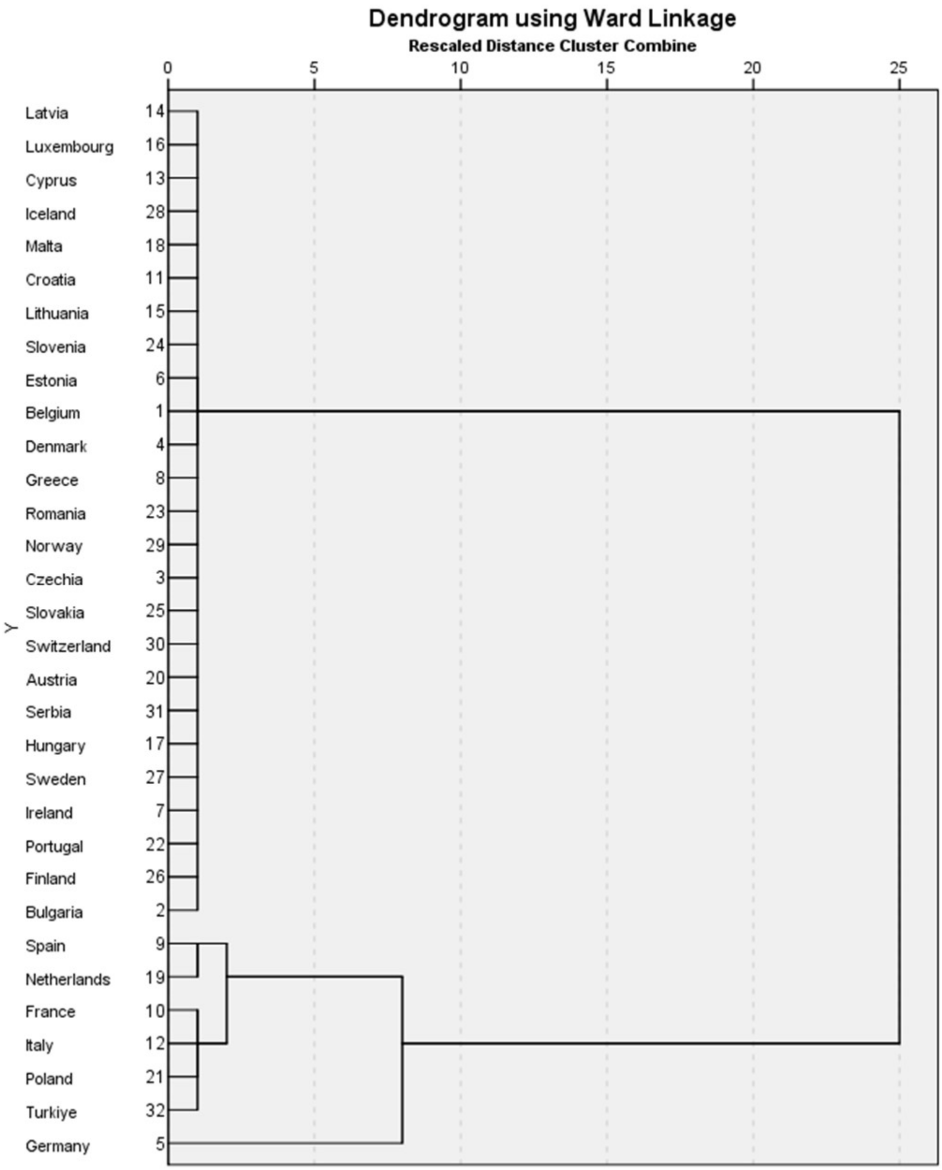
Methane: The Netherlands joined the second cluster, while Romania moved to cluster 1.

Figure 12. Cluster analysis for methane



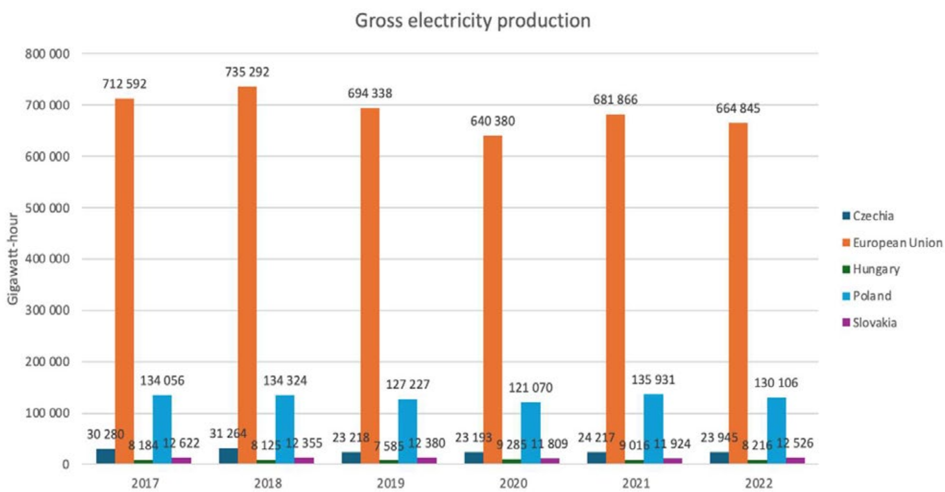
Carbon dioxide: the situation is similar to the one presented in the calculations for the methane cluster. Therefore, we can identify similarities between the countries included in the clusters. The countries that form both clusters are dissimilar in a number of characteristics (economic, social, and environmental). At the same time, the fact that the countries of the Visegrad Group are divided into two clusters is important in this research.

Figure 13. Cluster analysis for Carbon dioxide



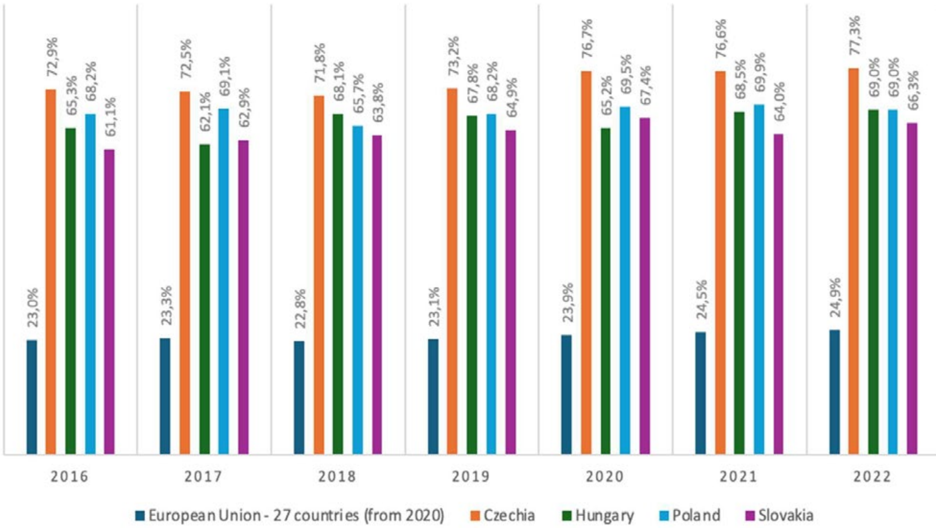
After considering the volume of greenhouse gas emissions for Ukraine and the EU countries, it should be noted that the main greenhouse gas emitters are economic activity entities. Since this research is focused on the Visegrad countries and Ukraine, further analysis will be conducted with a focus on the following countries: Poland, Hungary, Czech Republic, Slovakia and Ukraine. The areas producing the largest greenhouse gas (GHG) emissions in Europe typically include specific industries, sectors, and regions with high energy consumption, industrial activity, or reliance on fossil fuels. One of the largest sources of greenhouse gas emissions is still the production of electricity based on fossil fuels. Among the Visegrad countries, Poland and the Czech Republic is a country where coal-fired power plants are still a significant part of the energy balance. The dynamics of Gross electricity production is illustrated in the figure below.

Figure 14. The dynamics of Gross electricity production in the EU and Visegrad countries



Passenger cars, freight trucks, and delivery vehicles are major contributors GHG due to reliance on diesel and gasoline. The transport sector is a significant contributor to greenhouse gas (GHG) emissions in Europe, accounting for approximately 23 % of the EU's total emissions in 2022. In 2022, EU-wide transportation-related GHG emissions rose by 7% from the previous year, reaching 1.04 million tonnes of CO_2 equivalent. Road transport is the predominant source within this sector, responsible for 73.2% of transport-related GHG emissions in 2022. Today, the road transport share in total freight transportation for the Visegrad countries remains quite significant, as can be seen from the figure.

Figure 15. Modal split of air, sea and inland freight transport in the EU and Visegrad countries, Percentage

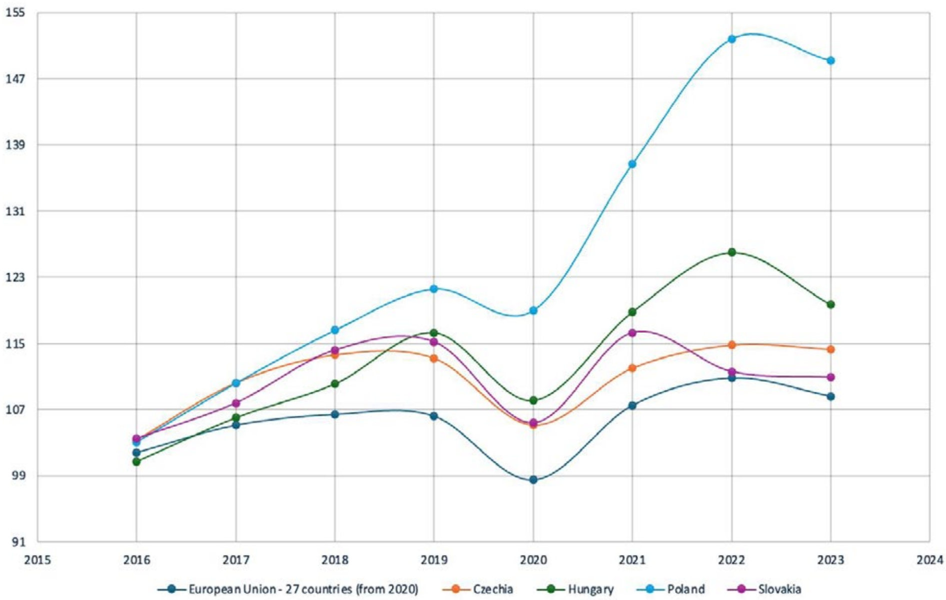


The heavy industry (steel, cement, chemical production, and other energy-intensive industries are significant emitters) and the construction sector are also significant emitters of greenhouse gas emissions. According to [14] in 2022, the energy supply sector accounted for just over 26% of the EU's total GHG emissions, while the manufacturing and construction sectors combined contributed approximately 20%. According to official data [15] after two successive increases, including an increase of 8.5% in 2021 compared with 2020 and a 0.4% increase in 2022 compared with 2021, the EU's production of manufactured goods recorded a decrease of 1.2% in 2023 compared with 2022. In nominal terms, the EU's value of sold production in 2023 amounted to €5 992 billion. Relatively high increases were recorded for the production of motor vehicles and for other transport equipment. On the other side of the spectrum the extraction of crude petroleum and natural gas decreased by 17.9%, the mining of coal and lignite by 15.9% [16]. It is important to note that, for example, Poland produced approximately 7.8 million tons of steel in 2022, maintaining its position as a significant producer within the EU. The Czech Republic's steel production was around 4.6 million tonnes in 2022, reflecting its robust industrial base. Slovakia contributed about 4.5 million tonnes to the EU's steel output in 2022. Hungary's steel production was approximately 1.5 million tonnes in 2022.

Regarding the construction industry, the total turnover of the EU construction industry reached approximately €2.1 trillion, with specialized construction activities accounting for the largest share [17], this sector also shows an increasing trend in the EU in general. In the Visegrad countries, this sector was growing before the COVID-19 pandemic, which caused a slowdown in the growth rate of this industry.

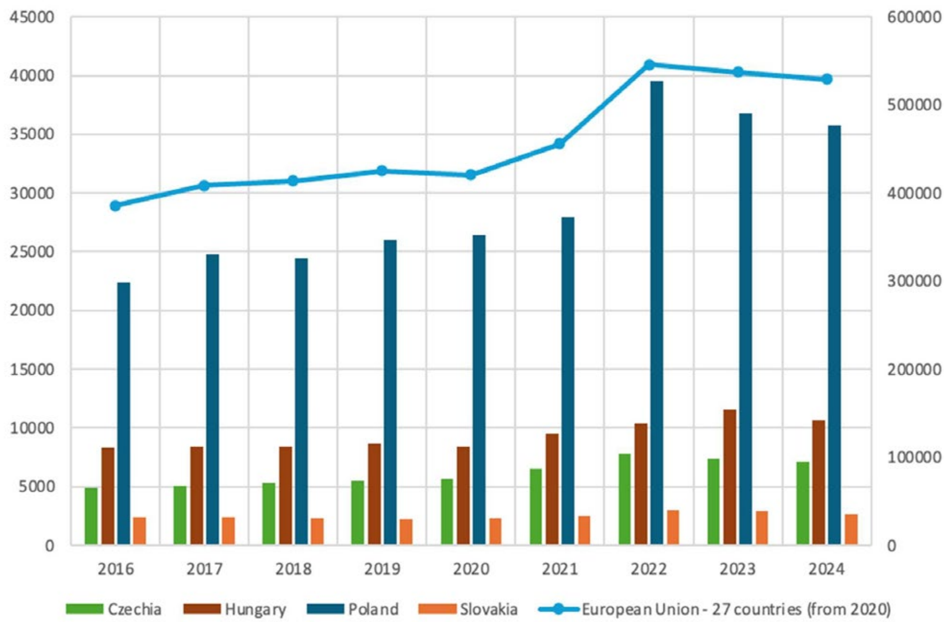
However, starting from 2021-2022, the industry showed signs of recovery, with gradual increases in construction activities. Continued growth was observed, supported by government investments and infrastructure projects. Based on the dynamics of production growth in general in the EU and Visegrad countries and, in particular, in the industries that directly or indirectly have the greatest impact on greenhouse gas emissions (Figure 16), it is worth noting that the problem of reducing greenhouse gas emissions requires a comprehensive approach that accumulates the efforts of both governments and producers.

Figure 16. Production in industry (Mining and quarrying; manufacturing; electricity, gas, steam and air conditioning supply), Index



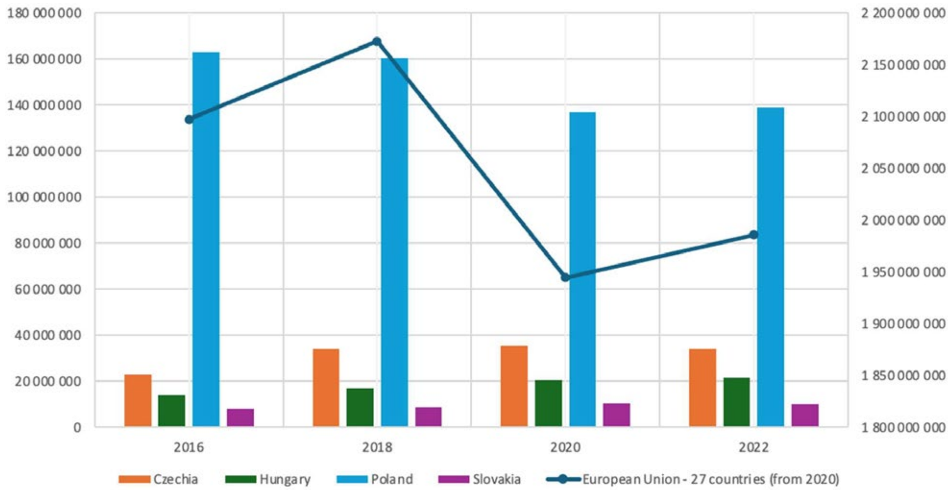
Another significant producer of greenhouse gas emissions is the agricultural sector. In 2023, the EU's agricultural industry generated a GVA of €223.9 billion, contributing 1.3% to the EU's GDP [18]. The EU's harvested production of grain maize and corn-cob-mix rebounded to 61.0 million tonnes in 2023, a 15.2% increase from 2022 [19]. Poland is the largest agricultural producer among the Visegrad countries. Hungary ranks second in agricultural production among the Visegrad countries [20]. Czech Republic and Slovakia have significant agricultural sectors, with diverse crop and livestock production. In this regard, as shown in Figure 17, this area also requires the implementation of a balanced, economically reasonable policy aimed at reducing greenhouse gas emissions.

Figure 17. Economic accounts for agriculture – values at current prices, Million euro



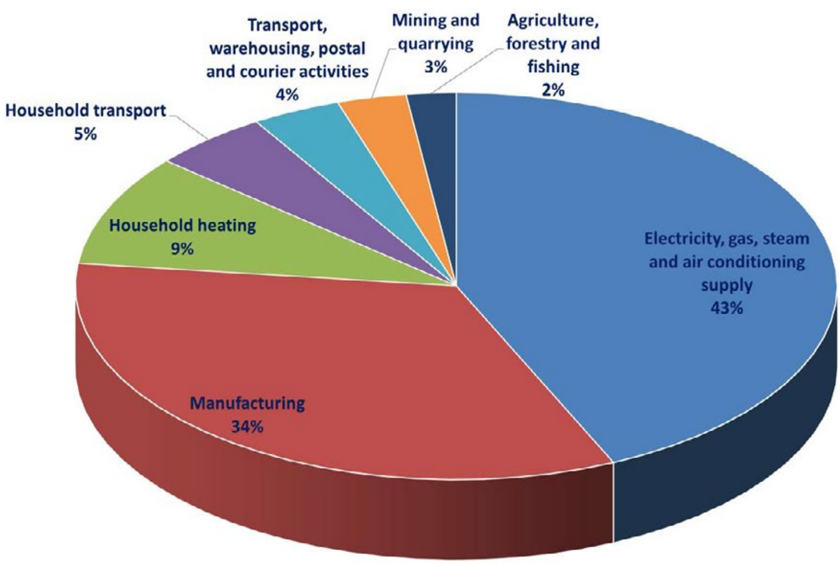
When analyzing the economic factors that contribute to the growth of greenhouse gas emissions, it is also important to pay attention to waste management. In 2022, the EU generated approximately 2,292 million tonnes of waste, with construction and demolition activities accounting for 37.1% of this total [21]. The EU has made significant strides in recycling municipal waste, achieving a recycling rate of 49.6% in 2021, up from 46% in 2017 [22]. In 2022, the EU treated 99.6 million tonnes of hazardous waste. As for the Visegrad countries, as of 2022, recycling rates approximately: Czechia – 40% of municipal waste, Hungary – 35%, Poland – 30%, Slovakia – 45%. Landfill Usage: Czechia – 20% of municipal waste, Hungary – 25%, Poland – 30%, Slovakia – 15%.

Figure 18. Treatment of waste by waste category, hazardousness and waste management operations, Tonne



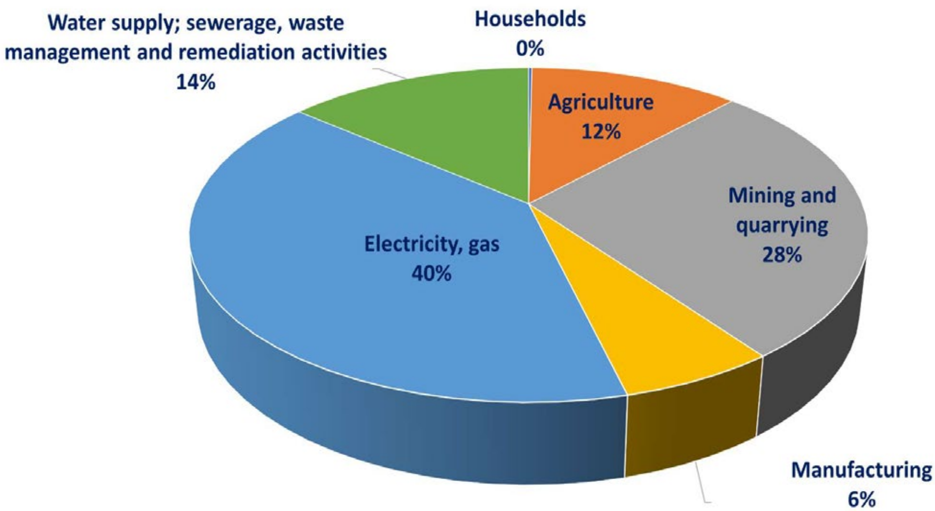
As for the main activities that are the largest GHG emitters in Ukraine, they are similar to those identified for the EU and Visegrad countries. The largest amount of carbon dioxide is emitted into the atmosphere as a result of the economic activity of thermal power stations and processing industry enterprises (Figure 19).

Figure 19. Structure of CO_2 Emissions by Sectors into the Atmospheric Air in Ukraine 2020 [23]



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. Thus, strategically, Ukraine is on track to reduce CO2 emissions and reduce its share of the greenhouse effect [23].

Figure 20. Structure of sources of methane emissions into atmospheric air in Ukraine, % (Greenhouse gases: Nitrogen, Methane) [23]



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 [24].

However, despite the fact that in Ukraine the sources of greenhouse gas emissions are identical to the EU countries, it is necessary to note that the problem of waste management and environmental pollution is more challenging than in the EU countries and significantly complicates the military operations on the territory of Ukraine. That is why an assessment of their impact on the environmental situation both inside and outside the country will be possible only after the war is ended.

The impact of the war in Ukraine on the environment

When comparing Ukraine with European countries, particularly those in the Visegrad group, it is important to note that Ukraine is engaged in full-scale military operations. This significantly complicates the assessment and comparison of the economic, social, and environmental factors that contribute to pollutant production, especially in the development of a methodology for evaluating the integrated potential for their reduction. In general, according to the Ministry of Environmental Protection and Natural Resources of Ukraine, as of the end of May 2024, at least 180 million tons of CO2 emissions were recorded as a result of military operations in Ukraine [25]. The objective need to increase the volume of ammunition, military equipment, and materials for the construction of defense facilities is characterized by high energy intensity, which leads to an increase in greenhouse gas emissions. In particular, the EU plans to increase the production of ammunition from 1 to 1.7 million per year by the end of 2024, and to 2.5 million by the end of 2025 [26]. In addition, the closure of airspace in Ukraine and the increase in road traffic in the EU have an impact on the growth of pollutant emissions; a significant number of temporarily displaced persons from Ukraine, which amounted to about 4.3 million people as of the beginning of 2024, causes an increase in household waste in the EU. Rebuilding the destroyed civilian and critical infrastructure of Ukraine will lead to an increase in the production of construction materials in Europe, which is extremely carbon-intensive [27]. Therefore, greenhouse gasses generated by the war in Ukraine will have an impact on global warming and may significantly slow down the achievement of global climate change goals. However, it is currently impossible to provide an accurate assessment of the impact of the war in Ukraine on greenhouse gas emissions and, as a result, on climate change in Europe and the world as a whole, because the phase of active military operations is ongoing.

Although, according to Eurostat and other analytical data, EU countries as a whole continue to take steps toward implementing their commitments to decarbonization and reducing greenhouse gas emissions (which amounted to 3.4 billion tons in 2023, reflecting a 5.1% decrease from 2022), the progress in achieving environmental sustainable development goals and reducing greenhouse gas emissions varies significantly among European countries and Ukraine. This issue is widespread and requires a collaborative approach to mitigate the negative impacts of climate change, which are already evident both nationally and globally. Therefore, in order to unify the data for Ukraine and the Visegrad countries, this research used data up to 2021 when developing a methodology for assessing the economic, social and environmental impact on greenhouse gas emissions. However, it is necessary to note that in the process of further research on the impact of greenhouse gas emissions on climate change in the global context, it is impossible to neglect the factor of the war's influence, as its environmental consequences are not limited to the administrative borders of Ukraine. 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.

Assessment of local greenhouse gas emission indexes and identification the sustainability types of their behavior

Ukraine

The assessment of greenhouse gas emissions potential is based on a conceptual view of emissions as a composite (aggregate) result of the interrelated impact of economic, social, and environmental factors. To implement the methodology of the research, a group of input components was selected for each of the local groups. The components were selected from those that corresponded to the following criteria: 1) described the dynamics of changes in resources, the use of which is related to greenhouse gas emissions; 2) were officially confirmed; 3) showed close correlations in the local group.

As a result of the calculation of the factors, the input traits were selected as following: for the economic group: 76 traits, for the environmental group – 38, and for the social group – 15.

Table 2. Identification of local component factors

Factor	Indicator
	Economic component
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

Factor	Indicator
	Environmental component
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
Social component	
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

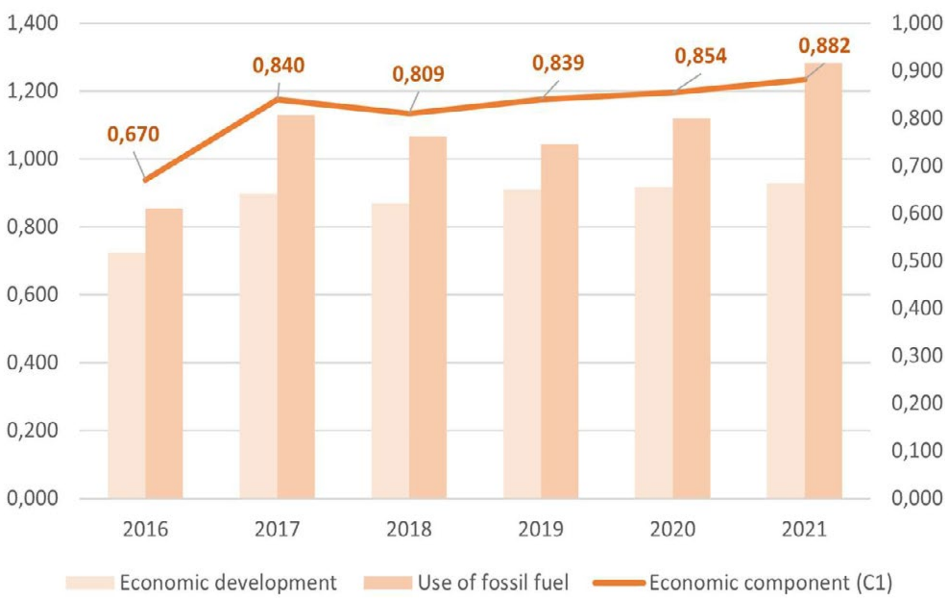
The factor analysis (Method Principal component analysis (Varimax Rotation, scores – Method Bartlett)) allowed us to identify the indicators that had the most significant impact on the determined factors.

As a result of the use of factor analysis, the size of the input sample was significantly reduced and the main factors in each component were singled out. To normalize the input traits within each component, the minimax method was used, whereby the selection of traits within each component was divided according to the criterion of their direct (destimulator) or reverse (stimulator) influence on the volume of greenhouse gas emissions. In general, the factor method made it possible to reduce the size of the input sample of traits of each of the components.

Based on the analysis of the composite index of economic component, the following conclusions were made:

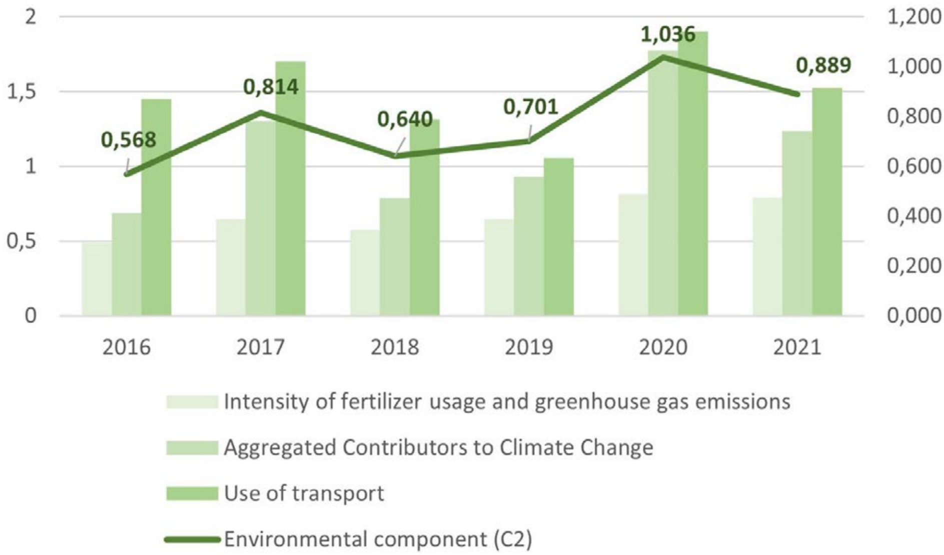
1) in the structure of the economic component, use of natural gas has a significant impact on greenhouse gas emissions (Figure 21).

Figure 21. Dynamics of the composite local index of economic factors of impact on GHG emissions in Ukraine



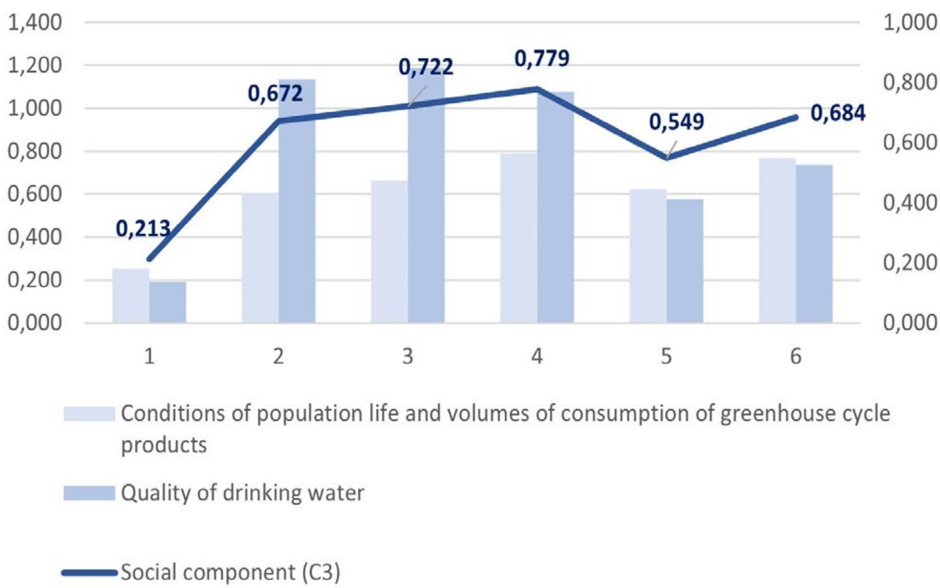
2) among the factor groups of the ecological component, the group of CO_2 emissions from road transport and the group of generalized producers of climate change exert the highest influence. The share of the Intensity of fertilizer use and greenhouse gas emissions group is significantly inferior to the volume of greenhouse gas emissions (Figure 22).

Figure 22. Dynamics of the composite local index of environmental factors of impact on GHG emissions in Ukraine



3) In the group of social factors influencing greenhouse gas emissions, there is a tendency to reduce the impact of the population on the environmental load (Figure 23).

Figure 23. Dynamics of the composite local index of social factors of impact on GHG emissions in Ukraine



Among the factor groups, the group of drinking water quality has a significant impact on greenhouse gas emissions, as deterioration of drinking water quality leads to an increase in its stagnation and evaporation in summer, which leads to an increase in vapor in the atmosphere.

The use of mathematical statistics methods to research the behavior of local indices allows us to identify the type of resistance and the direction of factors in terms of their impact on greenhouse gas emissions.

The type of resistance can be characterized as: resistant, nonresistant, and conditionally resistant. And the type of behavior, in particular, as: Aimed at a slight increase in emissions, Uneven dynamics, aimed at reducing emissions by the population etc.

Table 3. Assessing the type of behavior of local components

Local component	Coefficient of variation of the component	Type of resistance	Type of behavior
Economic	0,35	non-resistant	Aimed at a slight increase in emissions
Social	0,33	non-resistant	Uneven dynamics
Environmental	0,23	moderately resistant	Aimed at reducing emissions by the population

Based on the results of the analysis, it will also be possible to present correlation of the composite index with greenhouse gas emissions.

As part of the research, it is suggested to implement and approve the methodology for assessing greenhouse gas emissions potential and to assess local greenhouse gas emission indices, determine the types of sustainability of their behavior, and conduct an integrated assessment of greenhouse-forming factors for the Visegrad countries. At the same time, because of the difficulties of using a similar statistical base compared to Ukrainian statistics (especially in terms of social indicators), the assessment will be carried out by economic and environmental components, based on the maximum similarity of the selected indicators.

Poland

The factor analysis (Method Principal component analysis (Varimax Rotation, scores – Method Bartlett) allowed us to identify the indicators that had the most significant impact on the determined factors. Based on the analysis of the composite index of economic component, the following conclusions were made: 1) in the structure of the economic component, waste management and environmental impact activities have a significant impact on greenhouse gas emissions (Figure 24). 2) the level of economic development also has a significant impact on the growth of greenhouse gas emissions. Environmental factors that are of significant importance for Poland include the intensity of mineral fertilizer consumption, forest cover, aggregated contributors to climate change and related economic losses.

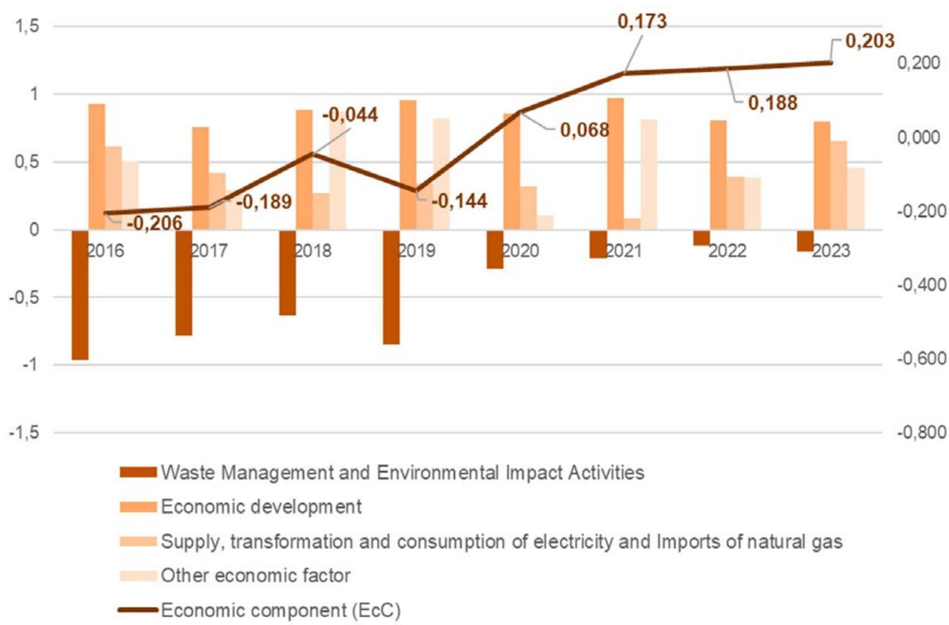
Table 4. Identification of local component factors (Poland)

Factor (% of Variance)	Indicator
Economic component	
Waste Management and Environmental Impact Activities (54,1 %)	Management of waste excluding major mineral waste, by waste management operations (Kilograms per capita)
	Management of waste excluding major mineral waste, by waste management operations (Tonne)
	Annual detailed enterprise statistics for Mining and quarrying industry (Production value – million euro)
	Modal split of inland freight transport (Roads/Percentage)
	Municipal waste by waste management operations (Waste generated / Kilograms per capita)
	Municipal waste by waste management operations (Thousand tonnes / Kilograms per capita)
	Treatment of waste by waste category, hazardousness and waste management operations (Hazardous and non-hazardous – total / Tonne)
	Treatment of waste by waste category, hazardousness and waste management operations (Hazardous and non-hazardous – total / Tonne / Disposal – landfill and other)
	Treatment of waste by waste category, hazardousness and waste management operations (Hazardous and non-hazardous – total / Tonne / Disposal – incineration (D10))

Factor (% of Variance)	Indicator
	Economic component
Economic development (20,2%)	Energy productivity (Euro per kilogram of oil equivalent)
	GDP and main components (output, expenditure and income) (Current prices, million euro)
	Real GDP per capita (Chain linked volumes (2010), euro per capita)
	GDP and main components (output, expenditure and income) (Chain linked volumes (2010), million euro)
	Municipal waste by waste management operations (Disposal – incineration (D10) and recovery – energy recovery (R1) / Kilograms per capita)
	Supply, transformation and consumption of electricity (Final consumption – transport sector – energy use / Gigawatt-hour)
	Supply, transformation and consumption of electricity (Final consumption – other sectors – commercial and public services – energy use / Gigawatt-hour)
	Supply, transformation and consumption of oil and petroleum products (Gross inland deliveries – calculated / Thousand tonnes)
	Road freight transport by type of goods and type of transport (t, tkm) (Total transported goods / Thousand tonnes)
Supply, transformation and consumption of electricity and Imports of natural gas (12,7%)	Final energy consumption by product (Thousand tonnes of oil equivalent)
	Final energy consumption by sector (Thousand tonnes of oil equivalent)
	Imports of natural gas by partner country (Million cubic metres)
	Supply, transformation and consumption of electricity (Available for final consumption / Gigawatt-hour)
	Supply, transformation and consumption of electricity (Final consumption – industry sector – energy use / Gigawatt-hour)
	Supply, transformation and consumption of electricity (Final consumption – other sectors – households – energy use / Gigawatt-hour)
Other economic factor (5,9%)	Municipal waste by waste management operations (Disposal – landfill and other (D1-D7, D12) / Kilograms per capit)
	Exports of natural gas by partner country (Million cubic metres)

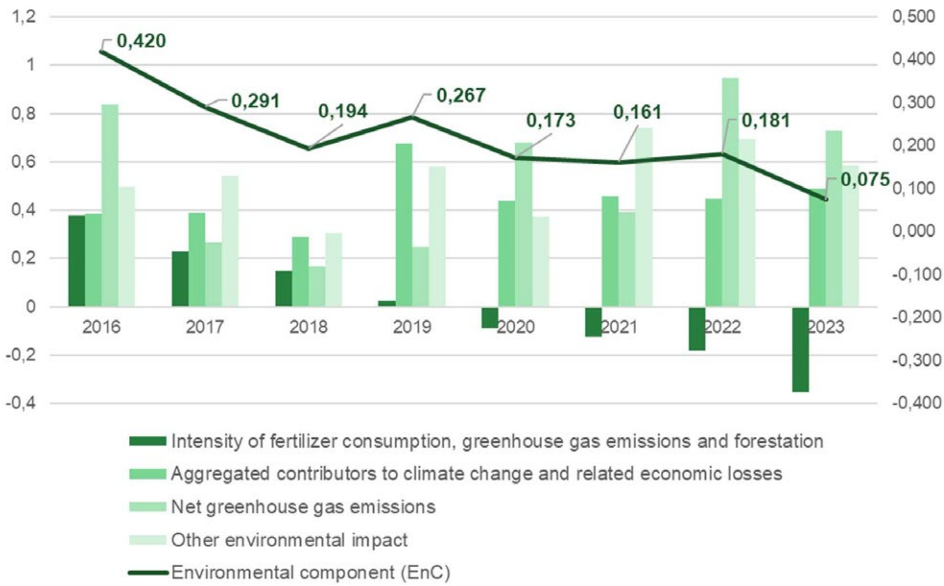
Factor (% of Variance)	Indicator
Environmental component	
Intensity of fertilizer consumption, greenhouse gas emissions and forestation (50,4 %)	Total nitrogen emissions, tonnes
	Nitrogen, kg of nutrient per ha (Gross nutrient balance per hectare UAA)
	Greenhouse gases (CO2, N2O in CO2 equivalent, CH4 in CO2 equivalent, HFC in CO2 equivalent, PFC in CO2 equivalent, SF6 in CO2 equivalent, NF3 in CO2 equivalent), Grams per euro, current prices
	Forest area, % of land area
	Fertilizer consumption, kilograms per hectare of arable land
	Consumption of Phosphorus, Tonne
	Carbon intensity of GDP, kg CO2e per 2021 PPP $ of GDP
	Air emissions (Carbon dioxide) by resident units (production activities and households), Tonne
Aggregated contributors to climate change and related economic losses (27,1%)	Utilised agricultural area excluding kitchen gardens (Fully converted to organic farming), hectare
	Contribution to the international 100bn USD commitment on climate related expending [sdg_13_50], Million euro
	Consumption of Nitrogen, Tonne
	Climate related economic losses – values at constant 2022 prices [sdg_13_40], Current prices, million euro
Net greenhouse gas emissions (10,2%)	Greenhouse gases (CO2, N2O in CO2 equivalent, CH4 in CO2 equivalent, HFC in CO2 equivalent, PFC in CO2 equivalent, SF6 in CO2 equivalent, NF3 in CO2 equivalent), Total (excluding memo items, including international aviation), Index, 1990=100
Other environmental impact (7,9%)	Average CO2 emissions per km from new passenger cars, Grams per kilometre
	Total environmental taxes, Percentage of gross domestic product (GDP)

Figure 24. Dynamics of the composite local index of economic factors of impact on GHG emissions in Poland



The indicators included in the Waste Management and Environmental Impact Activities factor, the leading place is occupied by the indicators of waste management. In recent years, Poland has seen a decrease in the amount of waste generated per capita due to the progressive adoption of more efficient management practices and an increase in recycling rates. It's reflecting the country's efforts to align with European Union (EU) directives and move towards a circular economy. In addition, it is also worth noting that from 2021 and further in 2022 and 2023, there is a gradual increase in recycling and a decrease in landfilling of various categories of waste [28], which may be an indication of the growing effectiveness of waste management policy in Poland. Despite the improvements, landfilling remains the predominant waste management method in Poland, and the waste recycling infrastructure requires investments in modern sorting facilities, increased recycling capacity, construction of composting facilities and other measures that will further reduce reliance on landfills and generate energy as a by-product. Other significant indicators affecting the growth of greenhouse gas emissions are the activities of the mining and quarrying industry and the modal split of inland freight transport. From 2018 to 2022, there was an increase in the cost of production in the mining industry, which may be related to an increase in production volumes and higher prices for raw materials. A decrease in the share of road transport (in 2022 and 2023 compared to 2021) in the overall structure of transportation may be the result of emission reduction policies and may contribute to the improvement of the environmental situation in the country. Therefore, given the trend of changes in the economic component, as well as the fact that the factors Waste Management and Environmental Impact Activities (54.1%) and Economic development (20.2%) have the greatest impact on it, with a total percentage of variation of almost 75% (Figure 24), it is important to note that a targeted impact on these factors by the state, business, and society can lead to a reduction in greenhouse gas emissions in Poland.

Figure 25 – Dynamics of the composite local index of environmental factors of impact on GHG emissions in Poland



In fact, according to the research, forest area is a significant factor in the structure of the environmental component. It is included either in the factor of the greatest or high impact.

If we analyze the European countries, the dynamics of the forest area indicator for 2016-2022 is generally increasing, but with low intensity:

Figure 26. Forest area (% of land area) of EU, 2016-2022 [29]

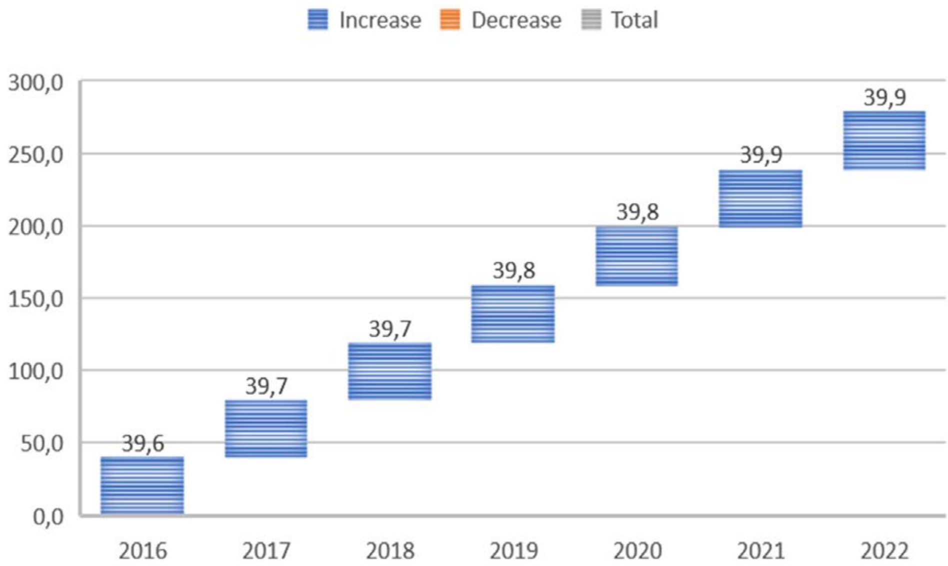
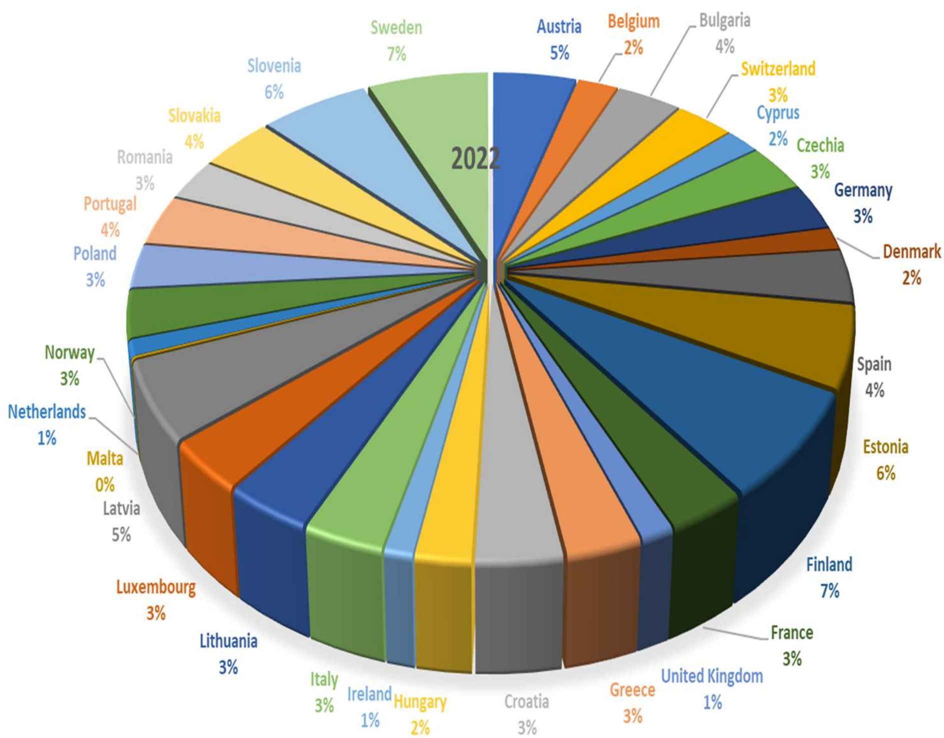


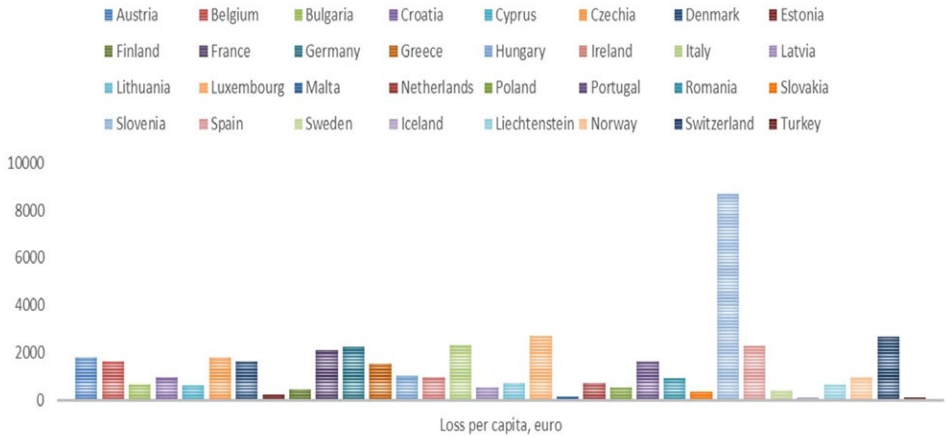
Figure 27. Forest area (% of land area), 2022 [29]



We can also talk about the significant impact of inorganic fertilizers on greenhouse gas emissions. According to the research [30] EU countries are actively implementing smart agriculture policies that gradually reduce fertilizer use while increasing yields. In general, as part of the circular economy programs, a number of provisions and regulations are adopted at the EU level, as well as policies aimed at minimizing the negative impact of fertilizers on the environment. EU countries are actively encouraging farmers to learn precision agriculture and promote organic farming and the use of organic fertilizers where possible. According to government officials and researchers, this will gradually reduce their carbon footprint. EIP-AGRI supports the development and implementation of operational programs. These include: Development of the production process of biological fertilisers (Italy); Technological, organisational, and marketing innovations in the field of fertilisation (Poland); Improving nitrogen efficiency (Germany); Integration of cover crops into field crop rotation (Slovenia); Operational group (OG) in smart agriculture in citrus irrigation and fertilisation (Spain) [31].

Climate related economic losses was also identified as a significant indicator for Poland. As noted in the methodological explanations to the indicator, the indicator measures economic losses from weather and climate-related events. In addition to annual figures, the indicator presents smoothed time series based on 30-year averages. In addition to annual indicators, we present a smoothed time series based on 30-year averages. In accordance with the normal climate period defined by the World Meteorological Organization, these 30-year averages reflect trends, excluding significant climate variability over shorter time intervals caused by natural factors [32]. At the same time, the issue of such losses is relevant for the EU countries in general. For example, according to [33], in general, extreme weather and climate events have lead to significant economic losses of assets. According to experts, these losses are estimated at €738 billion for the period 1980-2023, of which about 22% are losses between 2021 and 2023.

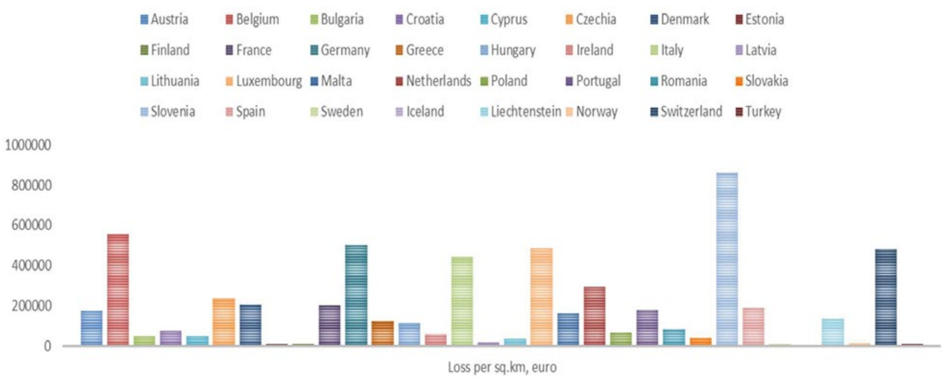
Figure 28. Economic losses and fatalities caused by weather and climate related extreme events (1980-2023) per capita, euro



As we can see from the figure, Poland is not the country with the highest economic losses and fatalities caused by weather and climate-related extreme events per capita. They are lower than in a number of the countries analyzed. At the same time, Slovenia is characterized by the highest indicator [34].

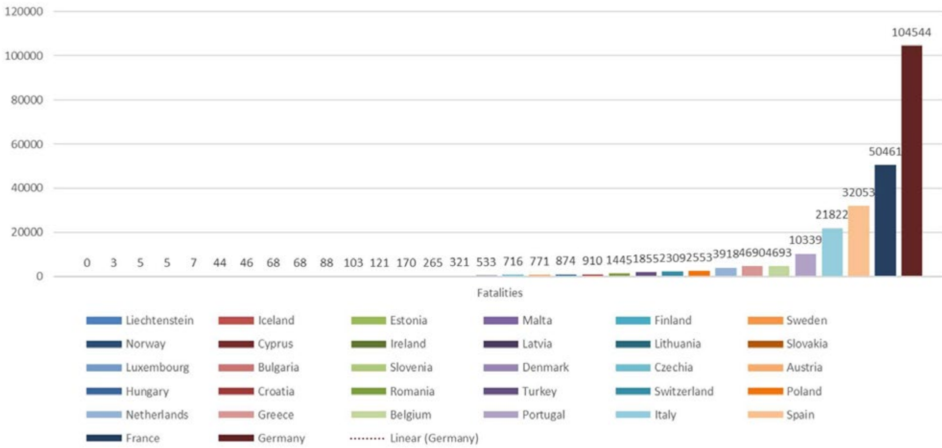
In absolute terms, the largest economic losses in the analyzed period were recorded in Italy, Germany, and France.

Figure 29. Economic losses and fatalities caused by weather and climate related extreme events (1980-2023) per sq.km, euro, euro [35]



According to the figure, Slovenia, Belgium, Germany, Italy, Luxembourg, and Switzerland have the highest economic losses and fatalities caused by weather and climate-related extreme events (1980-2023) per sq. km. Poland also ranks high in terms of fatalities:

Figure 30. Fatalities caused by weather
and climate related extreme events (1980-2023) [35]



The EU has developed an Adaptation Strategy to support actions to minimize economic losses and fatalities, including at the national level.

Hungary

The country is a signatory to international climate agreements. For example, in 2019, the country passed a law on building with a new climate paradigm in mind. Among other things, it emphasizes green spaces. The National Energy Strategy until 2030 was also adopted, and the Hungarian National Bank launched its green strategy [36]. For Hungary, Table 5 summarizes the economic and environmental factors that have an impact on reducing greenhouse gas emissions. Based on the analysis of the composite index of economic component, the following conclusions were made: 1) in the structure of the economic component, Economic development and waste management have a significant impact on greenhouse gas emissions (Figure 31); 2) the growth of greenhouse gas emissions is also significantly influenced by Energy and gas consumption.

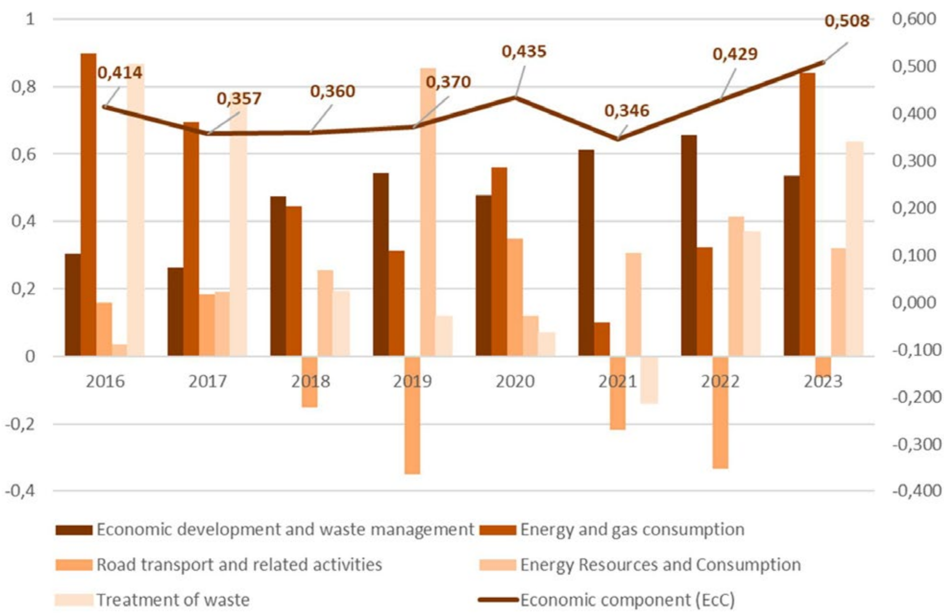
Table 5. Identification of local component factors (Hungary)

Factor	Indicator
	Economic component
Economic development and waste management (54,9%)	Energy productivity (Euro per kilogram of oil equivalent)
	GDP and main components (output, expenditure and income) (Current prices, million euro)
	Real GDP per capita (Chain linked volumes (2010), euro per capita)
	GDP and main components (output, expenditure and income) (Chain linked volumes (2010), million euro)
	Management of waste excluding major mineral waste, by waste management operations (Kilograms per capita)
	Management of waste excluding major mineral waste, by waste management operations (Tonne)
	Municipal waste by waste management operations (Waste generated / Kilograms per capita)
	Municipal waste by waste management operations (Thousand tonnes / Kilograms per capita)
	Municipal waste by waste management operations (Disposal – incineration (D10) and recovery – energy recovery (R1) / Kilograms per capita)
	Municipal waste by waste management operations (Disposal – landfill and other (D1-D7, D12) / Kilograms per capit)
	Supply, transformation and consumption of electricity (Available for final consumption / Gigawatt-hour)
	Supply, transformation and consumption of electricity (Final consumption – industry sector – energy use / Gigawatt-hour)
	Supply, transformation and consumption of electricity (Final consumption – transport sector – energy use / Gigawatt-hour)
	Supply, transformation and consumption of electricity (Final consumption – other sectors – households – energy use / Gigawatt-hour)
	Treatment of waste-by-waste category, hazardousness and waste management operations (Hazardous and non-hazardous – total / Tonne)
Energy and gas consumption (16,8%)	Final energy consumption by product (Thousand tonnes of oil equivalent)
	Final energy consumption by sector (Thousand tonnes of oil equivalent)
	Supply, transformation and consumption of gas (Inland consumption – calculated / Terajoule (gross calorific value – GCV)

Factor	Indicator
Economic component	
Road transport and related activities (13,4 %)	Modal split of inland freight transport (Roads/Percentage)
	Supply, transformation and consumption of oil and petroleum products (Gross inland deliveries – calculated / Thousand tonnes)
	Road freight transport by type of goods and type of transport (t, tkm) (Total transported goods / Thousand tonnes)
Energy Resources and Consumption (7,0%)	Imports of natural gas by partner country (Million cubic metres)
	Annual detailed enterprise statistics for Mining and quarrying industry (Production value – million euro)
	Supply, transformation and consumption of electricity (Final consumption – other sectors – commercial and public services – energy use / Gigawatt-hour)
Treatment of waste (3,5%)	Treatment of waste by waste category, hazardousness and waste management operations (Hazardous and non-hazardous – total / Tonne / Disposal – landfill and other)
	Treatment of waste-by-waste category, hazardousness and waste management operations (Hazardous and non-hazardous – total / Tonne / Disposal – incineration (D10))
Environmental component	
Net greenhouse gas emissions, forestation, organic farming and taxes (56,3%)	Total nitrogen emissions, tonnes
	Nitrogen, kg of nutrient per ha (Gross nutrient balance per hectare UAA)
	Greenhouse gases (CO2, N2O in CO2 equivalent, CH4 in CO2 equivalent, HFC in CO2 equivalent, PFC in CO2 equivalent, SF6 in CO2 equivalent, NF3 in CO2 equivalent), Total (excluding memo items, including international aviation), Index, 1990=100
	Greenhouse gases (CO2, N2O in CO2 equivalent, CH4 in CO2 equivalent, HFC in CO2 equivalent, PFC in CO2 equivalent, SF6 in CO2 equivalent, NF3 in CO2 equivalent), Grams per euro, current prices
	Utilised agricultural area excluding kitchen gardens (Fully converted to organic farming), hectare
	Forest area, % of land area
	Carbon intensity of GDP, kg CO2e per 2021 PPP $ of GDP
	Total environmental taxes, Percentage of gross domestic product (GDP)

Factor	Indicator
	Environmental component
Fertilizer consumption, contribution of residents to emissions and economic losses (20,5%)	Fertilizer consumption, kilograms per hectare of arable land
	Consumption of Phosphorus, Tonne
	Consumption of Nitrogen, Tonne
	Air emissions (Carbon dioxide) by resident units (production activities and households), Tonne
	Climate related economic losses – values at constant 2022 prices [sdg_13_40], Current prices, million euro
Other environmental impact (12,4%)	Contribution to the international 100bn USD commitment on climate related expending [sdg_13_50], Million euro
	Average CO2 emissions per km from new passenger cars, Grams per kilometre

Figure 31. Dynamics of the composite local index of economic factors of impact on GHG emissions in Hungary



Among the indicators that formed the Economic development and waste management factor, the leading place is occupied by Energy productivity (Euro per kilogram of oil equivalent), indicators GDP and Management of waste. Between 2000 and 2023, Hungary achieved a 44% reduction in the energy intensity of its economy, indicating significant improvements in energy efficiency [37]. Hungary's substantial reduction in energy intensity and improvements in energy efficiency across various sectors reflect a positive trajectory toward more efficient energy use, this is confirmed by the growing dynamics of the indicator Energy productivity (Euro per kilogram of oil equivalent) (Figure 32).

Figure 32. Energy productivity, Euro per kilogram of oil equivalent

As for the generalized indicators of Hungary's economic development, which also formed the basis for the formation of the factor that has the greatest impact on greenhouse gas emissions, Hungary's Gross Domestic Product (GDP) has experienced notable fluctuations in recent years, reflecting various economic challenges and recovery efforts. For example, in 2022, the economy expanded by 4.6%, but in 2023 GDP contracted by 0.9%, marking the first economic downturn in three years [39]. At the same time, the largest share in the GDP structure is occupied by the following sectors: services sector – 64.8%, industry – 31.3%, agriculture represents 3.9% of the GDP.

Hungary's waste management system has undergone significant changes in recent years, aiming to align with European Union (EU) directives and promote sustainable practices. In 2020, Hungary reported a recycling rate of around 35% for municipal waste [39]. However, despite Hungary's progress in waste management, the country still disposes of a significant amount of waste in landfills (Figure 33).

Figure 33. Treatment of waste-by-waste category

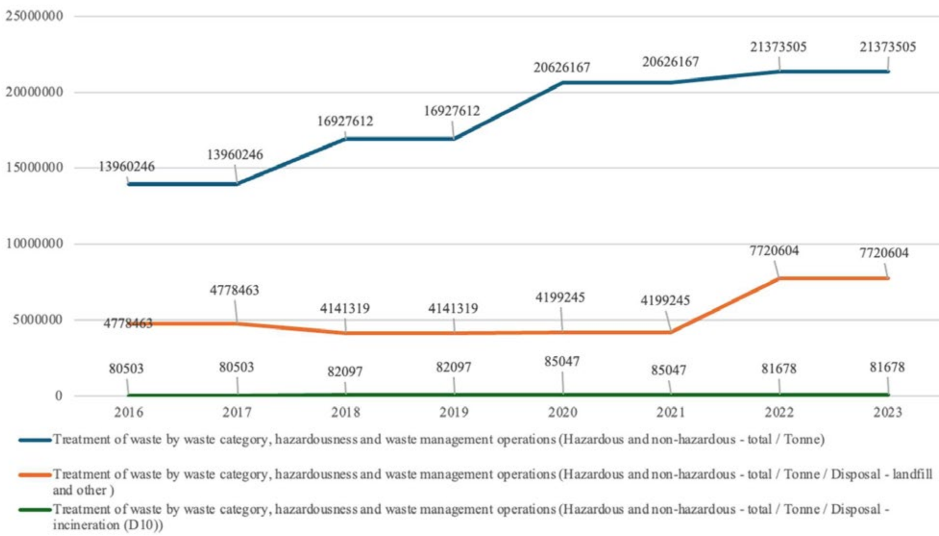
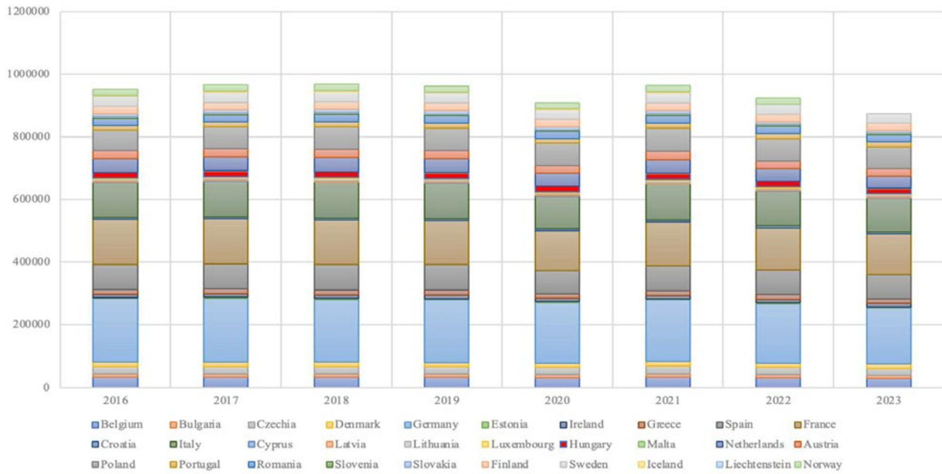


Figure 34 shows Final energy consumption by sector for EU countries. In general, between 2000 and 2022, energy efficiency measures resulted in significant energy savings, estimated at 240 million tonnes of oil equivalent, equating to 27% of FEC. Electricity consumption decreased by 3% in 2022 and by 3.5% in 2023, totaling 2,405 TWh, slightly below the 2005-2019 average of 2,500 TWh [40].

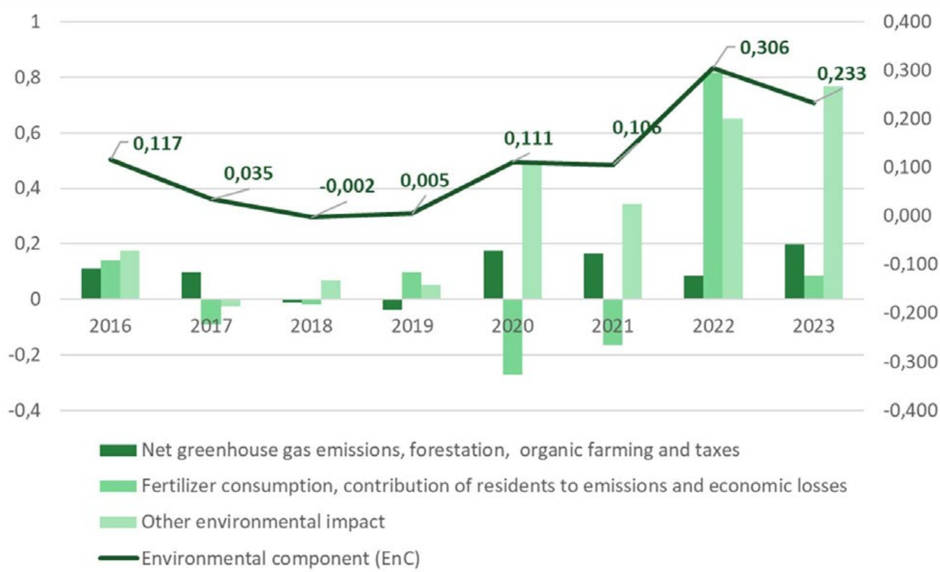
Therefore, considering the trend of changes in the economic component, as well as the fact that the greatest influence on it is caused by the factors Economic development and waste management (54.1%) and Energy and gas consumption (16.8%), which cumulative % of Variance is nearly 71% (Figure 31), it is important to note that conscious active actions on the part of the government and business in these components can lead to a reduction in greenhouse gas emissions in Hungary.

Figure 34. Final energy consumption by sector for EU countries, Thousand tonnes of oil equivalent



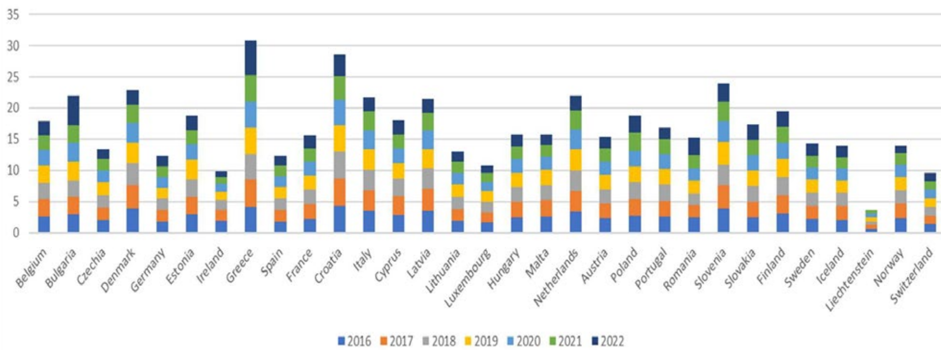
The analysis revealed that the most important environmental factor is the one that includes total nitrogen emissions, nitrogen, kg of nutrient per ha, greenhouse gases in CO2 equivalent, fully converted to organic farming, forest area, carbon intensity of GDP and total environmental taxes.

Figure 35. Dynamics of the composite local index of environmental factors of impact on GHG emissions in Hungary



In particular, we will focus on environmental taxes. The experience of European countries, including Hungary, is interesting for Ukraine, as the environmental taxation policy in a number of European countries can be defined as "best (effective) practice". At the same time, the "polluter pays" principle is clearly evident. The overall dynamics of total environmental taxes in Hungary corresponds to the average level of most European countries:

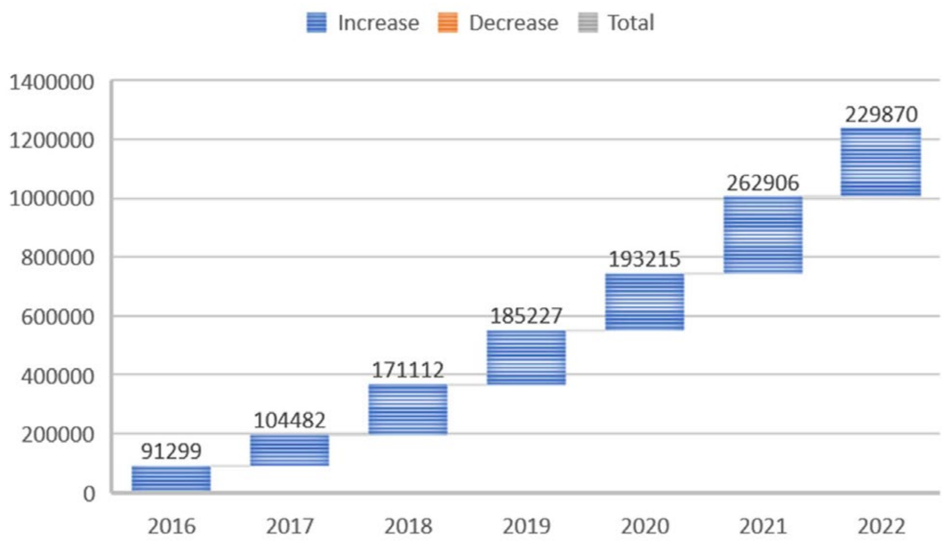
Figure 36. Total environmental taxes, % of GDP (2016-2022) [41]



At the same time, in July 2023, Hungary made changes to the Environmental Tax Law and new rules concerning activities, in particular, in the field of waste management (the so-called extended producer responsibility scheme) will come into force [42]. At the same time, as noted in [43], the green tax legislation of this country generally provides several possible options that can provide significant tax savings, but often businesses do not review their logistics from the perspective of this tax, so in some cases they pay more green taxes than necessary.

Organic farming is also an important component in reducing greenhouse gas emissions and has a significant impact on social indicators of society. In Hungary, it has been growing significantly in recent years. At the same time, the opportunities (in particular, subsidies and market access) provided by EU membership are the basis for further development of organic farming in the country [44].

Figure 37. Fully converted to organic farming – utilised agricultural area excluding kitchen gardens, Hungary (2016-2022) [45]



In that context, we should agree that food production with low negative impact on the environment, specifically organic farming, allows us to build a sustainable food system in Europe. For example, in 2021, the European Commission approved an action plan to support organic farming. According to this plan, at least 25% of agricultural land should be covered by organic production, and the growth of aquaculture should be increased gradually. Indicator targets under the "Farm to Fork Plan and Strategy" are to be achieved by 2030. Member states should identify appropriate scientifically based national targets for organic agriculture [46].

Czechia

Table 6 summarizes the economic and environmental factors that influence the reduction of greenhouse gas emissions in the Czech Republic. Based on the analysis of the composite index of economic component, the following conclusions were made: 1) in the structure of the economic component, Economic development and waste management have a significant impact on greenhouse gas emissions (Figure 34). 2) Resource and waste management also has a significant impact on the growth of greenhouse gas emissions.

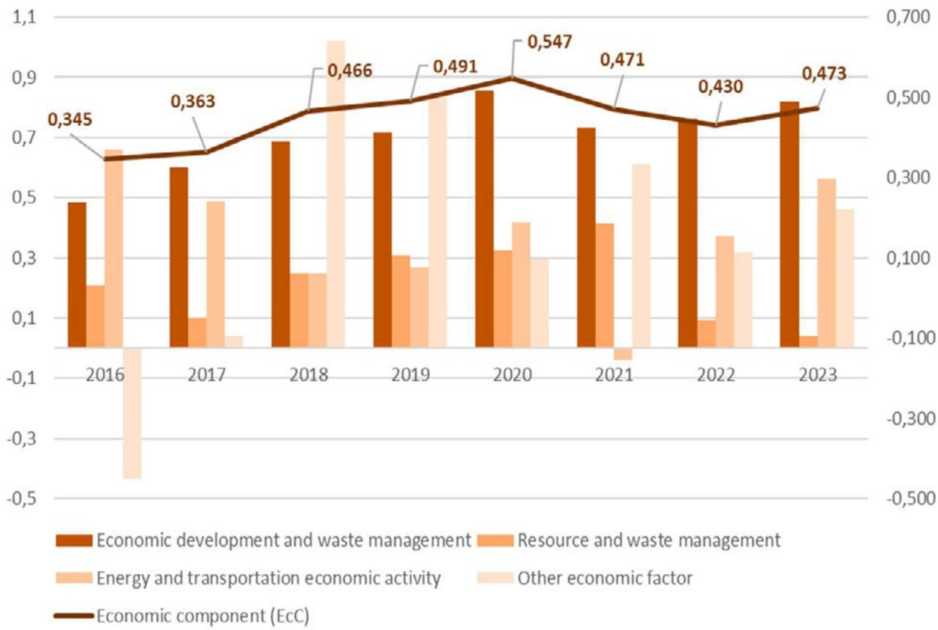
Table 6. Identification of local component factors (Czechia)

Factor	Indicator
	Economic component
Economic development and waste management (42,9%)	Energy productivity (Euro per kilogram of oil equivalent)
	Final energy consumption by sector (Thousand tonnes of oil equivalent)
	GDP and main components (output, expenditure and income) (Current prices, million euro)
	Real GDP per capita (Chain linked volumes (2010), euro per capita)
	GDP and main components (output, expenditure and income) (Chain linked volumes (2010), million euro)
	Municipal waste by waste management operations (Waste generated / Kilograms per capita)
	Municipal waste by waste management operations (Thousand tonnes / Kilograms per capita)
	Municipal waste by waste management operations (Disposal – landfill and other (D1-D7, D12) / Kilograms per capita)
	Supply, transformation and consumption of electricity (Final consumption – industry sector – energy use / Gigawatt-hour)
	Supply, transformation and consumption of electricity (Final consumption – transport sector – energy use / Gigawatt-hour)
	Supply, transformation and consumption of oil and petroleum products (Gross inland deliveries – calculated / Thousand tonnes)
	Treatment of waste by waste category, hazardousness and waste management operations (Hazardous and non-hazardous – total / Tonne)

Factor	Indicator
	Economic component
Resource and waste management (31,1%)	Management of waste excluding major mineral waste, by waste management operations (Kilograms per capita)
	Management of waste excluding major mineral waste, by waste management operations (Tonne)
	Annual detailed enterprise statistics for Mining and quarrying industry (Production value – million euro)
	Modal split of inland freight transport (Roads/Percentage)
	Municipal waste by waste management operations (Disposal – incineration (D10) and recovery – energy recovery (R1) / Kilograms per capita)
	Supply, transformation and consumption of electricity (Final consumption – other sectors – commercial and public services – energy use / Gigawatt-hour)
	Supply, transformation and consumption of electricity (Final consumption – other sectors – households – energy use / Gigawatt-hour)
	Treatment of waste by waste category, hazardousness and waste management operations (Hazardous and non-hazardous – total / Tonne / Disposal – landfill and other)
Energy and transportation economic activity (14,8%)	Final energy consumption by product (Thousand tonnes of oil equivalent)
	Imports of natural gas by partner country (Million cubic metres)
	Supply, transformation and consumption of electricity (Available for final consumption / Gigawatt-hour)
	Supply, transformation and consumption of gas (Inland consumption – calculated / Terajoule (gross calorific value – GCV)
	Road freight transport by type of goods and type of transport (t, tkm) (Total transported goods / Thousand tonnes)
Other economic factor (5,7%)	Treatment of waste by waste category, hazardousness and waste management operations (Hazardous and non-hazardous – total / Tonne / Disposal – incineration (D10))

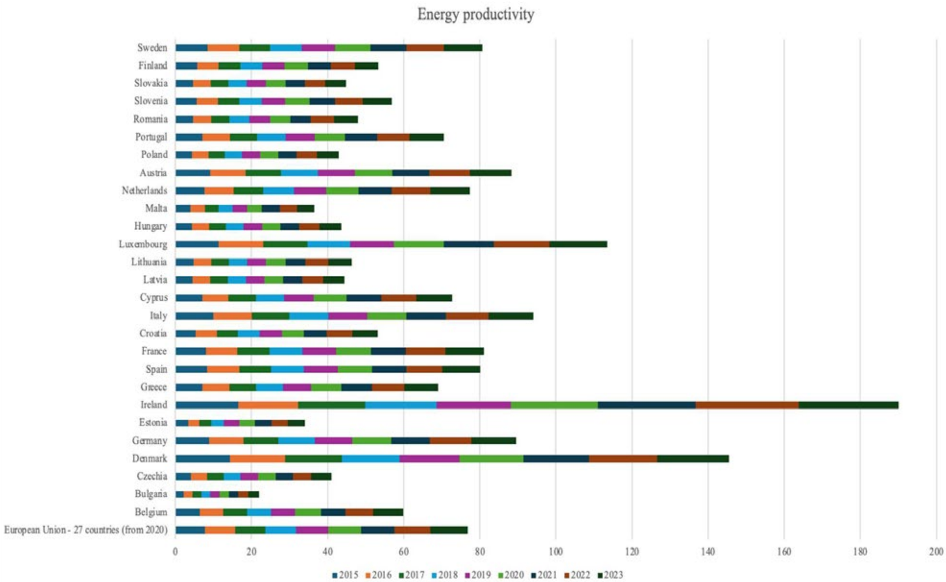
Factor	Indicator
	Environmental component
Greenhouse gas emissions intensity, fertilizer consumption and contributors to climate changes (59,5%)	Nitrogen, kg of nutrient per ha (Gross nutrient balance per hectare UAA)
	Greenhouse gases (CO2, N2O in CO2 equivalent, CH4 in CO2 equivalent, HFC in CO2 equivalent, PFC in CO2 equivalent, SF6 in CO2 equivalent, NF3 in CO2 equivalent), Grams per euro, current prices
	Utilised agricultural area excluding kitchen gardens (Fully converted to organic farming), hectare
	Forest area, % of land area
	Fertilizer consumption, kilograms per hectare of arable land
	Contribution to the international 100bn USD commitment on climate related expending [sdg_13_50], Million euro
	Consumption of Nitrogen, Tonne
	Carbon intensity of GDP, kg CO2e per 2021 PPP $ of GDP
	Total environmental taxes, Percentage of gross domestic product (GDP)
Net greenhouse gas emissions, phosphorus fertilizer consumption and emissions from new cars (17,9%)	Greenhouse gases (CO2, N2O in CO2 equivalent, CH4 in CO2 equivalent, HFC in CO2 equivalent, PFC in CO2 equivalent, SF6 in CO2 equivalent, NF3 in CO2 equivalent), Total (excluding memo items, including international aviation), Index, 1990=100
	Consumption of Phosphorus, Tonne
	Average CO2 emissions per km from new passenger cars, Grams per kilometre
Carbon dioxide emissions by residents (10,3%)	Air emissions (Carbon dioxide) by resident units (production activities and households), Tonne
Other environmental impact (8,6%)	Total nitrogen emissions, tonnes
	Climate related economic losses – values at constant 2022 prices [sdg_13_40], Current prices, million euro

Figure 38. Dynamics of the composite local index of economic factors of impact on GHG emissions in Czechia



Among the indicators included in Economic development and waste management, the leading place is occupied by indicators: Energy productivity (Euro per kilogram of oil equivalent) та Final energy consumption by sector (Thousand tonnes of oil equivalent), GDP and Management of waste. In 2022, the EU's energy productivity was approximately €8.0 per kilogram of oil equivalent. n 2022, Czechia's energy productivity was around €5.5 per kilogram of oil equivalent [47]. Czechia's energy productivity is below the EU average, indicating potential for improvement in energy efficiency and economic output per energy unit, as you can see in the figure.

Figure 39. Energy productivity for EU countries



In 2021, Czechia's FEC reached 25 million tonnes of oil equivalent (Mtoe), an increase of 1 Mtoe compared to 2000. Analyzing the change in energy consumption by individual sectors, it is important to highlight that: industry decreased by 22%; services decreased by 18%; households increased energy consumption by 15%, but energy consumption in transport increased by 64%. [48]. The substantial rise in energy consumption within the transport sector, in particular, suggests a need for targeted energy efficiency measures and the promotion of sustainable transport solutions.

As for the generalized indicators of economic development of the Czech Republic, which also formed the base for the determination of the factor that has the greatest impact on greenhouse gas emissions, the following are in 2023, Czechia's GDP was approximately $330.86 billion USD, accounting for about 0.31% of the global economy [49]. In 2023, the GDP per capita was estimated at $29,000 USD, indicating a relatively high standard of living [50].

Another factor with a high impact on greenhouse gas emissions is Resource and waste management (31,1%). In terms of the waste management indicator, the Czech Republic is showing progressive dynamics, as evidenced by the fact that between 2017 and 2021, the volume of recycled waste in the Czech Republic grew from over 14 million metric tons to more than 17 million metric tons. In 2020, Czechia generated approximately 5.8 million tonnes of municipal waste, equating to 543 kg per capita, slightly above the estimated EU average of 505 kg per capita. In the same year, 47.7% of municipal waste was landfilled, while 12.6% underwent incineration, primarily with energy recovery [11]. The general dynamics of household waste recycling and waste disposal in the EU and Visegrad countries is shown in the figure 40, 41, 42 below.

Figure 40. Municipal waste by waste management operations, Thousand tonnes

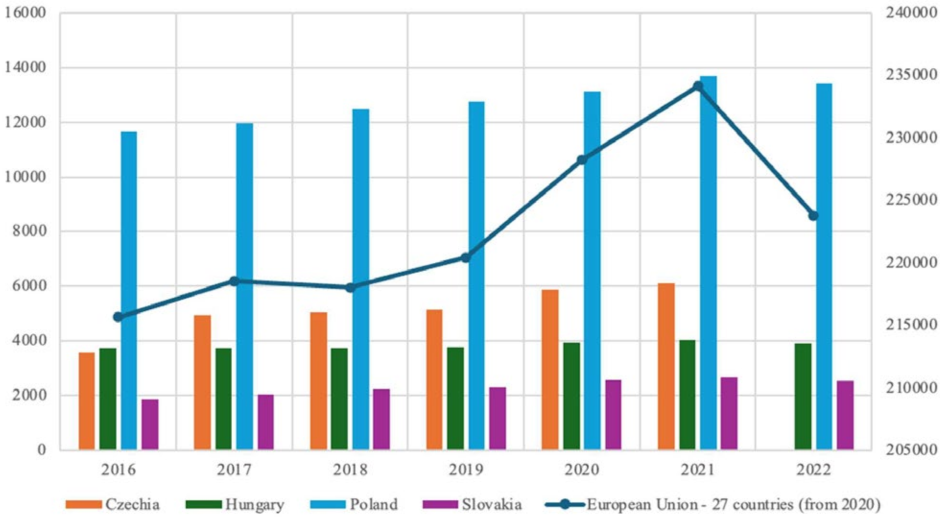


Figure 41. Municipal waste by waste management operations (Disposal – incineration [D10] and recovery – energy recovery [R1]), Thousand tonnes

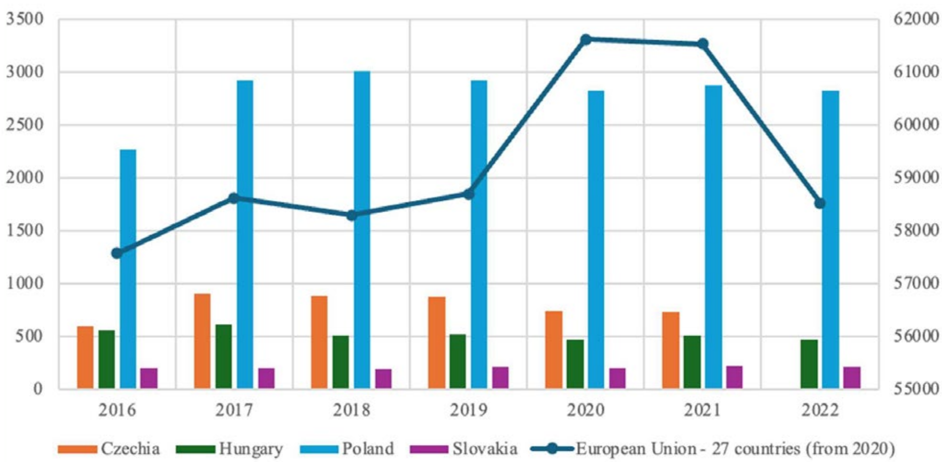
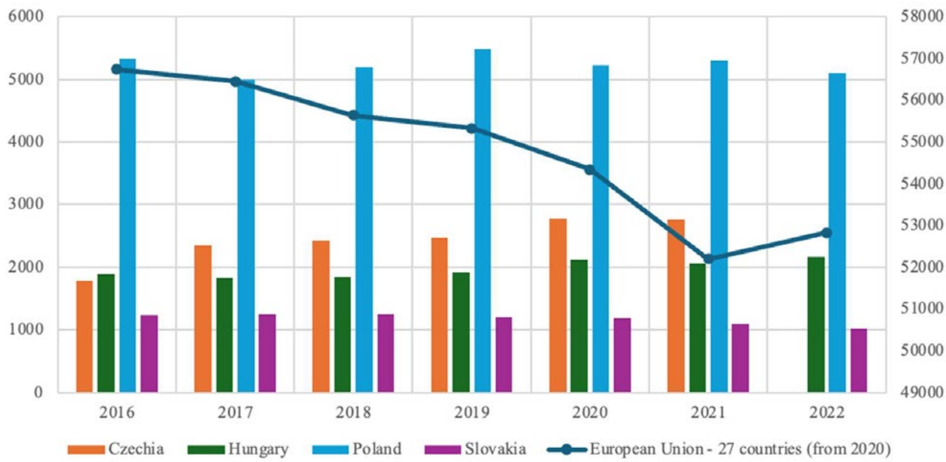


Figure 42. Municipal waste by waste management operations (Disposal – landfill and other), Thousand tonnes

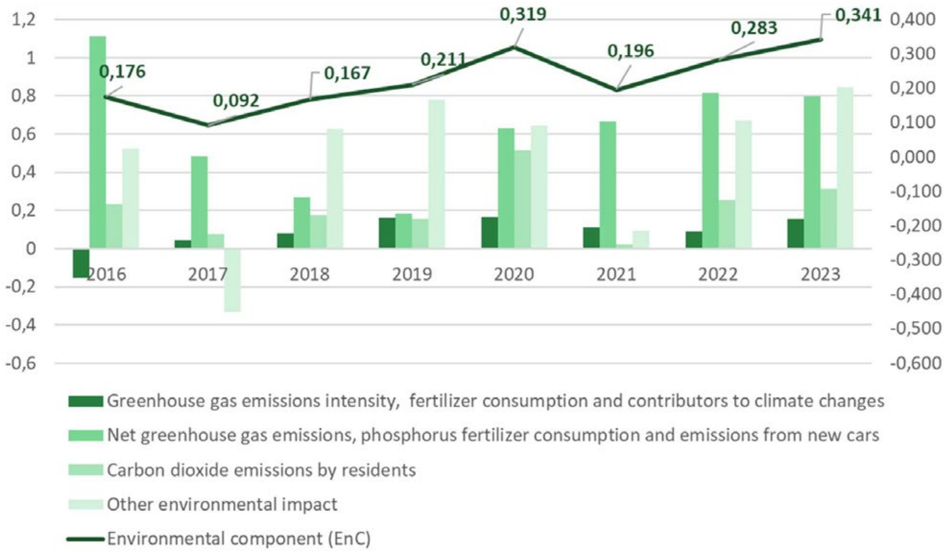


Therefore, given the trend of changes in the economic component, as well as the fact that it is most influenced by the following factors Economic development and waste management (42,9%) and Resource and waste management (31,1%), with a cumulative % of Variance of almost 74% (Figure 34), it is important to note that the country needs to increase the share of renewables in the energy mix by accelerating investments in wind, solar, and biomass energy sources, Promote electric vehicle (EV) adoption, incentives for carbon capture and storage (CCS) technologies in heavy industries and power generation, Encourage sustainable farming practices that reduce methane emissions etc.

As the analysis shows, the Czech Republic is mostly in line with the general trends described above in terms of the indicators of the greatest impact. That is why we will focus on certain indicators and policies that allow us to identify the state of the environment and general steps taken by the Czech Republic to prevent climate change. The Czech Republic has developed and is currently implementing the State Environmental Policy of the Czech Republic 2030 with a 2050 perspective. Its principles are based on both the EU's overall strategic focus on decarbonization and reducing its carbon footprint, and also take into account national specifics [51]. In general, the Czech Republic is showing a trend of stable economic growth, despite the COVID-19 pandemic, when almost all EU countries slowed down their economic development.

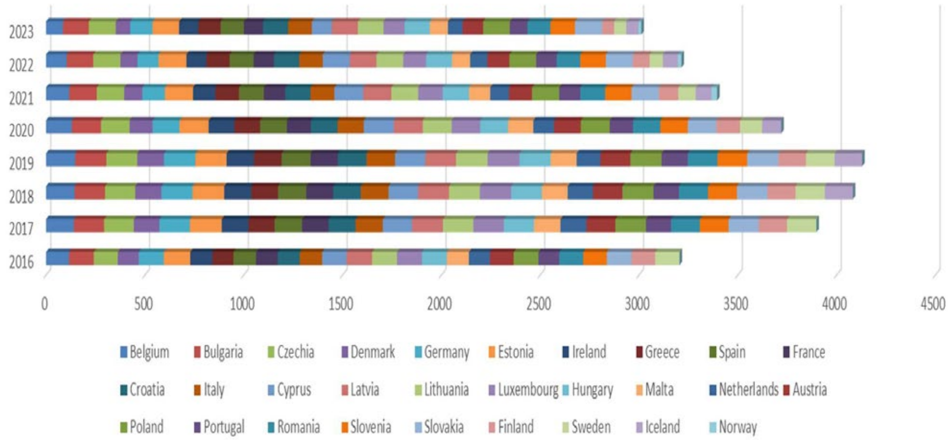
The environmental situation in Europe, which has not spared the Czech Republic, is forcing the government and civil society to respond to climate change more actively than ever. According to [52], the Czech Republic periodically faces droughts, but in the period from 2015 to 2021, the country experienced the most severe drought caused by a lack of precipitation and high temperatures in its recorded history. In addition, high temperatures have reduced the ability of water to dissolve oxygen. The growth of toxic cyanobacteria is accelerating, which, combined with the negative effects of economic activity, leads to pollution of both surface and groundwater. This entails complex economic, social and further environmental consequences.

Figure 43. Dynamics of the composite local index of environmental factors of impact on GHG emissions in Czechia



Of the indicators included in the Net Greenhouse Gas Emissions, Phosphate Fertilizer Consumption and Emissions from New Cars component (17.9%), we would like to highlight the Average CO2 emissions per km from new passenger cars (Grams per kilometer).

Figure 44. Average CO2 emissions per km from new passenger cars, Grams per kilometre [53]



Since 2020, this indicator has begun to decline in the Czech Republic after a significant increase in 2017-2019, while in 2023 the Czech Republic ranked second in terms of Average CO2 emissions per km from new passenger cars (136.3 Grams per kilometer) after Slovakia (137.6 Grams per kilometer). Poland, for example, ranks 3rd in this indicator. Hungary also had a high value of Average CO2 emissions per km from new passenger cars.

At the same time, realizing the complexity of the problem of emissions caused by road transport, as cars and vans produce about 15% of CO2 emissions in the EU, the parliament supported the Commission's proposal for "0" CO2 emissions for these types of transport by 2035. Interim targets were set for 2030: 55% for cars and 50% for vans [54]. Accordingly, all new cars that will be introduced to the EU market starting in 2025 must have CO2 emissions of "0". However, these rules do not apply to existing cars.

Slovakia

Table 7 summarizes the economic and environmental factors that have an impact on reducing greenhouse gas emissions in Slovakia. Based on the analysis of the composite index of economic components, the following conclusions were made: 1) Economic, energy and environmental development (57.6%) have a significant impact on greenhouse gas emissions (Figure 45). 2) Energy resources consumption (17.4%) also has a significant impact on the growth of greenhouse gas emissions.

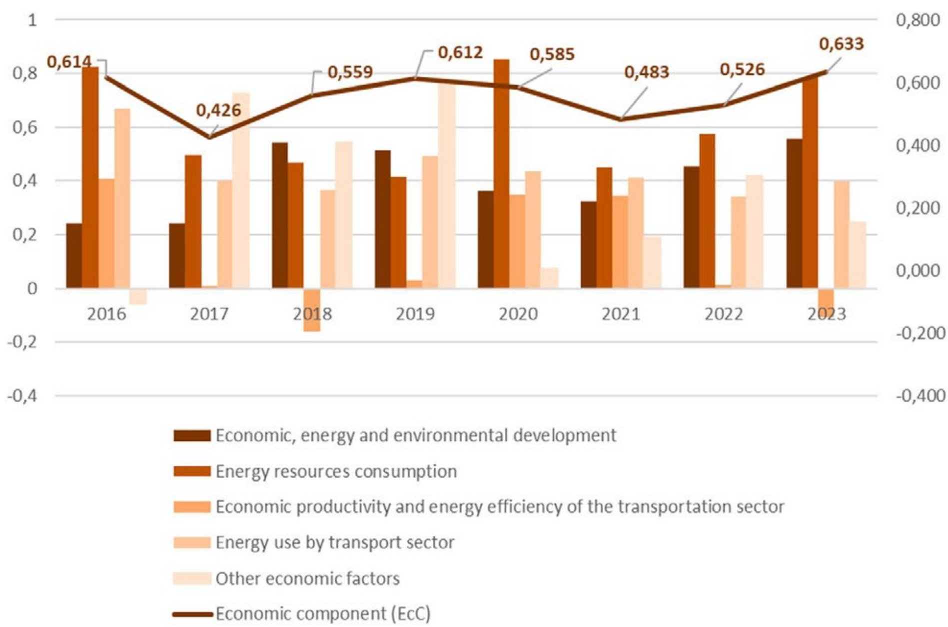
Table 7. Identification of local component factors (Slovakia)

Factor	Indicator
	Economic component
Economic, energy and environmental development (57,6%)	Energy productivity (Euro per kilogram of oil equivalent)
	GDP and main components (output, expenditure and income) (Current prices, million euro)
	GDP and main components (output, expenditure and income) (Chain linked volumes (2010), million euro)
	Management of waste excluding major mineral waste, by waste management operations (Kilograms per capita)
	Management of waste excluding major mineral waste, by waste management operations (Tonne)
	Annual detailed enterprise statistics for Mining and quarrying industry (Production value – million euro)
	Modal split of inland freight transport (Roads/Percentage)
	Municipal waste by waste management operations (Waste generated / Kilograms per capita)
	Municipal waste by waste management operations (Waste generated / Kilograms per capita)
	Municipal waste by waste management operations (Thousand tonnes / Kilograms per capita)
	Municipal waste by waste management operations (Disposal – landfill and other (D1-D7, D12) / Kilograms per capita)
	Supply, transformation and consumption of electricity (Final consumption – industry sector – energy use / Gigawatt-hour)
	Supply, transformation and consumption of electricity (Final consumption – other sectors – households – energy use / Gigawatt-hour)
	Treatment of waste by waste category, hazardousness and waste management operations (Hazardous and non-hazardous – total / Tonne)
	Treatment of waste by waste category, hazardousness and waste management operations (Hazardous and non-hazardous – total / Tonne / Disposal – landfill and other)
	Treatment of waste by waste category, hazardousness and waste management operations (Hazardous and non-hazardous – total / Tonne / Disposal – incineration (D10))

Factor	Indicator
	Economic component
Energy resources consumption (17,4%)	Final energy consumption by product (Thousand tonnes of oil equivalent)
	Final energy consumption by sector (Thousand tonnes of oil equivalent)
	Supply, transformation and consumption of electricity (Available for final consumption / Gigawatt-hour)
	Supply, transformation and consumption of electricity (Final consumption – other sectors – commercial and public services – energy use / Gigawatt-hour)
	Supply, transformation and consumption of gas (Inland consumption – calculated / Terajoule (gross calorific value – GCV)
	Supply, transformation and consumption of oil and petroleum products (Gross inland deliveries – calculated / Thousand tonnes)
Economic productivity and energy efficiency of the transportation sector (8,9%)	Real GDP per capita (Chain linked volumes (2010), euro per capita)
	Supply, transformation and consumption of electricity (Final consumption – transport sector – energy use / Gigawatt-hour)
Energy use by transport sector (7,5%)	Supply, transformation and consumption of electricity (Final consumption – transport sector – energy use / Gigawatt-hour)
Other economic factors (4,4%)	Imports of natural gas by partner country (Million cubic metres)
	Municipal waste by waste management operations (Disposal – incineration (D10) and recovery – energy recovery (R1) / Kilograms per capita)
	Environmental component
Intensity of greenhouse gas emissions and organic farming (44,9%)	Total nitrogen emissions, tonnes
	Greenhouse gases (CO2, N2O in CO2 equivalent, CH4 in CO2 equivalent, HFC in CO2 equivalent, PFC in CO2 equivalent, SF6 in CO2 equivalent, NF3 in CO2 equivalent), Total (excluding memo items, including international aviation), Index, 1990=100
	Greenhouse gases (CO2, N2O in CO2 equivalent, CH4 in CO2 equivalent, HFC in CO2 equivalent, PFC in CO2 equivalent, SF6 in CO2 equivalent, NF3 in CO2 equivalent), Grams per euro, current prices
	Utilised agricultural area excluding kitchen gardens (Fully converted to organic farming), hectare
	Carbon intensity of GDP, kg CO2e per 2021 PPP $ of GDP

Factor	Indicator
	Environmental component
Nitrogen consumption, forestation and emissions from new cars (21,4%)	Nitrogen, kg of nutrient per ha (Gross nutrient balance per hectare UAA)
	Forest area, % of land area
	Average CO2 emissions per km from new passenger cars, Grams per kilometre
Mineral fertilizer consumption and environmental taxes (19,0%)	Fertilizer consumption, kilograms per hectare of arable land
	Consumption of Phosphorus, Tonne
	Consumption of Nitrogen, Tonne
	Total environmental taxes, Percentage of gross domestic product (GDP)
Other environmental impact (7,4%)	Contribution to the international 100bn USD commitment on climate related expending [sdg_13_50], Million euro
	Air emissions (Carbon dioxide) by resident units (production activities and households), Tonne
	Climate related economic losses – values at constant 2022 prices [sdg_13_40], Current prices, million euro

Figure 45. Dynamics of the composite local index of economic factors of impact on GHG emissions in Slovakia



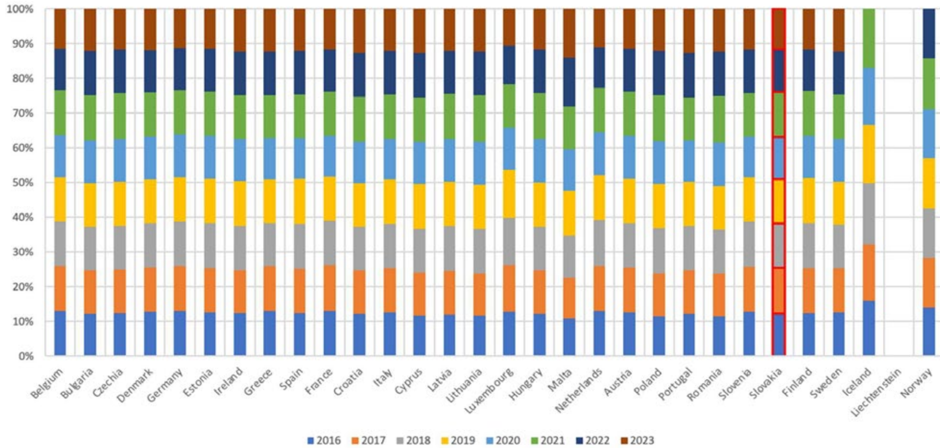
Among the indicators included in Economic, energy and environmental development, as in almost all Visegrad countries except Poland, the leading place is occupied by Energy productivity (Euro per kilogram of oil equivalent), GDP and Waste management (especially Municipal waste). Between 2000 and 2018, Slovakia's energy productivity increased by a factor of 2.083, indicating significant improvements in energy efficiency. This growth rate surpasses the EU average increase of 1.345 during the same period [55]. In 2021, Slovakia's energy productivity was reported at €6.13 per kgoe, placing it among the mid-range performers within the EU.

As for the overall indicators of economic development in Slovakia, which also formed the basis for the determination of the factor that has the greatest impact on greenhouse gas emissions, Slovakia's GDP in 2022 was approximately $115.47 billion USD. GDP per capita in 2022 was $18,733 USD, reflecting an increase from the previous year. [56]. In 2023, Slovakia's Gross Domestic Product (GDP) was approximately $132.79 billion USD, representing about 0.13% of the global economy [57]. In general, sustainable GDP growth may indicate an increase in the standard of living and quality of life in the country and the possibility of further focusing on decarbonization policies and the introduction of energy and resource-saving technologies.

In 2022, Slovakia generated approximately 2.6 million tonnes of municipal waste, equating to 478 kilograms per capita. Despite efforts to reduce landfilling, it remains a significant method of waste disposal in Slovakia. Slovakia has been striving to improve its recycling rates, with ongoing initiatives aimed at enhancing waste separation and recycling infrastructure. However, specific data for 2022 is not readily available [58].

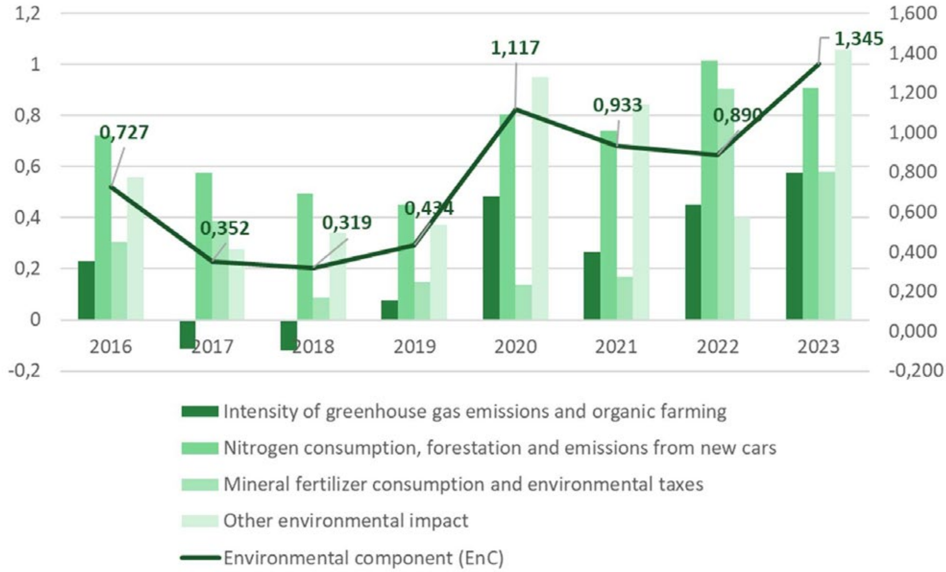
Another factor with a high impact on greenhouse gas emissions is Energy resources consumption (17.4%). With regard to this factor, the main indicator of which is Final energy consumption, between 2021 and 2022, Slovakia experienced a decrease in total final energy consumption, notably within the industrial and residential sectors. The industrial sector consumed about 36.8 TWh, accounting for 32% of the total final energy consumption, with a 6.34% decrease from the previous year. The transport sector used approximately 30.9 TWh, representing 27% of the total, and experienced a 1.55% increase compared to the previous year [59]. The overall dynamics of the EU and Visegrad countries in terms of Final energy consumption by sector is shown below Figure 43.

Figure 46. Final energy consumption by sectors, Thousand tonnes of oil equivalent



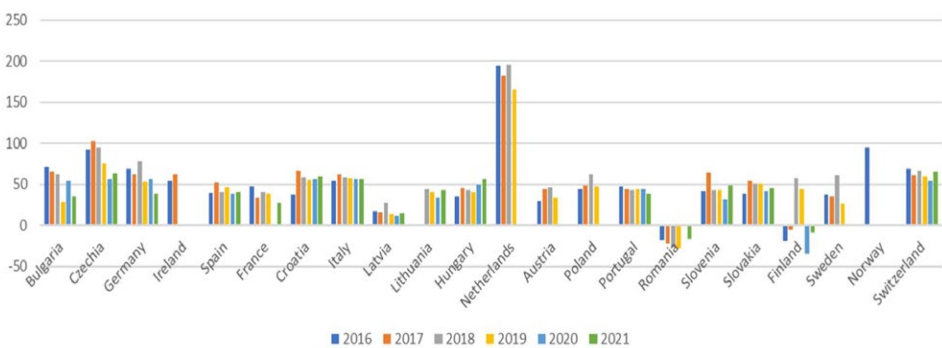
For Slovakia, the most important environmental factor was total nitrogen emissions, Greenhouse gases (CO2, N2O in CO2 equivalent, CH4 in CO2 equivalent, HFC in CO2 equivalent, PFC in CO2 equivalent, SF6 in CO2 equivalent, NF3 in CO2 equivalent), Greenhouse gases (CO2, N2O in CO2 equivalent, CH4 in CO2 equivalent, HFC in CO2 equivalent, PFC in CO2 equivalent, SF6 in CO2 equivalent, NF3 in CO2 equivalent, Grams per euro, current prices), Utilised agricultural area excluding kitchen gardens (Fully converted to organic farming) та Carbon intensity of GDP. The second most important factor was the following Nitrogen in kg of nutrient per ha, Forest area in % of land area and Average CO2 emissions per km from new passenger cars. And as shown above, for example, by the indicator Average CO2 emissions per km from new passenger cars this country was ranked 1st in 2023.

Figure 47. Dynamics of the composite local index of environmental factors of impact on GHG emissions in Slovakia



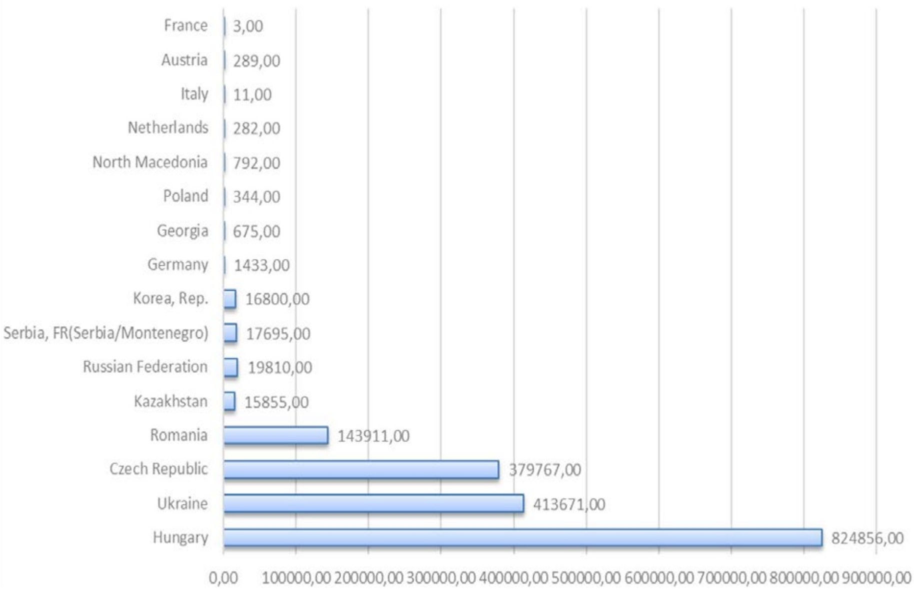
If we analyze the indicator Nitrogen in kg of nutrient per ha, we can see that in Slovakia this indicator is gradually increasing, but is at the average level for European countries.

Figure 48. Nitrogen, kg of nutrient per ha (Gross nutrient balance per hectare UAA), 2016-2021 [60]



At the same time, Nitrogen is the dominant fertilizer in the structure of inorganic fertilizers. This trend was also characteristic of previous time periods. The country is an exporter of mineral or chemical fertilizers with nitrogen. In 2021, according to WITS data, it sold 1836190 kg of Mineral or chemical fertilizers with nitrogen in the world [61]. The main countries to which supplies were made are shown in the figure below.

Figure 49. Slovak Republic Mineral or chemical fertilizers with nitrogen, exports by country in 2021 [61]



In general, the Slovak Republic has developed and implemented the "Strategy of the environmental policy of the Slovak Republic until 2030" to minimize greenhouse gas emissions and their negative impact on the environment and human life [62]. According to it, the country is developing a roadmap for solving the problems of more environmentally friendly and sustainable agriculture, waste management, conservation and restoration of flora and fauna, expansion of green spaces, etc. At the same time, it is planned to further improve the environmental taxation system and to continue using the EU ETS as a key pillar for cost-effective reduction of greenhouse gas emissions in industry, energy and air transport, along with other instruments and mechanisms. Currently, the ETS covers about 50% of total annual greenhouse gas emissions [62].

Integral assessment of greenhouse-forming factors

A comprehensive assessment of the joint impact of the behavior of all local indexes on greenhouse gas emissions is proposed to conduct on the basis of the suggested methodology for calculating the integral index of greenhouse-forming factors. Calculating an integral index is necessary because of the need to combine three local indexes that have different quantitative data, different dynamics of their changes in a particular time period of assessment, and different weights of influence on total greenhouse gas emissions.

The integral index of greenhouse-forming factors was calculated as a geometric average weighted value according to formula 1.

$$II = \sqrt[\sum_{i=1}^{3} \alpha_i]{EcC^{\alpha_1} \cdot EnC^{\alpha_2} \cdot SC^{\alpha_3}}, \quad (1)$$

where *II* – Integral Index, *EcC* – Economic Component, *EnC* – Environmental Component, *SC* – Social Component, α_i – weighting factors.

Weighting factors were calculated based on the Coefficient of variation of the component. The practical significance of the proposed methodology lies in its ability to identify the direction of the combined behavior of all local influencing factors on greenhouse gas volumes (Ukraine – Figure 47, Poland – Figure 48, Hungary – Figure 49, Czechia – Figure 50, Slovakia – Figure 51).

Figure 50. Dynamics of the integral index and local components of greenhouse-forming factors (integral index on the auxiliary scale), Ukraine

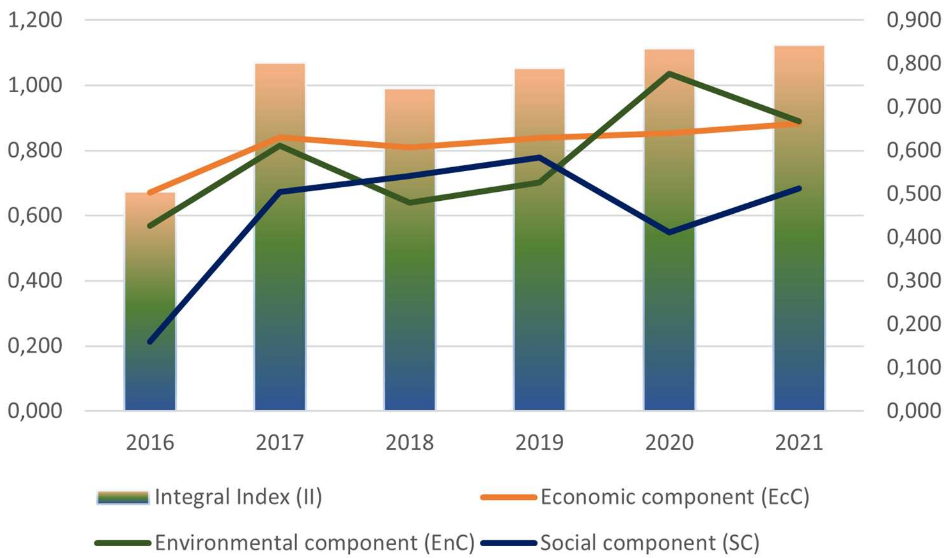


Figure 51. Dynamics of the integral index and local components of greenhouse-forming factors (integral index on the auxiliary scale), Polska

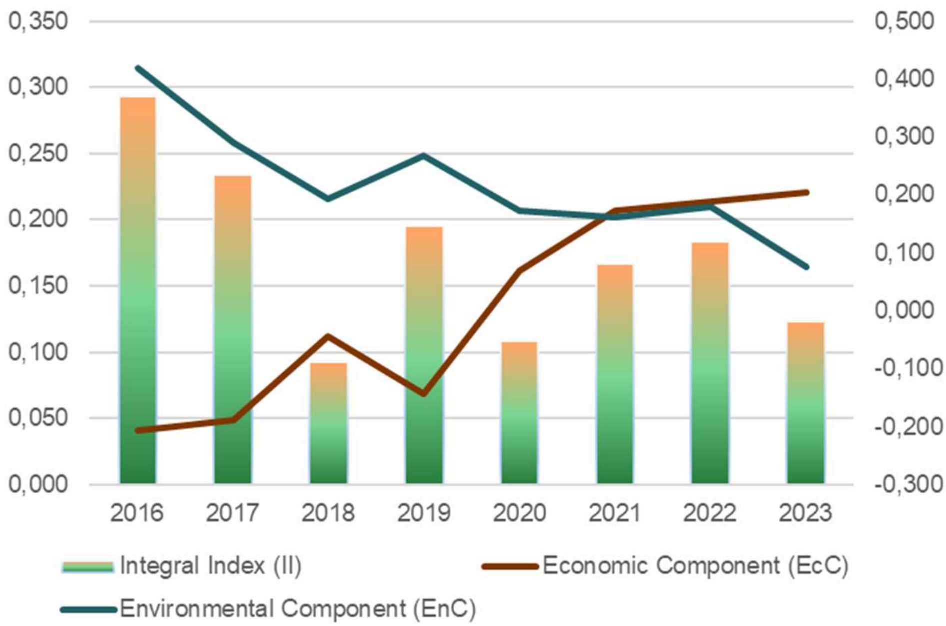


Figure 52. Dynamics of the integral index and local components of greenhouse-forming factors (integral index on the auxiliary scale), Hungary

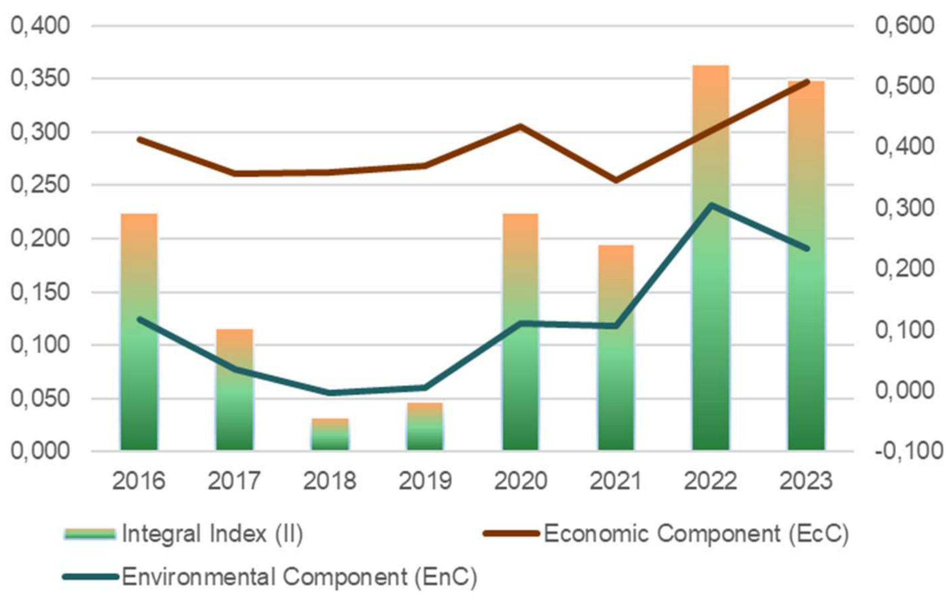


Figure 53. Dynamics of the integral index and local components of greenhouse-forming factors (integral index on the auxiliary scale), Czechia

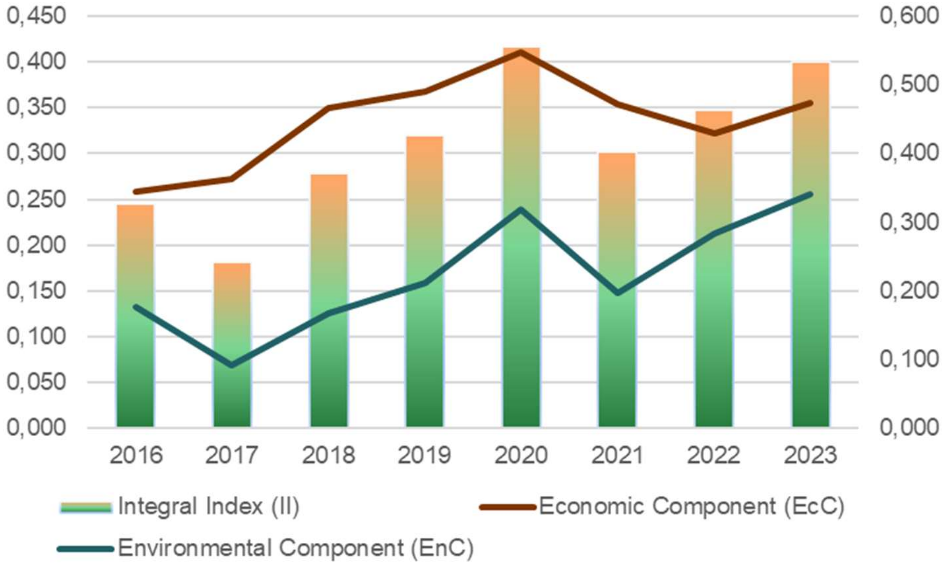
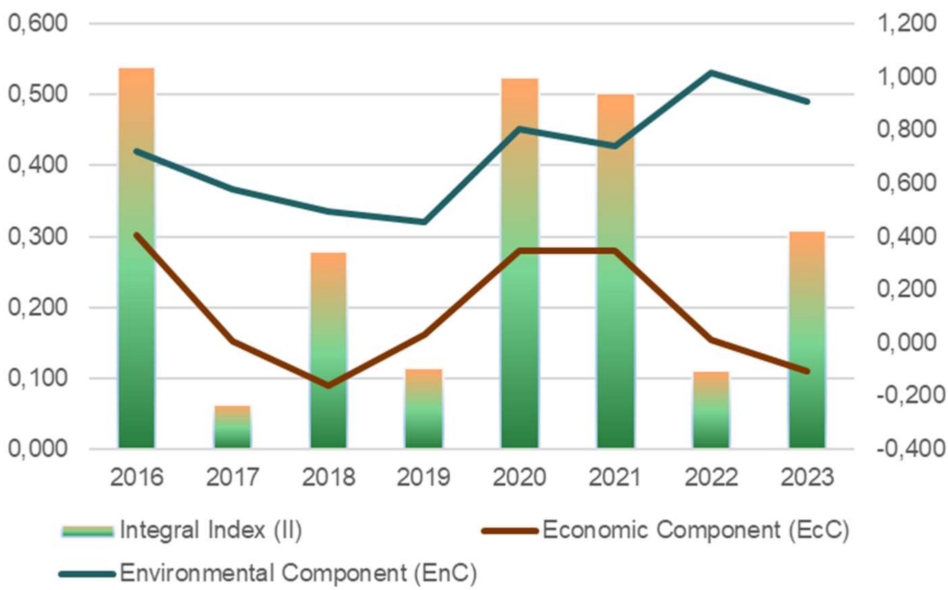


Figure 54. Dynamics of the integral index and local components of greenhouse-forming factors (integral index on the auxiliary scale), Slovakia



The calculation of the integral index for assessing greenhouse-forming factors shows an increase in the negative factor impact on greenhouse gas emissions in Ukraine in 2016-2021, in the Visegrad countries in 2016-2023. This conclusion indicates the need to intensify decisions directed at decarbonizing the economic activities of business entities and households.

The correlation analysis of local components and the integral index allowed us to identify a complex of factors that have the greatest impact on the dynamics the integral index of greenhouse-forming factors (Table 8).

Table 8. Correlation analysis of the influence the local components on the integral index

Local components	The correlation coefficient of local components with the integral index				
	Ukraine	Polska	Hungary	Czechia	Slovakia
Economic component (EcC)	0,995	0,688	0,779	0,803	0,980
Environmental component (EnC)	0,762	0,846	0,971	0,970	0,212
Social component (SC)	0,833	–	–	–	–

According to the correlation analysis, the dynamics of the integral index demonstrates a close statistical connection with the combination of indicators of economic, social and environmental components for Ukraine, of economic and environmental components for Visegrad countries.

Moreover, the greatest influence on the formation of the trend of the integral behavior of the greenhouse-forming factors index (except in Slovakia) is exerted by economic factors, which demonstrate the greatest variability in a certain time period.

Therefore, in order to achieve the goals of sustainable development, Ukraine's efforts should be focused on decarbonization in the energy, metallurgy, and transportation sectors. Unfortunately, the Paris Agreement did not drive significant changes to reduce greenhouse gas emissions.

Ways to Reduce Ghgs in the Context of Implementing a Global Decarbonization Policy

The steady increase in air temperature and the set of negative manifestations of global warming prompted the adoption of the “Paris Agreement” in 2015. The Paris Climate Agreement is an international agreement within the United Nations (UN) Framework Convention on Climate Change framework to regulate measures to reduce carbon dioxide emissions from 2020. Unlike the Kyoto Protocol, the Paris Agreement provides that all states, regardless of their level of economic development, undertake obligations to reduce harmful emissions into the atmosphere.

However, it has not become a driver of large-scale global changes to reduce greenhouse gas emissions. Because of this, in 2019, the European Union (EU) approved a new large-scale European Green Deal program to transform the economy by 2050. It provides for a complete abandonment of the use of fossil fuels and the displacement of industries that create harmful emissions from the economy. Subsequently, the EU expanded its initiative to include 127 countries and launched the Climate Neutrality program. On July 14, 2021, the European Commission (EC) developed a package of proposals called Fit for 55, which aims to combat climate change and make Europe the world’s first climate-neutral continent by reducing carbon dioxide emissions in the EU by at least 55% compared to 1990 and reaching net zero by 2050.

In July 2021, the Government of Ukraine approved Ukraine’s Updated Nationally Determined Contribution (NDC2) to the Paris Agreement. The document sets a goal of reducing greenhouse gas emissions by 35% compared to 1990 by 2030.

The analysis of the possibilities for implementing the declared goals is determined by the structure of greenhouse gas emission sources and a set of measures to change it. In each country of the world, the structure of CO_2 emissions is determined by the structure of its economy, however, on a global scale, the main pollutants are the energy and metallurgy sectors. Thus, in Ukraine in 2020, 43% of the total CO_2 emissions are associated with electricity, gas, steam, and conditioned air supply, and 34% – the processing industry (metallurgy).

So, according to the structure of greenhouse gas emission sources, the largest producer in the world and Ukraine is energy, especially in the field of fossil fuel extraction and the sources of electricity generation that burn fossil fuels and wood. Thus, in Ukraine in the pre-war period, 36% of electricity was generated at thermal power plants and heat power plants (Table 9).

Table 9. Electricity supply in Ukraine for 2017-2020 [63]

Types of Generating Enterprises	Electricity supply, million kWh			
	2017	2018	2019	2020
Total	144883	148324	141213	137197
including				
thermal power plants	41113	43773	40910	36300
combined heat and power plants	10595	10922	10738	12837
nuclear power plants	80295	79383	77948	71249
hydropower plants[1]	10370	11826	7712	7415
other power plants	2510	2420	3906	9396
of which				
wind power plants	1602	1182	1760	3271
solar power plants	758	1103	1883	5684

Accordingly, minor changes in the implementation of decarbonization measures should begin with a change in the structure of types of electricity generation. Taking into account the structure of electricity production in Ukraine, reducing the share of thermal generation is a reliably determined direction for reducing CO_2 emissions and other harmful gases into the atmosphere.

"Emissions of thermal power plants for the production of 1 MWh (on brown coal) are 0.898 t of carbon dioxide (excluding other harmful emissions into the atmosphere and greenhouse gases). That is, if we assume that the thermal power plant produces 753.5 MWh per year, then carbon dioxide emissions into the atmosphere will be 676.643 t. Over 25 years – 16,916.075 t» [64]. Taking into account the total volume of electricity generated at thermal power plants and CHPs, Ukraine's potential is 49,137 million kWh *0.898 t/1000= 44 million t CO_2.

In the world, the implementation of long-term intentions to reduce greenhouse gas emissions occurs through collective agreement and/or unilateral actions within the framework of program measures of a country or group of countries. But today the world is faced with the undesirable possibility of influencing changes in the structure of greenhouse gas generation sources and through forced external influences in the form of war, natural disasters, etc. Thus, during the targeted aggressive destruction of Ukraine's energy infrastructure by Russia, 42 power units or 9 GW of TPP and HPP generation were lost (as of June 2024). Old thermal power plants operated on fossil coal and gas with 24-25% efficiency.

Unfortunately, the hostilities caused significant damage to solar electricity generation, which has gained considerable development since 2011. In 2019, Ukraine entered the TOP 10 countries in the world in terms of the pace of development of green energy, and in 2020 – in the TOP 5 European countries in terms of solar energy development. During the hostilities, Ukraine lost about 40% of solar generation since industrial solar power plants are concentrated in the southern and southeastern regions, which suffer the most from enemy shelling.

In addition to the industrial production of solar generation, its generation by private households is actively developing in Ukraine, which is aimed at meeting their own needs and selling surplus generation to the country's energy system.

Despite all the problems that Ukraine has faced, the country is faced with a choice of a way to restore the economy's energy supply based on compliance with its climate commitments and the implementation of a global energy transition policy.

The experience of European countries is an example of the successful use of green energy to transition to a state of climate neutrality. Regarding the possibilities of its implementation in Ukraine, it is worth taking into account three fundamental factors: a significant territory, the geographical features of the area, the needs of the economy, and the population.

The lack of sufficient solar intensity in the autumn-winter-spring period reduces the efficiency of solar generation, and the insufficient volume of nuclear and hydroelectric generation requires the need for partial restoration of generation based on the use of modern gas-piston power plants with an efficiency of 45% and closed-type gas turbines – 60%. Gas consumption in such TPPs is 2.5 times less than gas consumption in old units, and therefore, CO2 emissions will decrease by approximately 2.5 times compared to their emissions in the pre-war period.

Regarding the reduction of coal use as a source of influence on global climate change, in 2023, Ukraine confirmed its intention to close all state-owned coal-fired power plants by 2035. When burning 1 ton of coal, 0.102 t of CO2 is released. 1 m^3 of natural gas (methane), when burned, produces about 2 kg of carbon dioxide [64].

The transition to the generation of energy products from alternative energy sources allows you to influence the reduction of greenhouse gas emissions, but it cannot be considered the only source of meeting the economy's needs for electricity and gas.

Metallurgy is one of the industries with significant CO2 emissions. According to the World Steel Association, in 2022, 1.91 tons of CO2 were emitted per ton of raw steel. The steel industry is responsible for 7 to 9% of global CO2 emissions [65].

In Ukraine, CO2 emissions from industrial activities in 2021 amounted to 38% of the total emissions in the country. Until 2016, Ukraine was among the ten largest producers of metallurgical products, however, since 2018, there has been a significant decrease in steel smelting volumes due to a decrease in domestic demand for metallurgical products. In the global context, the largest metallurgical producer is China.

On average, about 2 billion tons of steel are produced worldwide. Part of Ukraine's share in the global steel production volume was 1.2%. The excess of steel production volumes over its domestic demand led to the need to export more than 80% of the smelted steel, which provided about 3.3% of world exports in the pre-war period [66].

Carbon emissions in the steel industry depend on the steelmaking process. The processes are based on the use of blast furnace (BF-BOF), scrap-based electric arc furnace (EAF), and direct reduced iron (DRI) steelmaking based on EAF, which produce different amounts of CO2 emissions.

Table 10. CO_2 emissions from crude steel production in the world [65]

Production method	Share in world production, %	CO_2 emissions, t/t
Steel production based on blast furnace oxygen	71,1	2,33
Direct reduced iron (DRI) steel production based on EAF	28,6	1,37
Steel production based on scrap in electric arc furnace (EAF)		0,68

In outdated traditional (blast) steelmaking plants, CO_2 is the result of burning coke and coal. In the production of open-hearth steel, the number of harmful substances emitted into the atmosphere is 40% higher, and greenhouse gases are twice as much compared to electric steelmaking and converter steelmaking methods. When using direct reduction reactors, the energy resource of the technological process is natural gas. To reduce CO2 emissions when using gas, modern technologies use green hydrogen and electrification at each stage of the entire production flow. DRI-EAF technology, when steel is produced in electric furnaces from direct reduction iron products, which is obtained using hydrogen, reduces carbon dioxide emissions by up to 90%. In this case, hydrogen should be generated by electrolysis using water and electricity from renewable sources. In the case of an increase in demand for electricity produced at thermal power plants, there may be an increase in CO_2 emissions in the power industry while reducing their emissions in metallurgy. The economy will redistribute CO_2 emission sources [67].

The world leader in the deployment of environmentally friendly hydrogen solutions for the green steel value chain, as well as the hydrogen value chain, is Hygenco Green Energies Private Limited.

Hydrogen is considered an alternative energy source for large industrial enterprises and urban areas due to its ability to accumulate and store energy for a long time. In addition, hydrogen is considered an alternative to coal and gas for electricity generation at CHP and TPP. Thanks to the use of hydrogen, it is possible to reduce the need for fossil fuels and, on this basis, reduce CO_2 emissions from fuel combustion at power plants.

In addition, hydrogen is used as an auxiliary fuel for power plants during peak load periods.

India is a country that is testing the possibilities of using hydrogen in metallurgical production. Jindal Stainless, in collaboration with Hygenco Green Energies Private Limited, has created an automated steel production based on the supply of green hydrogen using special solar energy and a storage tank. As a result, the reduction in CO_2 emissions will amount to approximately 54,000 tons of CO2 emissions over 20 years [68].

In Europe, hopes for the introduction of carbon-free production in steel production are associated with the implementation in 2025 by the Swedish startup company H2 Green Steel of environmentally friendly steel production by replacing coal with green hydrogen, which runs on electricity without the use of fossil fuels. Decarbonization of steel production provides "clean" metals for automotive, mechanical engineering, construction, household appliance production, etc.

The integrated process will reduce energy consumption by 70 percent and replace natural gas, which is usually used in the traditional process.

Summarizing the above, it should be noted that the world is moving towards the search for technological solutions aimed at reducing greenhouse gas emissions. However, such a path requires time and capital investments and can affect the reduction of CO_2 concentration in the long term and only if the scale of its use is gradually expanded. After all, the lack of geographical boundaries for the localization of greenhouse gases and collective coherence in the implementation of the intentions of decarbonization of production can level the impact of point changes on global processes. When declaring a reduction in emissions in a separate company, the existing dynamics of emission reduction in a separate country and the global impact on the change in the trend of increasing air temperature will not be observed. This fact is confirmed by the increasing air temperature trends in all countries of the world.

Today, various instruments have been developed around the world aimed at stimulating the decarbonization of production. The most common of them are:

- market instruments, which are based on the CO_2 emissions trading system;
- tax instruments in the form of environmental taxes, CO_2 emissions taxes, taxes on imports of goods with a carbon footprint;
- regulation and subsidies as environmental standards, subsidies for technological changes;
- financial instruments – creation of modernization funds, innovation funds, restrictions on lending to traditional industries with significant CO_2 emissions.

In addition to technological solutions, a way to influence greenhouse gas emissions is emission limits (quotas) and emissions trading. The European Emissions Trading System (EU ETS) is based on the European Union Emissions Trading Directive 2003/87/EC and has been operating on the "cap-and-trade" principle since 2005.

The EU ETS includes more than 11,000 installations, which generate more than half of European CO_2 emissions. The EU ETS covers four sectors: energy (thermal power plants with a capacity of more than 20 MW, oil refineries, and coke ovens); production and processing of ferrous metals; extractive industry (including cement, brick, glass, and ceramics); pulp and paper industry [69]. According to the "cap and trade" model, all enterprises covered by the scheme are given a total number of allowances that they must trade with each other to determine the value of their carbon emissions. This means that carbon emitters must then make a choice between buying enough allowances to cover the carbon emissions produced by their activities or reducing their carbon emissions if they cannot afford to not get enough allowances. They buy carbon emission permits. One permit means that the holder can emit 1 tonne of CO_2 [70].

Revenues generated from the sale of CO_2 emission permits under the EU ETS provide Member States with revenue that can be used for projects to reduce carbon emissions and introduce renewable energy sources [69]. Companies not included in the EU ETS pay a carbon tax.

Environmental taxes are a tool for influencing the reduction of greenhouse gas emissions. The CO_2 tax is established by countries in order to create economic incentives to reduce carbon emissions, to create sources of investment in the development of decarbonization processes, in particular, in the direction of transition to the introduction of alternative energy sources, and to compensate for part of the cost of green energy.

The main goal of introducing a CO_2 tax is to encourage the abandonment of the use of fossil fuels and the transition to renewable energy sources. This tax increases the prices of gasoline, diesel fuel, fuel oil, and natural gas due to the CO_2 content.

In Ukraine, the CO_2 tax was introduced in 2011 and is part of the environmental tax.

For a long time, the tax rate was very low at €0.013 per ton of CO_2 emissions, which did not stimulate entrepreneurs to introduce energy-efficient measures and switch to renewable energy sources. Since January 1, 2019, the tax rate has increased 24 times to €0.32 per ton of CO_2 emissions. Today, the tax rate has increased to €0.68/t (as of January 2025) for enterprises emitting more than 500 tons of carbon per year. However, all funds were directed to the general fund of the state budget without targeted use.

Since 2024, the State Fund for Decarbonization and Energy Efficient Transformation has been established in Ukraine, the task of which is to form a source of reforming the structure of industries that use fossil fuels. The main direction of the fund's activity is financing projects related to the implementation of decarbonization projects and increasing the efficiency of energy production.

Regarding the CO_2 emission tax, it is worth noting that today in European countries, different rates are applied (Figure 1), and various instruments of support for tax subjects are used: from reducing income tax rates (Sweden, Finland), reducing the rate of social contributions (Denmark, Great Britain), providing free quotas for export-oriented enterprises (EU).

A study of the relationship between CO_2 emission tax rates and trends in such emissions allowed us to conclude that greenhouse gas emissions have significantly decreased in countries with high tax rates.

In Ukraine, in 2020, 29% of greenhouse gas emissions were taxed, in 2022 – 71%, which is dictated by the deployment of hostilities in the area where environmental taxpayers are located.

A comparative analysis of CO_2 tax rates in Ukraine and Europe casts doubt on the broad possibilities of generating the necessary amounts of CO_2 tax funds in the Decarbonization Fund.

The unequivocal conclusion is that in the conditions of the need to join the European decarbonization policy, Ukraine will face the need to increase the CO_2 tax rate. To do this, a methodological basis must be formed for forming a tax base based on an assessment of the amount of CO_2 emissions and a tariff per unit of emissions.

The need for tax reform in the approach to CO_2 emissions is also due to the expansion of decarbonization measures not only for the EU ecosystem but also for the indirect impact on the decarbonization process of its trading partners. Since 2026, the EU has been implementing a mechanism for regulating carbon emissions at the border with the European Union, the Carbon Border Adjustment Mechanism (CBAM). The basis of such a mechanism is a tax on imports of goods with a carbon footprint. The objects of taxation are electricity, iron, steel, aluminum, cement, and fertilizers.

The need to implement such a CBAM mechanism is due both to the intentions to solve global problems of humanity by influencing the economic interests of the participants in their formation and to the intentions to prevent the relocation of European production to countries with low rates of environmental taxes or the cost of purchasing emission quotas. The reasons for such processes are the increase in environmental tax rates for fossil fuel extraction enterprises in the EU and the intention to reduce the number of free quotas for producers of products produced using fossil fuels.

The lack of reform of industries that emit CO_2, in the context of the introduction of the border carbon adjustment mechanism, will lead to the loss of European markets due to the increase in the price of goods, the filling of European decarbonization funds, and the reduction of the utilization of metallurgical capacities in Ukraine and non-EU countries.

Regarding the participation of the banking system in shaping trends in carbon-free production, the EU has developed a package of regulatory documents on sustainable financing of the economy (Regulation (EU) 2020/852, Commission Recommendation (EU) 2023/1425, Sustainable Europe Investment Plan. European Green Deal Investment Plan, 2020, Sustainable finance package [73]. Indeed, in the current global focus on activating zero-emissions policies, the risk of non-repayment of loans by a borrower who emits greenhouse gases is increasing for banks. It becomes logical that the fact that under conditions of increased control over greenhouse gas emissions, products of enterprises produced using fossil fuels will not be in demand on the markets.

Conclusions

This study underscores the complexity and multifaceted nature of greenhouse gas (GHG) emissions, emphasizing the interconnected influence of economic, environmental, and social factors on their formation and dynamics. The integral methodology developed and applied within the research provides a robust framework for evaluating these influences, particularly within the context of Ukraine and the Visegrad countries. Economic activities, especially in energy, metallurgy, and transportation, are the most significant contributors to GHG emissions. The economic component exhibited the highest variability, indicating a need for targeted decarbonization strategies in these sectors. Emissions from road transport and agriculture emerged as primary environmental contributors. The intensity of fertilizer usage and GHG emissions highlighted the critical role of sustainable agricultural practices in reducing emissions. Social dynamics, including population behaviors and consumption patterns, significantly impact GHG emissions. Improving public awareness and promoting sustainable practices are essential for reducing the environmental burden. The calculated integral index revealed a rising negative impact of local factors on GHG emissions from 2016 to 2021, indicating the urgent need for comprehensive decarbonization policies.

The research also highlighted the unique challenges posed by the ongoing war in Ukraine, which has intensified GHG emissions through increased military activities, infrastructure destruction, and reconstruction needs. This situation underscores the global interconnectedness of environmental impacts and the necessity for collaborative international efforts to address climate challenges.

To align with sustainable development goals, future policies must focus on decarbonizing key economic activities, adopting advanced clean technologies, and fostering resilience within social and environmental systems. The proposed methodology offers valuable insights for policymakers, enabling more effective strategies to mitigate climate change and achieve long-term sustainability.

Based on the generalization of scientific research and publications, practical actions on the implementation of the decarbonization policy, the following directions for achieving net zero CO2 emissions in the long term can be summarized:

- reducing the demand for electricity produced based on the use of fossil fuels by implementing a full-scale energy conservation policy;
- reducing the share of energy in the structure of industrial production through the use of energy-efficient processes and actions;
- increasing the production of electricity produced from renewable energy sources;
- increasing the share of hydrogen in electricity production;
- reducing the area of landfills based on an increase in the share of sorted waste;
- technological changes in automotive production by stimulating the use of electric vehicles;

- increasing carbon tax rates with the simultaneous development of mechanisms for financial support for taxpayers;
- equalizing carbon tax rates to a level that will make it impossible to transfer production to countries with low tax rates;
- creating a system of objective statistics on carbon emissions by unifying methods and means of monitoring and reporting on carbon emissions;
- developing the practice of incentives and financial support for intentions to decarbonize production in the form of investment incentives and "green" lending.

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Improving accessibility in integrated transport hubs as an example of enhancing social inclusion

Theoretical introduction

The journey from the starting point to the destination usually consists of multiple interconnected stages, such as: the segment from home to the curb, followed by the segment from the curb to the vehicle; traveling within the vehicle; transferring to another vehicle; the segment from the vehicle to the curb, then from the curb to the building; and finally, entering the destination. The lack of accessibility at any of these stages makes completing the journey impossible. Therefore, it becomes essential to assess accessibility and continuously improve it for each stage of the journey.

In this context, accessibility is defined with consideration for individuals with specific needs. In most countries, approximately 12 to 16% of residents identify as individuals with specific needs. These individuals may constitute 20 to 25% of public transport passengers [1, 2]. Thus, accessibility, which ensures that public transport and integrated transport hubs are usable by all users, is a critical aspect. Continuous improvement of accessibility will allow real-time identification of barriers and facilities present within the area of integrated transport hubs.

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Analysis of Literature Sources on Available Solutions

Improving Accessibility

Enhancing accessibility also aims to improve personal safety within integrated transport hubs (ITH), which is addressed on both national and international levels through the development of standards and norms. Similarly, the economic considerations of accessibility (and its improvement) should be managed through national legislation. Thus, improving accessibility will impact all aspects of sustainable transport development: economic, environmental, and social.

Increasing social inclusion relates to human rights equality and the elimination of discrimination based on the degree or type of disability. The costs associated with improving accessibility, such as applying universal design principles during the planning of new ITH or modernizing existing ones, can be justified by the enhancements in safety and accessibility for all passengers. The development of public transport and the growth in the number of passengers will lead to reduced transport costs and a positive environmental impact (lower greenhouse gas emissions by reducing the number of private vehicles on the roads).

Accessibility is often substituted by mobility in various literature sources and legal regulations. **Mobility** refers to an individual's ability (person, user, passenger) to move and encompasses two aspects. The first aspect is the efficiency of the transport system, influenced by the user's location, time of day, and travel direction. The second aspect involves the user's specific characteristics and their preferences regarding travel modes (private car, bus, train, airplane, walking). Accessibility defines the user's ability to utilize the transport system [3].

Accessibility, along with universal design principles, considers the user experience of the transport system, all connections (including substitutes for specific transport modes and types of travel), and transport costs. Accessibility-based planning (of cities, neighborhoods, integrated transport hubs, and transport infrastructure elements) includes multimodal solutions that facilitate cycling and walking.

Survey results indicate that people typically spend 60–90 minutes daily and 15–20% of their household budget on transport. Most simple services (e.g., shopping or commuting to school/kindergarten) can take around 5–10 minutes, and if these services are sufficiently accessible, the majority of respondents may choose walking. Transport systems that force users to exceed these time and cost thresholds are perceived as burdensome [3].

Factors Influencing Accessibility Improvement [3]:

- **Demand for Access and Mobility**: Conducting research to better understand people's needs, preferences, and capabilities regarding accessibility and mobility. Using social marketing strategies to develop better options that address these needs and encourage users to choose more efficient and equitable options.

- **Basic Access and Mobility**: Prioritizing transport improvements and actions that facilitate access to goods, services, and activities deemed essential for society.
- **Mobility**: Enhancing traffic speed and capacity, for example, through road upgrades and expansion.
- **Transport Options**: Improving the convenience, comfort, safety, reliability, affordability, and speed of transport options, including walking, cycling, driving, ridesharing, taxis, car-sharing, and public transport.
- **User Information**: Enhancing the quantity and quality of user information about travel options and locations, including signs, maps, brochures, websites, and phone services. Particular focus can be given to providing accessible information on alternative transport modes and efficient locations.
- **Integration**: Improving connections between different transport modes and destinations, such as more integrated information, fare systems, walkability, luggage transfers, and parking facilities for cars and bicycles.
- **Affordability**: Improving the affordability of transport modes (walking, cycling, ridesharing, public transport, taxis, and telecommuting) and affordable housing in accessible locations.
- **Mobility Substitutes**: Enhancing the quantity and quality of telecommunications and delivery services that replace physical travel.
- **Land Use Factors**: Improving land use accessibility by increasing density and diversity. Creating urban villages that are walkable, bikeable, and transit-friendly, with adequate housing, workplaces, and services.
- **Transport Network Connectivity**: Improving road and pathway connections to enable more direct travel between destinations, including specific shortcuts for non-motorized travel where appropriate.
- **Road Design and Management**: Upgrading roads to improve traffic flow (e.g., by reducing driveway cuts), favoring vehicles with higher passenger capacity, and improving conditions for pedestrians and cyclists.
- **Prioritization**: Using mobility and parking management strategies to prioritize higher-value trips and resource-efficient vehicles, as well as encouraging more accessible land use planning.
- **Payment Systems Improvement**: Enhancing methods for charging road and parking fees to reduce transaction costs and increase the feasibility of implementing pricing reforms to improve the overall efficiency of the transport system.
- **Inaccessibility**: To achieve community goals such as environmental protection, mobility and accessibility may need to be limited in some cases.

Planning Aligned with Accessibility Improvements

Terms such as “smart growth,” “location-efficient development,” “multimodal planning,” “urban villages,” and more recently, “15-minute neighborhoods” are used to describe planning that promotes compact, mixed-use, multimodal, and walkable urban areas. In these areas, frequently used services are easily accessible without lengthy commutes, enabling residents to function without the need for private vehicles. Research suggests that many residents would prefer shorter or fewer commutes, rely more on alternative transportation modes, and choose more accessible locations – provided these options are convenient, comfortable, safe, and affordable [3].

Accessibility Improvements for Users with Specific Needs [4]:

- Upgrading roads and sidewalks.
- Safe pedestrian crossings.
- Dedicated bicycle paths.
- Traffic calming measures.
- Safety education.
- Law enforcement.
- Incentive programs.
- Bicycle parking facilities.

User Groups, Identified Issues, and Proposed Improvements [3]:

1. **Urban Commuters**
   a. **Issues**: Traffic congestion and parking difficulties.
   b. **Improvements**: Expanding roads and parking facilities, improving alternative transport modes (e.g., grade-separated public transport), and introducing congestion charges.
2. **Low-Income Commuters**
   a. **Issues**: High fuel and parking costs, unreliable vehicles.
   b. **Improvements**: Enhancing affordable transport options (walking, cycling, ridesharing, public transport) and increasing the affordability of housing in accessible locations.
3. **Non-Drivers**
   a. **Issues**: Inadequate alternative transport and poor connectivity (e.g., difficulty bringing bicycles onto buses).
   b. **Improvements**: Enhancing walking and cycling conditions, ridesharing services, public transport, user information, and connections between transport modes.
4. **Children/Youth**
   a. **Issues**: Poor conditions for walking and cycling, insufficient public transport services.
   b. **Improvements**: Improving pedestrian and cycling infrastructure (especially safety), enhancing public transport, and providing appropriate user information.
5. **Visitors and Modal Transfers**
   a. **Issues**: Inconvenient user information.
   b. **Improvements**: Improving the quality of user information.

6. **Perception of Alternative Modes**
   a. **Issues**: Stigma (walking, cycling, and public transport are perceived as inferior).
   b. **Improvements**: Marketing campaigns to elevate the status of alternative transport modes.
7. **Disabled Individuals**
   a. **Issues**: Inadequate pedestrian facilities, inappropriate vehicles (cars, public transport, and taxis), insufficient user information.
   b. **Improvements**: Enhancing pedestrian and vehicle facilities to accommodate disabilities and improving user information.
8. **Physically Disabled Individuals**
   a. **Additional Issues**: Financial limitations.
   b. **Improvements**: Reduced transport and taxi fees, targeted discounts for low-income disabled individuals, and specialized phone and internet services.
9. **Carriers/Delivery Services**
   a. **Issues**: Traffic delays, inconvenient parking (especially in urban deliveries), high fuel costs.
   b. **Improvements**: Congestion charges to prioritize higher-value trips on congested roads, better delivery vehicle parking options, and development of more fuel-efficient transport services (e.g., rail transport).

Enhancing Accessibility: A Comprehensive Approach

Improving accessibility requires a more comprehensive analysis as no single method can assess all accessibility factors. Diverse methodologies are needed to reflect various impacts, scales, and perspectives. A better understanding of user situations, preferences, and characteristics is essential. Individuals with specific needs, when planning a journey, must consider all barriers and facilities at every stage. Addressing a single barrier is insufficient as accessibility remains limited, and travel for people with specific needs becomes impossible. Only by making all stages of a journey accessible can individuals with specific needs fully benefit from mobility without obstacles [5].

Accessibility Indicators

In the literature, indicator-based methods are used to measure accessibility. Calculating accessibility indicators requires collecting and verifying data from Geographic Information Systems (GIS) and conducting audits. Audits, though time-consuming, provide highly detailed information. These results can be utilized for monitoring accessibility and informing decisions about changes in the infrastructure.

Infrastructure Audits

According to [2], an infrastructure audit should focus on four elements: sidewalks, pedestrian crossings, bicycle paths, and public transport stops. The audit involves recording data in the studied area to establish a database of infrastructure attributes. Accessibility-related data and attributes are recorded to evaluate accessibility levels. Questions and checklists should be based on legal regulations and policies of the relevant region or country. Complex indicators are calculated as the sum of their subcategories, with each indicator assigned specific weights.

After completing the checklist, the percentage of verified attributes for each infrastructure type is calculated by dividing the number of checked indicators by the total number of indicators for the respective type. Audits address accessibility aspects for diverse user groups, but in the *Barrier-Free Transfers* project, they specifically focus on individuals with specific needs as defined in a previously developed catalog.

Example Indicators for Specific Infrastructure Elements

Sidewalks:

- **Indicators**: Five basic and two composite indicators (11 questions total):
  - Sidewalk width.
  - Minimum available pedestrian width.
  - Minimum available pedestrian height.
  - Parking markings along the sidewalk.
  - Properly parked vehicles.
- **Composite Indicators**:
  - Accessible parking for disabled individuals (width, availability, curb access, etc.).
  - Accessibility for disabled individuals (tactile surfaces, even surfaces without cracks or gaps, etc.).

Pedestrian Crossings:

- **Indicators**: One basic and four composite indicators (11 questions total):
  - Accessibility of pedestrian crossings.
- **Composite Indicators**:
  - Minimum pedestrian width and ramp accessibility.
  - Safe crossing conditions (damage-free, obstacle-free).
  - Properly marked crossings (signage, reflective markers, flashing lights).
  - Accessibility for disabled individuals (audible signals, buttons, traffic lights).

Bicycle Paths:

- **Indicators**: Five basic and one composite indicator (8 questions total):
  - Desired path width and separation from motor vehicle lanes.
  - Parking regulations compliance.
  - Uninterrupted movement along the path.
  - Use of materials that support all active transport modes without vibrations.
  - Availability of proper signage and markings.

Public Transport Stops:

- **Indicators**: Five basic and one composite indicator:
  - Accessibility of curbs, tactile warning strips, shelters, and seating.

– **Composite Indicator**: Other facilities (e.g., stop identifiers, schedules, real-time information, audio features).

Flexible Audit Tool

The developed audit is highly adaptable and can be conducted by various organizations to evaluate accessibility for different user groups and infrastructure types. The checklist can be used to create a comprehensive database of infrastructure attributes for local governments. These data can then be leveraged to enhance accessibility.

Survey Form for Accessibility Assessment

A survey form was also used in [2] to identify parameters enabling mobility within an integrated transport hub and estimate the time required to reach specific destinations using various modes of transport.

Survey Structure:

1. **Part One**:
   a. Questions on the most frequently used travel modes.
   b. Vehicle ownership (yes/no).
   c. Travel time by car (<5, 5-10, 10-15, 20-30, 30-45, >45 minutes).
   d. Satisfaction with travel (Likert scale: 1–5, with 5 indicating high satisfaction).
2. **Part Two**:
   a. Questions on public transport usage frequency (daily, 3–5 times a week, weekly, monthly, rarely, never).
   b. Satisfaction with public transport (Likert scale: 1–5).
   c. Acceptable walking time to the nearest stop (<3, 3–5, 5–10, 10–15, 15–20, 20–30, >30 minutes).
   d. Acceptable travel time by public transport to six destinations (seven time ranges: <10, 10–20, 20–30, 30–40, 40–50, 50–60, >60 minutes).

This methodology allows for the identification of critical factors influencing accessibility and helps shape future infrastructure and policy improvements.

Detailed Survey Structure

The survey consisted of multiple sections targeting different user groups to assess their mobility patterns, preferences, and challenges. Below is a detailed breakdown of the survey structure:

<u>Section 3: Cyclists</u>

This section focused on cyclists and included the following:

- **Key Questions**:
  – Ownership of a bicycle.
  – Frequency of bicycle use.
  – Average travel time by bicycle.
  – Acceptable travel time to six different destinations.
  – Time cohorts: <5 min, 5–10 min, 10–15 min, 15–20 min, 20–30 min, >30 min.

- **Final Question**:
  - Respondents rated the importance of eight issues (e.g., road safety, infrastructure quality) that may arise during cycling using a Likert scale (1–5, where 5 = very important).

Section 4: Pedestrians

This section mirrored the structure of the cyclist section, with a focus on pedestrians.

- **Key Questions**:
  - Similar to the cyclist section, but acceptable travel times were categorized as: <3 min, 3–5 min, 5–10 min, 10–15 min, 15–20 min, 20–30 min, >30 min.
- **Final Question**:
  - Respondents evaluated eight potential issues they might encounter while walking in integrated transport hubs, using the same Likert scale.

Section 5: Individuals with Specific Needs

Respondents who identified as having specific needs (from screening questions) were directed to this section, which comprised four subsections:

Subsection 1: General Travel Information

- Questions about:
  - Most frequently used mode of travel.
  - Availability of a driver's license (yes/no).
  - Availability of a vehicle for daily use (yes/no).
  - Whether they commonly use roads with low traffic volumes on foot or in a wheelchair (yes/no).

Subsection 2: Public Transport

- Questions about:
  - Frequency of public transport use (daily, 3–5 times/week, 1–2 times/week, 3–5 times/month, rarely, never).
  - Preferred modes of transport (bus, metro, tram, suburban train).
  - Travel purposes (work/education, errands/shopping/leisure, medical visits, unexpected travel).
  - Problems encountered when using public transport.
  - Acceptable travel time to seven destinations using public transport.
  - Time cohorts: <3 min, 3–5 min, 5–10 min, 10–15 min, 15–20 min, 20–30 min, >30 min.

Subsection 3: Disabilities

- If respondents reported mobility issues, they were asked to:
  - Rate satisfaction (Likert scale: 1–5) with wheelchair accessibility across eight areas (e.g., parking, public transport stops, boarding buses, navigating streets).
- If respondents reported visual impairments, they were asked to:
  - Rate satisfaction with auditory aids (e.g., crossing streets, navigating public transport stops, sidewalks, and streets).

Subsection 4: Local Travel Needs

- Respondents rated the importance of 10 issues they face during travel in their neighborhood (Likert scale: 1–5).
- This section highlighted the importance of the first stage of journeys, particularly in suburban or rural areas.

Final Section: Shared Assessment of Infrastructure Improvement

In this concluding section, all respondents were asked to:

- Evaluate the importance (Likert scale: 1–5) of improving:
  - Pedestrian crossings.
  - Sidewalks.
  - Public transport stops.
  - Bicycle paths in their neighborhood.
- Provide socio-demographic information, such as:
  - Country of origin, gender, age, education level, and employment status.

Significance of the Survey

The survey offers a comprehensive view of the preferences, challenges, and needs of different user groups, especially individuals with specific needs. This data can help policymakers and urban planners enhance infrastructure, accessibility, and inclusivity in transport systems, particularly within integrated transport hubs.

The **Infrastructure Accessibility Index (IAI)** measures the extent to which a specific type of infrastructure is suitable for various types of users in completing their journeys to a destination. It depends on the condition and design of the infrastructure, as well as on user priorities regarding the improvement of each type of infrastructure.

An audit is conducted for each side of a road segment (i.e., left and right) and for each type of infrastructure *kk*k. The indices *IlkI_{lk}*Ilk and *IrkI_{rk}*Irk are calculated for the left (*ll*l) and right (*rr*r) sides of road segment *ii*i, respectively. The average of these two values is estimated as the infrastructure accessibility index for road segment *ii*i, road *jj*j, and infrastructure type *kk*k (e.g., sidewalk, pedestrian crossing, bicycle path, or public transport stop): *Iik,jI_{ik,j}*Iik,j.

The **road segment accessibility index** (*Ii,jI_{i,j}*Ii,j) takes into account all available types of infrastructure for segment *ii*i (*i=1…ni = 1…n*i=1…n) of road *jj*j (*j=1…mj = 1…m*j=1…m) and is estimated based on Equation (1).

$$I_{i,j} = \sum\nolimits_{k=1}^{4} I_{i,j}^{k} \times w_k$$

Where *kk*k represents:

- Sidewalk (1),
- Pedestrian crossing (2),
- Bicycle path (3),
- Public transport stops (4).

Where *wkw_k*wk is the weight assigned to each type of infrastructure, reflecting user priorities for improving each type of infrastructure (i.e., sidewalks, pedestrian crossings, bicycle paths, and public transport stops). The relative weights for prioritizing infrastructure types are calculated by considering respondents' answers based on their respective rankings. The estimated weights, derived as the sum of the rankings, are assigned to each type of infrastructure. The most important type of infrastructure is given a value of 1, and the least important is given a value of *nn*n, according to Equation (2):

$$w_k = \frac{(n - r_k + 1)}{\sum_{k=1}^{4}(n - r_k + 1)}$$

Infrastructure Accessibility Index (IAI)

The **Infrastructure Accessibility Index (IAI)** measures how well a particular type of infrastructure accommodates various user types in completing their journeys to a destination. It depends on the condition and design of the infrastructure and the users' priorities for improving each type.

- *kk*k refers to sidewalks (1), pedestrian crossings (2), bicycle paths (3), and public transport stops (4).
- *rkr_k*rk represents the rank of the *kk*k-th type of infrastructure.
- *wkw_k*wk denotes the weight for each infrastructure type, reflecting the priorities users assign to improving it.

The weights are calculated based on respondents' survey answers and rankings. The most critical infrastructure type is assigned a value of 1, while the least important is assigned a value of *nn*n, as shown in Equation (2).

The **average value of *Ii,jI_{i,j}*Ii,j** for all road segments provides the **IAI** for each road *jj*j, and the average of all *IAIjIAI_j*IAIj gives the **Infrastructure Accessibility Index** for the studied area.

The **IAI values** range from 0 to 100, with the following intervals:

- **0**: No accessibility.
- **1–25**: Poor accessibility.
- **26–50**: Moderate accessibility.
- **51–75**: Satisfactory accessibility.
- **76–100**: Excellent accessibility.

Opportunity Accessibility Index (OAI)

The **Opportunity Accessibility Index (OAI)** complements the IAI by accounting for users' ability to reach destinations (opportunities). It relies on spatial planning to address user needs appropriately.

Seven destinations were considered:

- Green spaces, recreational areas, educational buildings, healthcare facilities, public utility buildings, commercial establishments, and public transport stops.

Four user types were analyzed:

- Pedestrians, individuals with specific needs, cyclists, and public transport users.

The OAI calculation incorporates the maximum acceptable travel time for each user type to reach the seven destinations. The process involves three steps:

1. **Estimating acceptable travel times** for each user type based on survey results.
2. **Creating isochrones** using QGIS with the ORS Tools plugin, which allows time- or distance-based isochrone generation for various modes of transport (e.g., driving, cycling, walking) while considering travel speed.
3. **Generating isochrone curves** around each destination to illustrate reachable areas within the acceptable travel time. These curves create unified areas displayed on thematic maps, indicating the potential coverage of the studied area.

OAI values range from 0 to 100:

- **0**: No destination is reachable by any user within the estimated area.
- **>1**: At least one destination is reachable by a user within the estimated travel time.
- **100**: All desired destinations are reachable by a specific user group within the estimated travel time.

Sustainability Indicators

Another indicator-based method for evaluating accessibility involves **sustainability indicators**, aligning with **Sustainable Development Goal (SDG) 11.2**:

"By 2030, provide access to safe, affordable, accessible, and sustainable transport systems for all, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities, and older persons."

Sustainability indicators are developed in a multilevel approach to enable national agencies and authorities to generate data, report progress, and inform actions for achieving the goal.

Three levels of metrics:

1. **Level 1 Metrics**: High-level frameworks for consistent international comparisons across four thematic areas.
2. **Level 2 Metrics**: Support the measurement of the four thematic areas with a second layer of information.
3. **Level 3 Metrics**: Include 33 factors for a deeper understanding of patterns within the four thematic areas.

Four thematic areas:

1. **Comfort and Safety** – Table A.
2. **Service Demand** – Table B.
3. **Connections to Destinations** – Table C.

4. **Support and Incentives** – Table D.

Tables with detailed indicators for each thematic area (Tables 1–4) have been developed to guide the evaluation process.

Table 1.

Indicator	Level 1	Level 2	Level 3
A1. OVERALL EXPERIENCE			
A1.1. Walking – overall satisfaction	X		
A1.2. Public Transport (PT) – overall satisfaction	X		
A2. SAFETY			
A2.1. Providing safe intersections		X	
A2.2. Feeling of safety from injuries caused by motorized traffic or cycling			X
A2.3. Number of injuries			X
A2.4. Number of fatalities			X
A3. PERSONAL SAFETY			
A3.1. Feeling of personal safety while walking		X	
A3.2. Level of human activity			X
A3.3. Women's perception of safety			X
A3.4. Availability of lighting			X
A4. PEDESTRIAN INFRASTRUCTURE			
A4.1. Provision of walking space		X	
A4.2. Quality of pavement materials			X
A4.3. Level of pedestrian surface maintenance			X
A4.4. Cleanliness of pedestrian environment			X

Indicator	Level 1	Level 2	Level 3
A4.5. Adequacy of path drainage			X
A5. PUBLIC TRANSPORT INFRASTRUCTURE			
A5.1. Accessibility of stations and stops for people with reduced mobility		X	
A5.2. Accessibility of vehicles for people with reduced physical mobility			X
A5.3. % of stations with step-free access from street to platform			X
A6. OPERATIONAL EFFICIENCY			
A6.1. Average service reliability		X	
A6.2. Number of annual trips by transport mode			X
A6.3. Vehicle kilometers traveled			X
A6.4. Passenger kilometers traveled			X
A6.5. Number of stops			X
A6.6. Total line length			X
A6.7. Number of vehicles in the fleet			X
A6.8. Average waiting time at stops (in minutes)			X
A6.9. Average operational speed of public transport			X
A6.10. Average service frequency			X
A6.11. Revenue and operational costs			X
A7. VEHICLE QUALITY			
A7.1. Average age of vehicles		X	

Indicator	Level 1	Level 2	Level 3
A8. IMPACT OF MOTORIZED TRAFFIC ON PEDESTRIAN MOBILITY			
A8.1. Feeling of appropriate traffic speeds		X	
A8.2. Noise perception			X
A8.3. Perception of air quality			X
A8.4. Perception of parking impact			X

Table 2.

Indicator	Level 1	Level 2	Level 3
B1. DAILY JOURNEYS	B1.1 Total number of daily walking and public transport journeys		
		B1.2 Share of walking and public transport journeys (%)	
		B1.3 Total time spent walking during daily journeys (minutes)	
		B1.4 Total time spent using public transport during daily journeys (minutes)	
			B1.4 Age (0-15; 16-30; 31-60; 60+)
			B1.5 Gender (F; M; Other)
			B1.6 Ability (able-bodied; disabled; assisted)
			B1.7 Travel frequency (daily, often, occasionally)

Table 3.

Indicator	Level 1	Level 2	Level 3
C1 ACCESS TO PUBLIC TRANSPORT STOPS	C1.1 Population living within <500 meters of a public transport stop (%)		
			C1.2 Distance traveled to reach the nearest public transport stop (minutes)
			C1.3 Motorized transport accessibility (Y, N)
C2 ACCESS TO JOBS AND SERVICES		C2.1 Number of jobs and urban services accessible within 60 minutes by public transport (%)	

Table 4.

Indicator	Level 1	Level 2	Level 3
D1 INFORMATION	D1.1 Ease of wayfinding (R-Y-G)		
			D1.2 Satisfaction with maps, timetables, and travel information (R-Y-G)
D2 ACCESSIBILITY – AMENITIES		D2.1 Pedestrian-oriented provisions such as trash bins, lighting, seating, and signage (R-Y-G)	
D3 AFFORDABILITY			D3.1 Average income spent on transport (%)
D4 INCENTIVES		D4.1 Number of passengers with concession/subscription tickets (trips made with concessionary/subscription tickets as % of total network trips)	

These indicators are calculated based on survey data and the establishment of percentage-based guidelines.

Development of a Custom Accessibility Improvement Procedure

Based on the analysis of literature sources, research on integrated transport hubs, and outputs from earlier project stages, the content of an accessibility improvement procedure was developed.

Purpose of the procedure:

The procedure aims to monitor, report, and evaluate the accessibility management system of integrated transport hubs using an indicator-based method. It also aims to implement actions for continuous improvement and enhancement of accessibility, considering the needs of individuals with specific needs.

Intended audience:

The procedure is intended for managers of integrated transport hubs and their infrastructure elements, all participants (users) of these hubs, and individuals with specific needs.

Criteria of the procedure:

Legal standards, best practices, and the requirements of customers and other participants in the transport system.

Elements of the Accessibility Improvement Process for Integrated Transport Hubs

1. **Audits**:
   a. Results from audits, reports, records, and notes from research and interviews with staff, users of the integrated transport hubs (ITHs), and support personnel on-site.
2. **Preventive and corrective actions**:
   a. Following identified nonconformities or audit findings, proposals for corrective actions must be prepared. Preventive actions should also be implemented to eliminate the root causes of nonconformities.
3. **Complaints**:
   a. In the event of complaints and/or recommendations from users of ITHs and travelers, the functionality of specific system components should be verified. Necessary changes should be implemented, or system functionality restored.
4. **Monitoring and reporting of accessibility indicators for ITHs**:
   a. Documentation and actions must be carried out to monitor the accessibility level of all system elements, including infrastructure, considering individuals with specific needs. Indicator-based methods should be implemented, and annual reviews of indicator values conducted. If negative results or significant deviations from previous assessments arise, actions for improvement and continuous system enhancement should be taken.

5. **Improvement and enhancement program**:
   a. Actions and records related to improving and enhancing the accessibility management system of ITHs and their infrastructure components should be implemented (accounting for multiple managers).

Procedure Framework

The accessibility improvement process should be continuous, with general actions presented in a recurring cycle (Figure 1). The indicator-based method adopted in the procedure requires data collection, surveys, and audits. This process is illustrated in Figure 2.

Figure 1. The Process of Continuous Accessibility Improvement

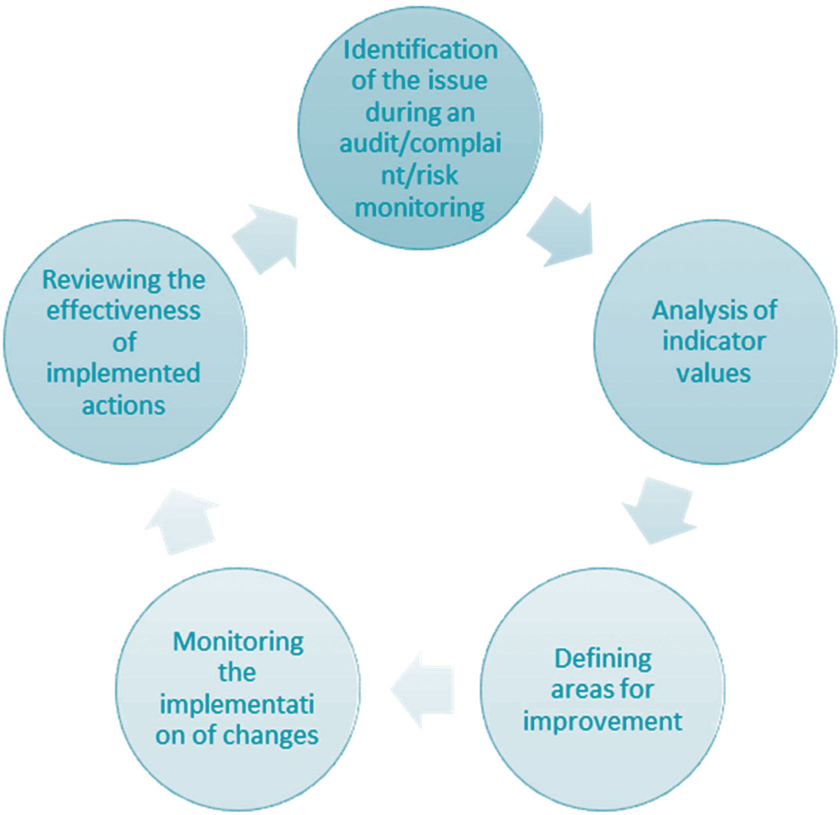
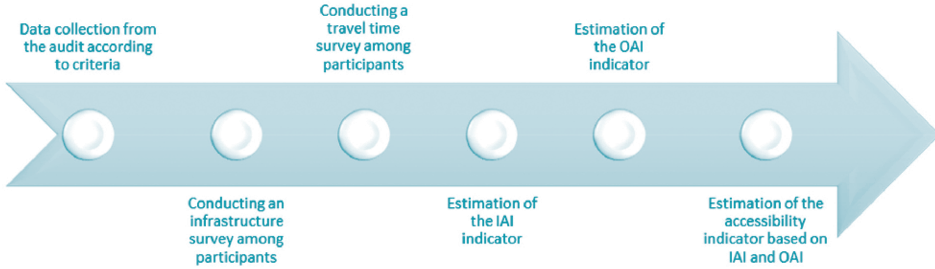


Figure 2. The Process of Estimating Accessibility Indicators



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Indicator Method for Studying Integrated Transfer Nodes, Enhancing Social Inclusion

1. THEORETICAL INTRODUCTION

The issue of free movement for people with special needs has been increasingly analyzed and studied in recent years. People with special needs face a lack of or limited ability to move between cities using various means of public transport. These difficulties stem from the lack of adaptation of spaces and points that are elements of integrated interchanges. Integrated nodes should be adapted for people with special needs and free of barriers within their area. The essence of transfer nodes is based on integration between cities and metropolises using various means of transport. This integrated intermodal approach is important not only for travel within city limits but also for long and short-distance travel. Usually, travel decisions are made by considering the most convenient means of transport for long distances (train, bus, airplane), but the fact is that last-mile connections are becoming increasingly important, especially in large metropolitan areas. The response to this integrated approach is to build transfer nodes with the principles of universal design in mind. Universal design (UD) aims to provide better accessibility and safety for all groups in the community. Initially, the principles of universal design could be observed in buildings

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and public places. Currently, programs concerning broadly understood accessibility are based on UD principles in the construction and integration of cities.

2. LITERATURE REVIEW

Mobility is a crucial issue for the social integration of people with disabilities. Thanks to mobility and the ability to combine several modes of different transport branches, people with special needs can cover long distances. Integrated Transfer Nodes (ITNs), defined in the Act on Public Transport (Act of December 16, 2010, on Public Transport), are places that integrate various types of public transport. This act will be cited further in this study. Some legal requirements include accessibility guidelines and universal design, taking into account the needs of people with special needs. These requirements encompass the safety of people and property and the protection of the health of those moving in areas that are elements of ITNs. According to the Act on Ensuring Accessibility for People with Special Needs (Journal of Laws of 2019, item 1696), it is necessary to implement minimum requirements for architectural, digital, and information-communication accessibility. The aim of the act is to increase the ability of the general public, including people with disabilities, to use services offered by public entities, thereby enhancing social inclusion.

Social inclusion refers to the process of ensuring that all individuals, regardless of their social, economic, cultural, or physical differences, fully participate in social, political, and economic life. It is a significant element of public policy and social development strategies, aimed at eliminating barriers that exclude certain social groups. Public transport plays a key role in promoting social inclusion, enabling individuals to access work, education, healthcare, and other essential services. Efficient and accessible public transport is the foundation of sustainable city and regional development, reducing social exclusion and supporting social mobility. Social inclusion in the context of public transport involves designing and managing transport systems that are accessible and affordable for all social groups, including people with disabilities, seniors, low-income individuals, and rural residents. Social inclusion in public transport is an essential element of sustainable development and the creation of a just society. Effective transport systems that are accessible to everyone can significantly contribute to reducing social and economic exclusion. However, continuous monitoring, policy adaptation, and the involvement of all stakeholders in creating and maintaining inclusive transport systems are crucial (Allen and Farber, 2020; Boisjoly and El-Geneidy, 2021; Cui et al. 2019).

Due to the lack of a universal method for assessing integrated transfer nodes, the indicator method present in the literature and used by other authors was adopted (Czekała et al., 2017; Olszewski et al. 2014). This method is based on eight quantitative indicators, whose main evaluation criteria are: the quality of basic infrastructure, spatial integration, accessibility for the elderly, disabled, people with young children, information, readability of the node, safety, and additional equipment. This method can successfully be used to evaluate both existing and functioning transfer nodes and the assessment of node projects (Czekała et al., 2017; Olszewski et al. 2014).

Integrated transfer nodes play a crucial role in modern transport systems, enabling seamless transfers between different modes of transport such as buses, trams, trains, or city bikes. One of the most important aspects of their operation is accessibility for people with special needs, including people with disabilities, seniors, parents with young children, and those with limited mobility. Particular attention is paid to providing infrastructure and amenities that allow all passengers to move freely. The accessibility of integrated transfer nodes is regulated by a series of guidelines and standards that must be met by designers and infrastructure managers. In the European Union, directives such as Regulation (EC) No 1371/2007 on rail passengers' rights and obligations set minimum accessibility standards (Regulation EC No 1371/2007). In Poland, similar requirements are included in national building regulations and public transport laws (Sitarz et al. 2023). A common issue in public transport is the lack of accessibility due to inadequate design and the absence of appropriate procedures. Time is also a challenge in implementing accessibility due to rapidly changing legal regulations and technological innovations that become outdated solutions. Another aspect of the lack of accessibility is the high cost of reconstructing and adapting public spaces. One reason for the lack of accessibility is the absence of uniform regulations, standards, and best practices that serve as a procedural model (Zając 2016; Nielsen 2024).

At the planning and design stages of integrated transfer nodes, arrangements should be made to achieve continuity between the node zone and the node itself. All elements of the transfer node (building, transfer points, access routes, and passages) should allow users with special needs to quickly use the available public spaces. The latest trends in universal design include guidelines for sustainable development (Lucietti et al. 2016; Nielsen 2023).

Since 2010, Poland has had a definition of an integrated transfer node in the aforementioned Act on Public Transport. To date, many authors of studies and scientific publications have attempted to more precisely define this facility. According to the Transport for London (TfL) study, an integrated transfer node is defined as a facility built for transfers – such as a train or bus station, or a set of tram-bus stops (Transport for London, 2021). In the "Masterplan for the Poznań Metropolitan Railway" project, a transfer node is defined as "an area in urban planning where there is direct locational contact between the road network and public transport with infrastructure elements used for moving people beyond transport means and waiting for transport means" (Masterplan for the Poznań Metropolitan Railway, 2015). Olszewski defines a transfer node as a place where transfers between different lines or means of transport are made (Olszewski et al. 2014).

In each of the given definitions, it is clear that elements of a station or stop (e.g., sidewalk, platform) can function as a transfer node. To clarify the definition and guidelines, Rychlewski (2016) in his work identified additional aspects of a transfer node that must be ensured:

- the ability to change the means of transport within the same platform (optimal case),
- minimizing height differences,
- minimizing distances within the node,
- good passenger information,
- comfortable waiting areas,
- services related to the transport function and beyond.

Bul (2017), in his study, indicates additional conditions that a transfer node should meet, which are:

- the node area must have at least two different public transport lines or one public transport line connected with a change from individual to collective transport,
- at least one journey in any relation passing through the node requires a change of transport means or communication line,
- the distance to be covered between points (passenger exchange positions) in the node must range from a few to a maximum of 150–300 meters (such large distances are practiced only in the largest transport stations and often include engineering solutions that facilitate movement within the node: elevators, escalators, moving walkways, etc.),
- there must be a physical connection between passenger exchange positions within the same node that can be overcome by transport users.

The aim of this study was to present a universal indicator method for studying integrated transfer nodes to increase social inclusion. The universal indicator method is based on selected social groups, considering those most often affected by social exclusion in travel planning. It also included an analysis of the accessibility of selected integrated transfer nodes (ITNs) in the GZM area and an assessment of their elements, taking into account people with special needs. Five ITNs were selected based on area and the number of passengers participating in transfers. Due to the large volume of data and research results, this study presents the calculation of the indicator method for one of the nodes – the International Bus Station in Katowice, located on ul. Sądowa.

3. METHODOLOGY

Selected Integrated Interchanges in the Metropolis GZM

The study focused on five integrated transfer nodes within the Upper Silesian-Zagłębie Metropolis, which have been modernized or newly built in recent years. The selected nodes include:

Katowice Station: The fourth most frequented railway station in Poland, reopened after its last reconstruction in 2013. Transport Integration: Connects rail, road (bus, tram), and air transport (direct bus and rail connections). Status: International.

Katowice International Bus Station: An international bus station in Katowice, a new investment completed in 2019. Transport Integration: Connects road transport (bus, tram within 300 m, personal vehicles), rail (within 300 m), and air transport (direct bus connection).

Chorzów Market: A transfer center opened in 2015; Transport Integration: Connects road transport (bus, tram, personal vehicles) with rail transport (300 m to Chorzów railway station).

Dąbrowa Górnicza Center: The largest transfer center in Dąbrowa Górnicza, modernized and reopened in 2024. Transport Integration: Connects road transport (bus, tram) with rail transport (300 m to the railway station).

Gliwice Transfer Center: One of the largest transfer centers in Silesia, featuring 12 stands for 40 bus lines, completed in December 2022 after 27 months of construction. Transport Integration: Connects road transport (bus) with rail transport (150 m to the railway station).

Sample Composition

A total of 265 passengers participated in the study, with 250 passengers interviewed by surveyors and 15 completing the online survey independently. The study aimed to achieve a sample size of 250 passengers, which was achieved at 106% of the target. Each transfer node met the minimum sample size requirement of 50 passengers.

Table 1. Sample achieved for each interchange N=265

Integrated Interchanges	Number of people	Percentage
Chorzów Market	50	18,9%
Gliwice Transfer Center	54	20,4%
Dąbrowa Górnicza Center	56	21,1%
Katowice Station	52	19,6%
Katowice International Bus Station	50	18,9%
Lack of answer	3	1,1%
All	**265**	**100,0%**

Research Method

The research component involving passengers, including those with special needs, was conducted through interviews using a survey questionnaire. The study was carried out using a quantitative method and modern research techniques, and the entire survey was conducted electronically without the need to print paper questionnaires, aligning with values of ecology and responsible business practices. The research was conducted in a manner that utilized broad access to respondents, both through direct contact and online. The questionnaire included closed, semi-open, and open questions, tailored to the specific characteristics of the respondent group and their perception, as well as the method of conducting the research. The questionnaire consisted of 32 questions, including 27 substantive questions and 5 demographic questions.

The study covered the following topics: initial questions (such as the purpose of travel, assessment of mobility, and affiliation with the group of people with special needs), demographic questions (such as gender, age, place of residence), general questions about the use of public transport (including needs, frequency of use, satisfaction assessment), and specific questions regarding a particular interchange hub (including needs, frequency of use, satisfaction assessment).

An indicator method for studying integrated interchange hubs was developed based on existing methods found in the works of Olszewski et al. 2014, Czekała et al. 2017, Bul et al. 2017, and Transplan materials. Existing indicators in the methodology were used, a sustainable development indicator (W9) was added, and the W3 indicator concerning the accessibility of people with special needs was modified. Table 2 presents the general characteristics of the modified method.

Table 2. Characteristic of indicators

Indicator	Name	Characteristic	Research method
W1	State of the node infrastructure	It is the ratio of the number of all platforms and passages that meet ZTM** guidelines and whose width has been adjusted to the traffic intensity, to the total number of platforms and passages in the nodes	audit / inspection / calculation and estimation method
W2*	Internal Integration (Coherence) of the nodes	Alternatively applied: Indicator 2.1 – dependent on the flow of transferring passengers. Indicator 2.2 – dependent on the flow of public transport vehicles through the node. Indicator 2.3 – dependent on the arrangement of bus stop platforms relative to each other	audit / inspection / calculation and estimation method
W3	Accessability for people with special needs	An audit form was developed on the basis of the created catalogues of barriers/facilities and people with special needs (Tab. 5)	audit / inspection / calculation method

Indicator	Name	Characteristic	Research method
W4	Internal logic of the node (legibility of the node)	It is the quotient of the average number of posts visible of each post at level 0 to the number total number of posts at level 0.	audit / inspection / calculation method
W5	State of personal security at the interchange	K.5.1 – quotient of the number of posts and transitions between them covered by video monitoring to the total number of posts. K.5.2 – intelligent monitoring (automatic detection of unusual behaviour, objects). The degree of 'intelligence' of the monitoring system will be assessed. Where detection of anything in the video is only possible by the operator this criterion will receive a value of 0%. K.5.3 – the quotient of the number of stands and aisles between them with sufficient lighting to the total number of stands. K.5.4 – presence of uniformed staff/security/guards. This criterion receives 0% if there is no uniformed service/security/guard at all.	audit / inspection / calculation method
W6	State of road safety at the interchange	This is the quotient of the number of street crossings without lanes and traffic lights to the number of all street crossings inside the interchange.	audit / inspection / calculation method
W7	Passenger information	K.7.1 – the quotient of the number of stands with electronic dynamic stop information boards to the total number of platforms at the interchange, K.7.2 – ratio of the number of stands with tariff information and interchange plans to the total number of stands in the interchange, K.7.3 – as above. in criterion K.7.2 but for information in English, K.7.4 – ratio of the sum of the number of guidance signs (e.g. arrows, signs) on the turns and forks to the total number of turns and forks in the interchange.	audit / inspection / calculation method

Indicator	Name	Characteristic	Research method
W8	Additional functions present in the node	a. A ticket vending machine for the sale of tickets and loading of ŚKUP*** cards b. a kiosk, selling tickets and recharging the APC cards, c. Toilet facilities, d. covered walkways between platforms, e. bike racks within monitoring range, f. Parking and Ride facilities g. Passenger benches h. Parking i. Space for a trolley under a shelter j. voice announcement system k. electronic timetable	audit / inspection / calculation method
W9	Sustainability	W9.1. Environmental indicator (calculation) a). Carbon footprint (using available applications and calculators or calculation methods) b). energy efficiency (number of electric vehicles and charging/refuelling infrastructure) W9.2. economic indicator (mixed – audit and survey) a). congestion (observation, knowledge of bottlenecks and peak-hour situations) b). delays (based on survey) W9.3. Social indicator – Travel comfort (mixed – audit and calculation) a). access to public transport service b). feeling of safety at the interchange c). number of fatalities and injuries (data taken from pre-established centres and institutions) d). noise at the junction (measurement) e). environmental pollution (measured or downloaded from pre-established centres and institutions)	audit / inspection / calculation method / survey method

* In this study, W2.3 was used for the calculation of the indicator

** ZTM – Zarząd Transportu Metropolitalnego (eng. The Metropolitan Transport Authority)

***ŚKUP – Śląska Karta Usług Publicznych (Silesian Public Services Card)

The general calculations for each integrated interchange are summarised in a separate table later in this publication. Some of the analyses and studies are presented in detail on a selected interchange – Katowice International Bus Station.

Accessibility study of the ZTM

Table 5 shows the identified barriers and facilities that were investigated during the audit/visual inspection of the integrated interchange, including aspects of accessibility for people with special needs. A catalogue of barriers and facilities was previously created for the visual inspection exercise (Sitarz et al. 2023). It is a universal tool for any type of interchange due to its similar design elements. The parameters correspond to a two-stage analysis in the form of determining whether a barrier/facility meets or does not meet (YES/NO) the accessibility criterion and whether it is suitable for people with special needs by means of a value of 0 when it does not meet and 1 when it meets the criteria.

4. RESULTS AND DISCUSSION

Questionnaire studies

In the study, 50.6% of participants were women and 48.3% were men (Figure 1). The sample for passenger age was selected to ensure a minimum of 50 individuals for each age category, resulting in participants of various ages, with each age group representing 19%-20% of the respondents (Figure 2). Additionally, 28.3% of the surveyed individuals declared themselves to be in the category of people with special needs.

Figure 1. Genders of respondents

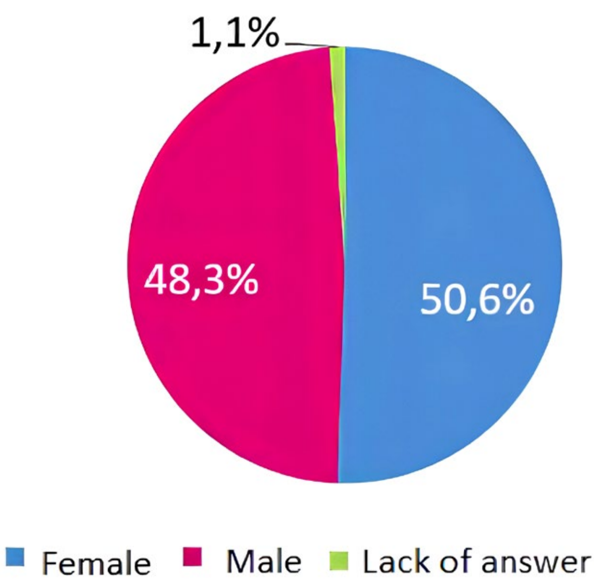
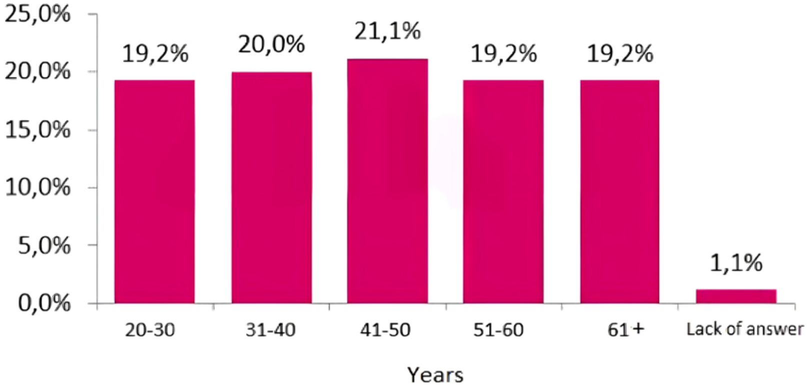
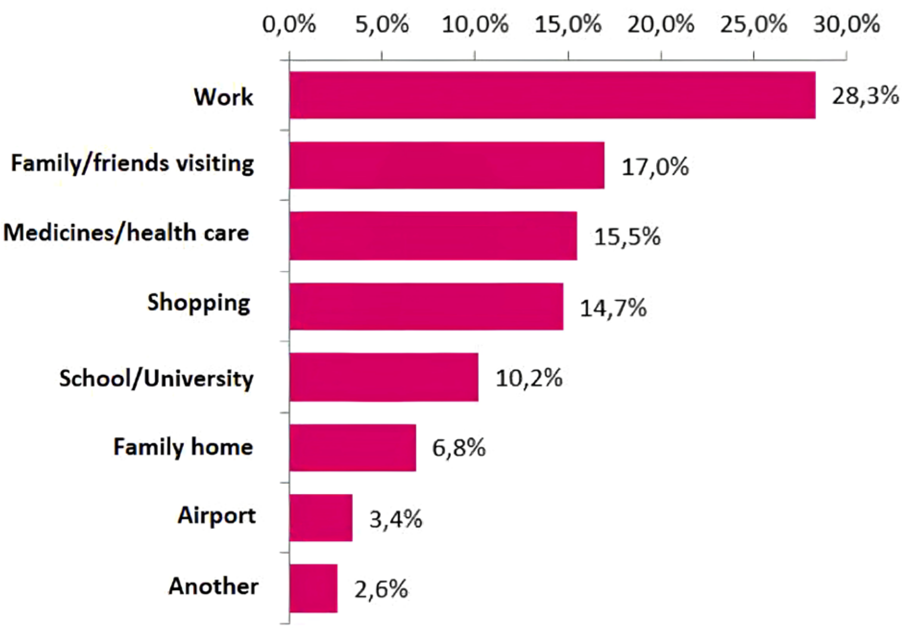


Figure 2. Age of respondens



Most of the surveyed passengers use interchange hubs for work purposes, with 28.3% commuting to their jobs. Next, 17.0% use public transport to visit family or friends, 15.5% for medical appointments, 14.7% for shopping, and 10.2% are students traveling to their university. Additionally, 6.8% travel to their family home, 3.4% to the airport, and 2.6% for other purposes such as part-time work, entertainment, gym, walking, visiting a café, or picking up a child from kindergarten.

Figure 3. Reason for travelling



Tables 3 and 4 compile data from the passenger survey conducted at five integrated interchange hubs, categorized by passenger age and type of hub.

The highest satisfaction scores among passengers were related to the ease of transfers and the accuracy of timetables, with average ratings of 4.5 and 4.4, respectively. Men reported a higher level of satisfaction (4.2) with the integrated interchange hubs compared to women (4.0). The highest average satisfaction ratings were given by individuals aged 20 to 40 (4.2), while the lowest were given by those aged 61 and older (3.9).

The aspect with the lowest rating was the sense of security among individuals aged 61 and older, which was 3.5 (compared to an overall average of 3.8). This is undoubtedly one of the aspects that should be analyzed in terms of road and personal safety, and security at the hubs should be improved.

The most satisfied passengers are those who use the hubs for:

- Katowice International Bus Station (average 4.2 – 88.0% satisfied passengers, 10.0% rate this hub as average, and only 2.0% dissatisfied)
- Katowice Station (average 4.1 – 82.7% are satisfied passengers, 15.4% rate this hub as average, and 1.9% are dissatisfied)
- Dąbrowa Górnicza Center (average 4.0 – 76.8% are satisfied passengers, 14.3% rate this hub as average, and 8.9% are dissatisfied). Slightly fewer satisfied passengers were among those who use the hub:
- Chorzów Market (average 3.9 – 80.0% satisfied passengers, 14.0% rate it as average, and 6.0% dissatisfied)
- and Gliwice Transfer Center (average 3.9 – 68.5% satisfied passengers, 24.1% rate this hub as average, and 7.4% dissatisfied passengers).

Passenger dissatisfaction was mainly caused by the availability and readability of timetables and the low level of security at the hub.

Table 3. Average passenger ratings, by gender and age

	All	Female	Male	20-30 years old	31-40 years old	41-50 years old	51-60 years old	61+
General satisfaction with the given hub	**4,0**	3,9	4,1	4,2	4,1	3,8	4,0	3,9
Ease of moving around the hub	**4,1**	4,0	4,2	4,4	4,2	3,9	4,1	3,9
Ease of finding the way	**4,0**	3,9	4,1	4,2	4,2	3,9	3,9	3,7
Accessability of timetables	**4,0**	4,0	4,1	4,1	4,2	4,0	4,0	3,6

	All	Female	Male	20-30 years old	31-40 years old	41-50 years old	51-60 years old	61+
Readability of timetables	**4,0**	4,0	4,0	4,2	4,2	4,0	4,0	3,7
Up-to-dateness of time-tables	**4,4**	4,4	4,5	4,5	4,5	4,4	4,4	4,3
Satisfaction with transfer options	**4,5**	4,4	4,6	4,5	4,5	4,3	4,5	4,4
Sense of security	**3,8**	3,6	4,0	3,8	3,9	3,9	3,7	3,5
Accessibility of the hub for people with special needs	**4,0**							
Accessibility of trans-portation for people with special needs	**4,0**							
Accessibility of spaces for people with special needs	**4,1**							
All	**4,1**	**4,0**	**4,2**	**4,2**	**4,2**	**4,0**	**4,1**	**3,9**

Table 4. Summary of average ratings according to the 5 integrated interchanges

	Chorzów Market	Transfer Center Gliwice	Dąbrowa Górnicza Center	Katowice Station	Katowice Intern. Bus Station
General satisfaction with the given hub	3,9	3,9	4,0	4,1	4,2
Ease of moving around the hub	4,1	4,0	4,0	4,2	4,2
Ease of finding the way	4,1	3,8	3,9	4,1	4,2
Accessability of timetables	3,7	4,1	4,0	4,1	4,1

	Chorzów Market	Transfer Center Gliwice	Dąbrowa Górnicza Center	Katowice Station	Katowice Intern. Bus Station
Readability of timetables	3,8	4,1	3,9	4,1	4,2
Up-to-dateness of timetables	4,7	4,3	4,2	4,3	4,7
Satisfaction with transfer options	4,7	4,2	4,1	4,6	4,8
Sense of security	3,4	3,6	3,9	3,8	4,2
Accessibility of the hub for people with special needs	4,0	4,1	4,0	3,9	4,1
Accessibility of transportation for people with special needs	4,0	4,0	3,9	3,9	4,1
Accessibility of spaces for people with special needs	4,0	4,2	4,0	4,0	4,1
All	**4,0**	**4,0**	**4,0**	**4,1**	**4,3**

Accessibility studies of integrated hubs based on example of Katowice International Bus Station

During the audit/inspection of the integrated transfer hub – the International Bus Station in Katowice, located at Sądowa Street, it was found that the biggest accessibility barriers for people with special needs were, among others (Table 5): lack of voice information, lack of information points, lack of induction loops, and lack of alternative and augmentative communication options. The most neglected group of barriers are organizational barriers/facilities. The absence of an assistant or a sign language interpreter leads to a lack of possibilities for travelers to get assistance or information. Many integrated transfer hubs in Poland lack universal principles and rules as well as procedures that would define how to act and proceed when providing services at integrated hubs for people with special needs. Developing an accessibility management system and creating a continuous improvement procedure for accessibility at integrated transfer hubs will address the missing facilities and reduce accessibility barriers.

Table 5. Accessibility studies of Katowice International Bus Station (W3)

Barrier/Facility Category	Barriers/Facilities	The general parameters YES/NO, 1/0	Another
	Physical barriers/facilities		
A. Limited accessibility	safe pedestrian routes	Y, 1	They occur throughout the entire integrated transfer hub; they do not occur outside of transfer hub, and they are not always symmetrical.
	large [unacceptable] access distance	N, 1	
	passenger amenities	Y, 1	Voice schedule button without Braille, card access in ticket machine too high
	area to properly serve people with special needs	Y, 0/1	Lack of adaptation of the ticketing area and lockers; shelters without covered space for wheelchair users
	FON or natural guiding elements	Y, 1	Sometimes are asymmetrical
	parking	Y, 1	
	distance to parking	Y, 1	
	excessive glazing	N, 1	
	unmarked glazing	N, 1	
	contrasting elements	N, 1	
	directional lines	Y, 1	
	crosswalks	Y, 1	
	pictograms	Y, 1	
	revolving automatic doors	N, 1	
	sliding automatic doors	Y, 0/1	Ticketing area without access through sliding doors
	moving walkways	N, 1	
B. Difference in terrain levels	slope of the terrain	N, 1	
	devices and elements to help overcome the difference in height (lifts)	Y, 1	
	Stairs	Y, 1	
	steps or thresholds	Y, 1/0	Threshold at the entrances to long-distance buses, lack of ramps

Barrier/Facility Category	Barriers/Facilities	The general parameters YES/NO, 1/0	Another
Physical barriers/facilities			
C. Existence of physical obstacles	continuity of moving route (collision crossings)	N, 1	
	construction poles within pedestrian routes	N, 1	
D. Restricted clearance	passage width	Y, 1	
	passage height	Y, 1	
E. Marking of pedestrian routes	visual markings	Y, 1	
	audibility of sound signals	N, 0	Lack of sound information
	overlapping sounds	N, 1	
F. Condition of pavements, corridors	uneven terrain	N, 1	
	non-slip surfaces	Y, 1	
G. Visibility	lighting	Y, 0/1	Ground floor of the building with limited lighting
	spot blackouts	Y, 0/1	Ground floor of the building
	lines indicating a change/threat	Y, 0/1	Do not meet construction requirements
H. Associated facilities	canopies	Y, 1	
	toilets for people with special needs	Y, 1	
	rest areas	Y, 1	
	wind shelters	Y, 1	Shelters without covered space for wheelchair users

Barrier/Facility Category	Barriers/Facilities	The general parameters YES/NO, 1/0	Another
	Information barriers/Facilities		
I. General information	information system	N, 0/1	Lack of dedicated information point
	information on the need and method of evacuation	Y, 1	In the building
	status of reading and inter-pretation of timetables	Y, 0/1	Without long-distance schedules
	status of reading and interpretation of plans	Y, 0/1	Present in the building; lack of map
	status of reading and interpretation of maps	Y, 0/1	Present in the building; lack of map
	status of reading and in-terpretation of information points	N, 0	Lack of information points
J. Guidance system wayfinding	travel guidance system	N, 0/1	Underdeveloped
	tactile map	Y, 1	Present in the building
K. Visual information	quality of communication of visual information – e.g. font	Y, 1	
	amount of advertisements	Y, 1	Without shelter
L. Tactile information	signage for the blind	Y, 1	Without shelter
	Braille lettering	Y, 1	
M. Audio information	audio information	Y, 0/1	Only in ZTM
	induction loops	N, 0	
	reverberation	N, 1	
N. Internet information	website for people with special needs	Y, 0/1	Does not meet requirements for blind individuals, lacks a map

Barrier/Facility Category	Barriers/Facilities	The general parameters YES/NO, 1/0	Another
Organisational barriers/facilities			
O. Support system	trained staff	N, 0	
	assistant or carer to serve people with special needs	N, 0	
	online translation amenities	N, 0	
	sign language interpreter	N, 0	
	space for an assistance dog	N, 0	
P. Management system	procedures, instructions dedicated to persons with special needs	N, 0	
	tools for assessing the functioning and management of amenities for persons with special needs including audit procedures	N, 0	
Q. Poor service quality	unreliability of service	N, 1	
	availability of service	N, 0	
Cognitive barriers/facilities			
R. Sense of insecurity	multiple alleys	N, 1	
S. Difficulty in understanding	multilingual information comprehension	N, 0/1	Visual only
	operation of automatic devices	N, 0/1	Not all are adapted
	augmentative and alternative communications [AAC]	N, 0	

Calculation of the evaluation method for integrated transfer hubs using indicators

In Table 6, detailed data from the calculation of indicators and their compilation as the overall evaluation method for integrated interchanges are presented. Estimation of indicator values involved converting the scale into percentages, considering the total sum of all elements, and determining the number of elements meeting the requirements (percentage). For indicator W2 concerning internal integration (compactness) of the hub, calculation method W2.3 was used, which measured the average distance between platforms within the hub. At the International Bus Station in Katowice on Sądowa Street, there are two types of vehicles and platforms: long-distance buses stop at 13 platforms, with one vehicle per platform. Additionally, there are two platforms for metropolitan and intercity buses of the Metropolitan Transport Authority. These platforms serve 9 and 12 bus lines respectively, traveling in different directions. The analysis considered both long-distance and local transportation platforms at the hub.

Indicator W3 has been developed in great detail, demonstrating through the applied audit/inspection form of the hub which analyzed elements of transportation infrastructure are not accessible to people with special needs. Some elements were not available or their absence was noted, which may hinder the use of the hub by individuals with special needs. In some cases, partial accessibility was observed, indicating areas that require improvement and enhancement. The majority (75%) of elements met accessibility criteria and were marked accordingly in the assessment sheet.

In the studies on indicator W5, it was noted that the analyzed facility lacks law enforcement presence and CCTV surveillance with special capabilities for detecting intentional behaviors without an operator present. The results of this analysis corroborate the findings from passenger surveys indicating a justified lack of sense of security at this hub. Additionally, there are two unlit passages within the structure of the examined integrated transfer hub, which were flagged and recorded under indicator W6, responsible for road safety.

All bus vehicles operating within the integrated transfer hub have electric drivetrains, which are emission-free, allowing the first component of indicator W9 to meet requirements. The average waiting time (delays) for transportation is 10 minutes. Surveyed passengers also indicated numerous inconveniences at the integrated interchanges location due to frequent traffic jams and congestion, which additionally hinder timely bus arrivals. Passengers rated their satisfaction with delays at an average of 3.5 on a 5-point scale, which corresponds to 70% (indicator W9.2). The value of indicator W9.3 is 86%, reflecting the average satisfaction rating of 4.2 on a 5-point scale for using the ZWP.

Table 6. Indicators method integrated interchanges assessment based on example of International Bus Station Katowice

Indicator	Name	Accessibility Level [%]	Justification
W1	State of the node infrastructure	100	All stands and crossings meet ZTM guidelines
W2	Internal Integration (Coherence) of the nodes	85m 10m	With this indicator it is possible to calculate the average distance between platforms (stands/passages). In the case of long-distance bus stands it is 10m, while ZTM bus stands are 85m.
W3	Accessability for people with special needs	75	On the basis of Table 5, fulfilling a criterion was assumed for 1 point, not fulfilling a criterion for 0 points, and partially fulfilling a criterion for 0.5 points. he total sum of requirements is 65. 48.5 points were obtained for MDA and converted to [%].
W4	Internal logic of the node (legibility of the node)	100	All sites meet the visibility criterion.
W5	State of personal security at the interchange State of road safety at the interchange Passenger information Additional functions present in the node	100	Video surveillance is in place throughout the transfer node and covers all sites.
		0	Detection of anything in the video footage is only possible by the operator.
		100	Within the hubs, lighting is available and sufficient for each stand
		0	There is a lack of uniformed staff/security/guards at the stands.
W6	Sustainability	78	Only two crossings on the whole site are not equipped with traffic lights (out of nine).
W7	State of the node infrastructure Internal Integration (Coherence) of the nodes Accessability for people with special needs Internal logic of the node (legibility of the node)	100	At each stand, both long-distance buses and ZTM, there are electronic dynamic bus stop information boards.
		100	At each ZTM stand, there are stands with fare information and plans of the interchange.
		100	As above. These are also in English.
		100	There are signs of a guidance signage system on the surface of the entire facility for turns and forks.

Indicator	Name	Accessibility Level [%]	Justification
W8	State of personal security at the interchange	100	All of the above are present on the integrated interchange.
W9	State of road safety at the interchange	100*	Electric buses run on the integrated hub surface at ZTM stations, however, there are no charging points or stations at this location. *point a) was taken as the highest value due to the lack of CO2 emissions from the vehicles.
		70	The average delay time for public transport vehicle measures is 10 minutes. Numerous traffic jams and congestion are present at the hub site during peak hours.
		86	The average rating on a 5-point scale for journey comfort was 4.2 which, on a percentage scale, is 86%.

5. CONCLUSION

Integrated transfer hubs are now common in Poland and are found throughout the country. Each of these hubs varies in terms of structure, types of serviced transportation, diversity of transport modes, and accessibility. Currently, a major challenge is the lack of unified standards for assessing and evaluating the accessibility of integrated transfer hubs for users with special needs. In the railway industry, standardization is easier due to common guidelines across Europe and globally. However, in road transport, especially in public mass transit, there are many different facilities that are incorrectly classified as integrated transfer hubs, such as regular bus stops, transfer centers, bus stations, or transfer nodes. The diversity in their construction and functions makes it difficult to create a universal assessment method.

Another challenge is the guidelines for sustainable development, gradually being implemented across Europe, encompassing three main aspects: economic, environmental, and social. To meet these expectations, an attempt has been made to develop a universal indicator-based method for assessing integrated transfer hubs. This method has been developed based on existing approaches, incorporating detailed data on accessibility for people with disabilities and sustainable development. Preliminary testing has been conducted at the International Bus Station in Katowice, located on Sądowa Street.

In the survey results presented, passengers generally expressed high satisfaction with using the hub (average rating 4.3/5.0). However, they frequently emphasized in interviews that personal and traffic safety aspects need to be re-evaluated and improved. The lowest average ratings (even as low as 3.5/5.0) suggest that this aspect requires urgent attention. Using an indicator-based method, survey findings were corroborated, noting that Indicator W5, which assesses personal safety, also showed low scores (even 0%).

The use of an audit/inspection form developed in previous studies identified gaps in solutions for people with special needs at the integrated transfer hub. Indicator W3, which assesses hub accessibility, similarly showed one of the lower values among all indicators (75%).

Thanks to the developed and presented method, it is possible to assess the integrated transfer hub across various aspects related to sustainable development and contemporary requirements. The method is intuitive and straightforward to apply, and with additional tools, it allows for detailed and precise analysis. Its universality and flexibility for modification and adaptation are advantages. Each indicator can be separately applied for individual analyses, enabling a comprehensive overview of the hub. It facilitates identifying critical points and areas needing immediate improvement.

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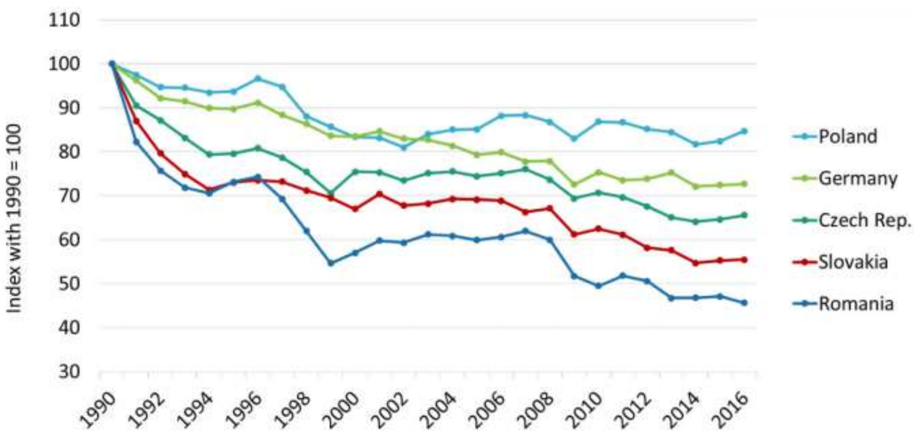
A low carbon growth of Slovakia

1. Introduction

As happened generally across formerly socialist economies, Slovakia's transition to a market economy had a co-benefit of sharply reduced carbon emissions. Slovakia's greenhouse gas emissions have fallen significantly in the last few decades. From 74 million metric tons of carbon dioxide equivalent in 1990, Slovakia's GHG emissions fell by 45 per cent by 2016. Even within Eastern Europe, where the closure of inefficient highly energy-intensive industrial plants during the transition to a market economy caused emissions to plummet, this was a strong performance. (Figure 1).

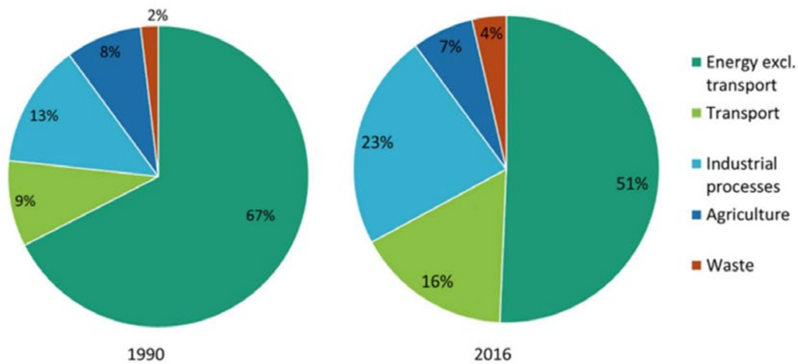
Figure 1. Changes in GHG emissions in Slovakia and four other EU countries, 1990 to 2016, index Slovakia´s emissions have declined significantly



Source: World Bank staff calculations based on EEA database.

Within Slovakia's declining emissions, its energy sector continues to dominate, but industry and transport emissions have risen in importance. The country's emissions continue to be mostly CO2. (Figure 3). The dramatic reduction of emissions from the energy sector has driven the sectoral trend in Slovakia's emissions profile. In contrast, those in other sectors have remained relatively unchanged, driving down the share of emissions from energy (excluding transport) from two-thirds of total emissions in 1990 to about half in 2016. Within energy emissions, about 60 per cent comes from coal-based electricity and heat generation. Industrial processes account for about one-quarter of today's emissions. They are generated mainly in the production of metal products (about half of industrial emissions) and minerals (about one-quarter) (Figure 2).

Figure 2. Greenhouse gas emissions by sector, 1990 and 2016, in % of total Industry and transport emissions, have grown in importance

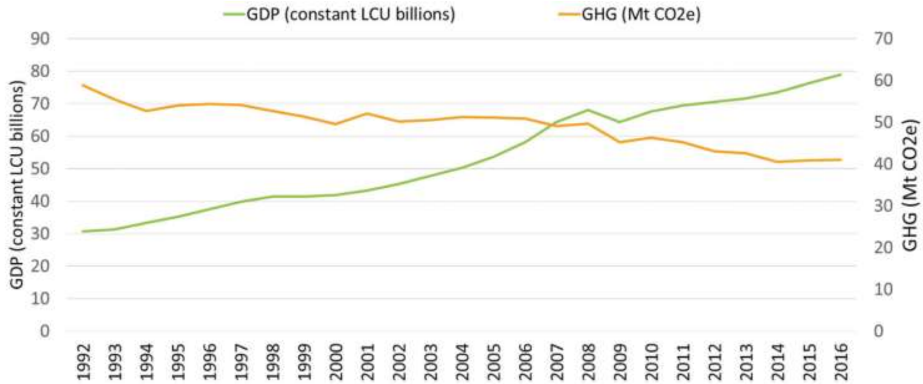


Source: World Bank staff calculations based on EEA database.

2. Analysis of the current situation

Importantly, Slovakia has made significant progress in delinking economic growth from emissions of greenhouse gases. From about 60 million metric tons of CO2 equivalent in 1992, Slovakia's emissions contracted at a slow but steady pace while output and income rose at a faster pace. At the same time, Slovakia's manufacturing sector was expanding to about a third of gross value added by 2010, nearly a 10 per cent increase from 1995. Further, the share of gross value-added of financial intermediation and real estate services fell from 20 per cent in 1995 to 15 per cent in 2010.3 These trends would tend to push up GHG emissions, but Slovakia's emissions continued steadily downward, demonstrating a delinking of growth from emissions that, unusual even in Eastern Europe, has continued unabated (Figure 3).

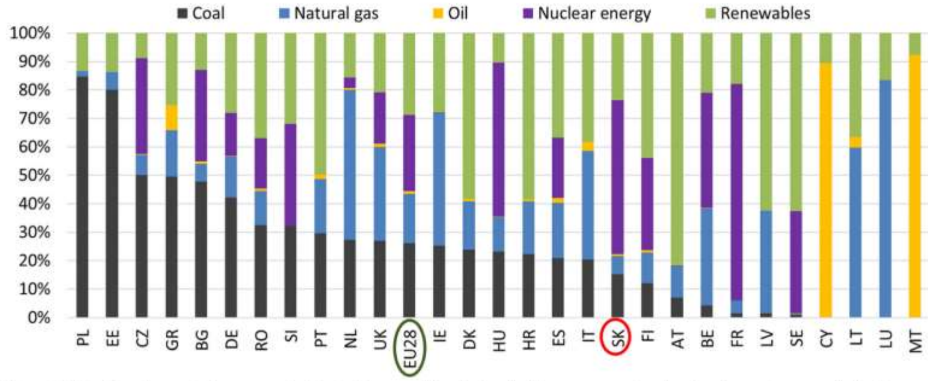
Figure 3. GDP and greenhouse gas emissions, 1992-2016, in constant LCU and MtCO2e
Slovakia has delinked growth from emissions



Source: GDP - WDI database, GHG - EEA database.

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. Poland has the most emissions-intensive electricity sector, with 85 percent coming from coal-fueled power plants. France has the largest share of nuclear power, generating 76 percent of its electricity, while Austria has the largest share of renewables in power, with 81 percent. The European Union on average generates 29 percent of its electricity from renewables, 27 percent from nuclear energy, and 26 percent from coal (Figure 4)

Figure 4. Gross electricity generation by source, Slovakia and EU members, 2015, % of total GWhe Slovakia depends mostly on nuclear power for electricity



Note: GWhe is gigawatt hour equivalent. Renewables include biomass-waste; hydro (pumping excluded) wind; solar; geothermal and other renewables.
Source: EU Reference Scenario 2016.

GHG abatement targets for the Slovak Republic are part of the EU 2030 package. Like every member state, Slovakia participates in the ETS. The high emissions intensity of the Slovakian economy argues that economic adjustment costs for energy-intensive (or ETS) sectors are likely to be high, but that intensity also may indicate that the country has a large potential for cost-efficient reduction in emissions (if adequate and well-informed policies and investments are implemented). Then, it faces non-ETS targets. According to the EC's July 2016 impact assessment,8 Slovakia's non-ETS targets are relatively high. Slovakia, despite having one of the best-performing EU economies since the global financial crisis, is expected to meet and exceed its 13 per cent non-ETS target for 2020 by a large margin. (As of 2017, non-ETS emissions stand 23 percent below 2005). The country's reduction target for 2030 for non-ETS, a reduction in GHG emissions by 12 per cent relative to 2005, may present some challenges.

The focus of the analysis summarized in this report is on the economic impacts of a low carbon growth path but, given the complexities and uncertainties involved, without the inclusion of several possible local co-benefits that could reduce overall costs. Such benefits may reduce the costs of low-carbon policy choices. For example, green tax reform proposes that higher tax revenues from a carbon tax might be used to reduce income taxes on labor which then, in turn, can reduce informality, broaden the tax base, and even boost growth. Further, policies that shift away from fossil fuels can provide benefits in terms of health, congestion, and road safety. Such benefits, which would require significant and complex additional modelling to quantify their impact on Slovakia, are not included in this analysis but, at a conceptual level, will likely be familiar to policymakers as they choose Slovakia's policies.

3. Policy scenarios to meet Slovakia´s climate commitments

The four decarbonization scenarios analyzed for Slovakia have been designed as contrasting combinations of energy efficiency and renewable targets, representing the trade-offs between targets. All scenarios include Slovakia's participation in the ETS, while each scenario differs in its targets for renewable energy and energy efficiency. To illustrate the trade-offs, an ambitious energy efficiency target is combined with a low renewables target (Decarbonization 1); median targets for renewables and energy efficiency are also analyzed (Decarbonization 2); a low energy efficiency target and an ambitious renewables target (Decarbonization 3) and moderate energy efficiency and very ambitious renewables (mainly in electricity) (Decarbonization 4). By design, each scenario achieves a similar reduction in GHG emissions (Table 1) and similar total energy system costs. (See Annex 1 for a non-technical explanation of the policy scenarios).

Table 1 Key Policy Targets and Outcomes by Policy Scenario, Decarbonization scenarios differ on targets for renewables and energy efficiency

Policy indicators	2015	2020	2030				
			Reference	DCarb1	Dcarb2	DCarb3	DCarb4
Total CO_2 emissions energy combustion (% change from 2005)	-27,29	-27,75	-27,75	-39,02	-40,80	-40,59	-41,48
ETS sectors, CO_2 emissions from energy (% change from 2005)	-30,78	-34,88	-38,40	-50,58	-53,46	-53,51	-54,99
Non-ETS sector, CO_2 emissions from energy (% change from 2005)	-21,39	-15,71	-9,91	-19,49	-19,42	-18,77	-19,66
Overall, RES share (%)	14,03	14,49	14,34	16,33	18,91	19,83	21,85
RES-H&C share (%)	14,16	13,24	14,04	16,89	20,65	22,07	19,55
RES-E share (%)	19,43	23,38	21,28	22,62	24,81	25,32	36,79
RES-T share (%)	8,26	10,05	10,20	11,49	11,74	11,80	13,12
Primary energy savings (%)	0,00	-20,16	-24,91	-30,32	-28,36	-27,25	-28,88

Notes: RES-H&C is a renewable energy source for heating and cooling. RES-E is renewables for electricity generation. RES-T is renewables in transport. Primary energy savings are compared to PRIMES 2007 baseline projections.

Source: E3-Modelling, CPS Technical Report.

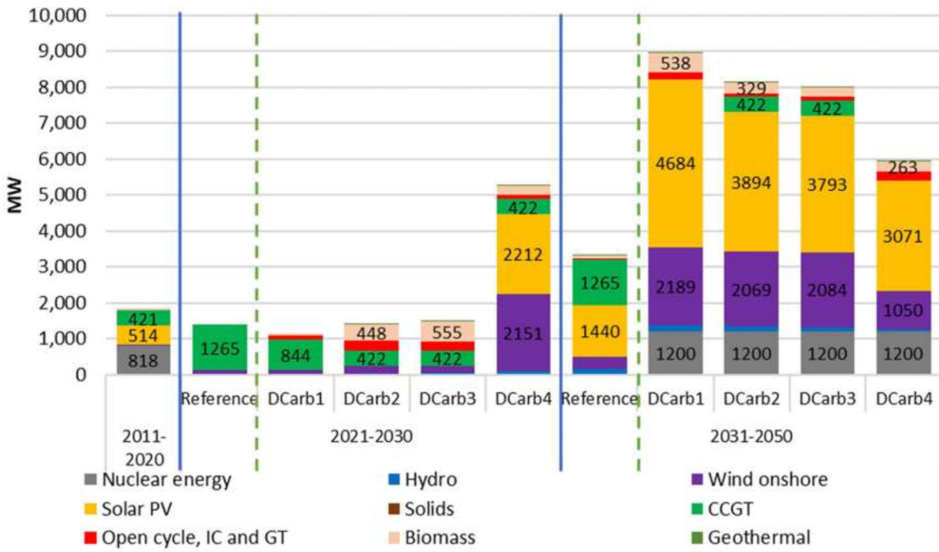
Modelling of decarbonization policies for the rest of the EU is pursued more simply. For the rest of the EU, the same level of detail in the modelling of decarbonization policies as for Slovakia is unavailable (because the CPS model covers Slovakia only). The cost of policies is imposed through the ETS CO2 price, common for all EU countries. The difference is that the response to such a carbon tax is modelled in a less explicit and detailed way than in the CPS model, i.e. using a top-down approach to the modelling of inter-fuel or capital-energy substitution. Emission reductions in non-ETS sectors for countries other than Slovakia were imposed, facilitated in a simplified way in the model by imposing an emission tax for those sectors (with the rate determined endogenously by the Slovak-CGE model). The assumed emission reductions versus the reference scenario were based on a comparison of policy simulations undertaken by the European Commission with the EU Reference Scenario 2016.

The two models are applied in a coordinated fashion, with the CPS providing detailed energy outputs to the CGE model. The CPS model is first solved to show the effects of decarbonization policies on the energy sector. Next, the CGE model run uses CPS results on energy intensities by sector and energy type (where intensity is measured either as energy use per unit of sector value added or per unit of GDP), investments in electricity and heat generation, electricity and heat generation mix, the average unit cost of electricity and heat generation, investments in energy efficiency, and energy use by fuel, by sector. The Slovak-CGE model also uses the CPS assumptions regarding the ETS CO2 price, which is uniform across decarbonization scenarios but significantly higher than in the reference scenario. The CGE simulation shows how output by sector adjusts, but these output changes are not iterated back to the CPS model (because the results were already similar). Consequently, energy demand levels are not identical between the CPS and CGE models, although energy intensities are identical (and the same relates to emissions). In this way, the CGE simulations show how the economy responds to a shock consisting of changes in the cost of energy and the choice of energy-related technologies (driven by carbon prices and other regulations).

4. Main findings

All four decarbonization scenarios involve the construction of a new nuclear generation capacity for Slovakia, continuing the importance of nuclear energy in the generation mix. This investment in nuclear displaces investment in CCGT compared with the reference scenario. The four decarbonization scenarios do differ in the extent to which renewables enter the generation mix. The importance of renewables increases from Decarbonization 1 to Decarbonization 4. Decarbonization 4 focuses on achieving the renewables target through the electricity sector and results in greater penetration of renewables, particularly wind. (Figure 5).

Figure 5. Newly installed capacity in electricity, by scenario, 2011-2050, in net MW, Investment in electricity capacity in the policy scenarios diverges from the reference scenario in magnitude and earlier solar PV



Source: E3-Modelling, CPS Technical Report.

Substantial investments in energy efficiency are also needed by businesses and households to achieve reductions in energy demand. For industries, such as heavy manufacturing, this involves focusing on the best available techniques through investment in heat recovery, processing and new equipment. For the tertiary sector (e.g. services sector), this mainly involves building renovations (i.e., improved insulation). Households undertake substantial house renovations to achieve the 2030 targets, while in the post-2030, there is a strong uptake of electric cars and fuel cell cars, replacing internal combustion engine cars. Notably, the electrification of the transport sector is common across scenarios since they are driven by policies at the EU level. The ambitious energy efficiency target of Decarbonization 1 compared to the other scenarios is reflected in the higher level of investment in building renovations by households and the tertiary sector, as well as higher investments in heat recovery in the industry (Table 2).

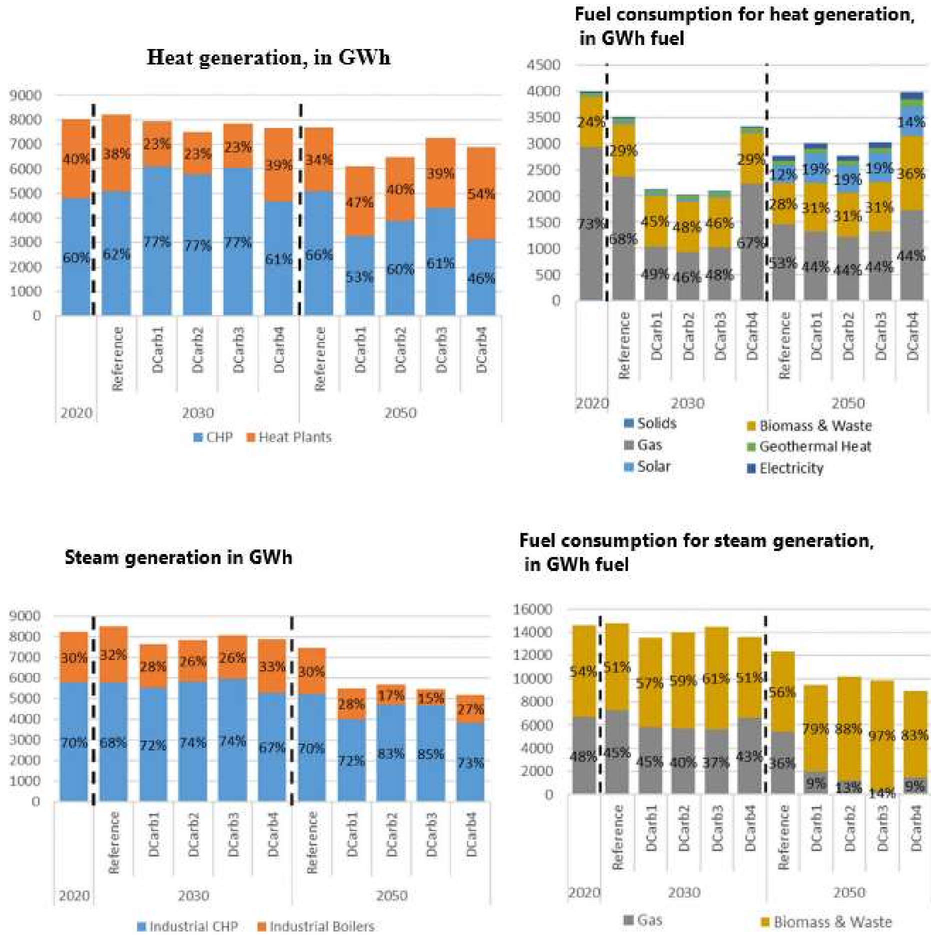
Table 2. Investments by subsector or type, by scenario, 2015, 2030 and 2050, in € millions and thousands of vehicles, Renovation, industrial heat recovery and electrification of transport allow Slovakia to meet its energy efficiency targets

	2015	2030					2050				
		Decarbonization scenario:					Decarbonization scenario:				
		Ref	1	2	3	4	Ref	1	2	3	4
Investment (M€)											
Heat recovery	–	115	954	292	116	85	126	1178	954	947	809
Processing	970	1555	1457	1470	1488	1490	1957	2234	2197	2198	2202
Equipment & Appliances	3429	7811	7865	7855	7856	7850	9811	9704	9698	9697	9702
Building renovation by households	–	257	3971	832	582	727	285	3498	1511	996	813
Passenger cars (thousands of vehicles)											
Electric cars	–	37	56	56	56	56	211	1641	1646	1643	1644
Fuel cell cars	–	0	0	0	0	0	73	350	347	350	347
ICE plug in cars	–	69	99	99	99	99	263	371	370	371	370
ICE cars	1754	2409	2357	2357	2357	2357	2561	1211	1211	1209	1212

Note: ICE are internal combustion engine passenger cars. Source: E3-Modelling, CPS Technical Report.

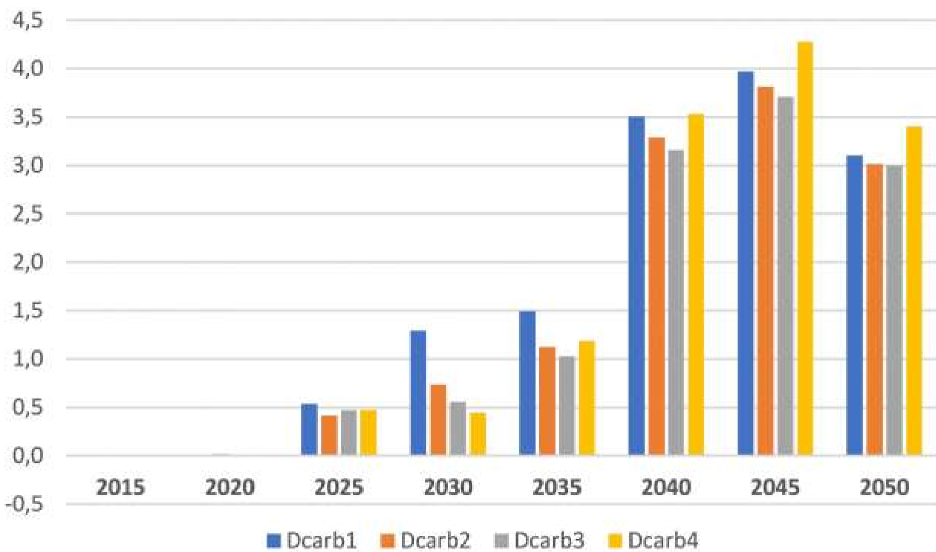
The demand for heat and steam declines in all the policy scenarios, driven by ever-rising energy efficiency. The demand for distributed heat maintains its position in share terms. The supply of distributed heat needs to comply with the rising ETS carbon prices and to deliver in terms of renewable targets. Cogeneration technology is more efficient than boilers, and thus the policy scenarios project that the CHP plants for heat production continue to have a significant place in the heat supply. However, they are changing fuels increasingly towards renewables and biomass. New clean heat production technologies emerge in the scenarios, such as electric boilers, high-temperature heat pumps and geothermal energy. Similarly, in the supply of industrial steam, cogeneration maintains its share but changes fuel in favour of biomass. Self-production of electricity in industry is less competitive in the long-term than under current conditions, since electricity generation, being subject to high ETS prices, transforms using RES and nuclear, putting downward pressure on prices for industrial electricity. Thus, industrial steam production declines in the long term and shifts strongly towards biomass boilers (Figure 6).

Figure 6. Heat and steam generation, levels and shares by generation source and by fuel, by scenario,2020, 2030, 2050 Biomass use for heat and steam and new clean heat production technologies expand under all scenarios



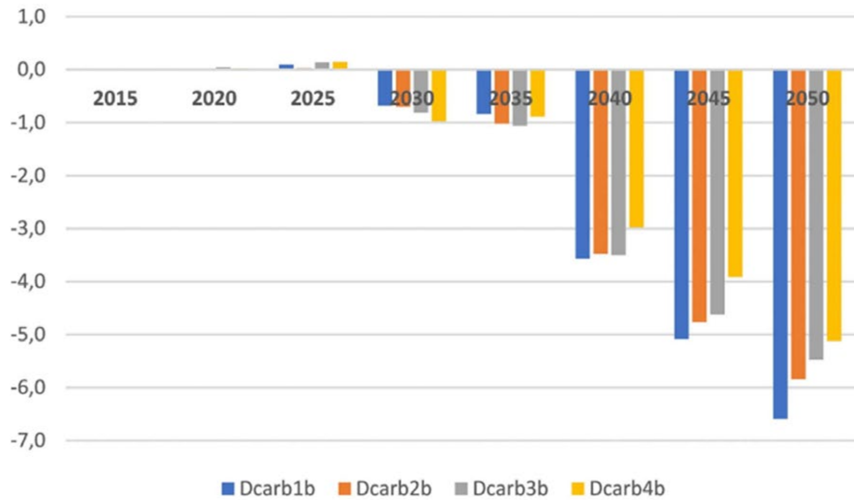
Moving to a low-carbon economy can potentially support higher GDP in the long term but could also lead to lower household consumption.18 Investments in energy efficiency reduce energy costs and lead to long-term gains in the productivity of the economy. In the short to medium term, these investments need to be funded. For industry and the tertiary sectors, these energy efficiency investments are passed on to consumers of their products in the form of higher prices. For households, they effectively fund the building renovations on their homes through a reduction in consumption. The cost of electrification in the transport sector is also felt by households, but this does not lead directly to a reduction in consumption. Rather, households replace their ICE (Internal Combustion Engine) vehicles with either an electric vehicle or a fuel-cell vehicle (Table 2). However, households are also affected by the higher prices passed on by businesses to reduce the cost of energy efficiency investments. Hence, all four scenarios involve a reduction of consumption (of three to six per cent compared to the reference scenario during 2040-2050). The fall in household consumption is largest in Decarbonization 1 since this scenario includes an ambitious target for energy efficiency which requires the largest investment. Notably, the size of the investment needed in electricity generation is dwarfed by the investments needed to improve energy efficiency. Overall, GDP increases above baseline by approximately 0.5 to 1.0 per cent during 2025-2035 and by three to four per cent during 2040-2050 (Figure 7, Figure 8, Figure 9).

Figure 7. GDP, by policy scenario, 2015-2050, in % change from reference scenario, GDP impact is positive in the medium-term for Decarb1 and for all policy scenarios over the long-term



Source: Slovak CGE model results

Figure 8. Private consumption, by policy scenario, 2015-2050, in % change from reference scenario, Consumption is reduced under all policy scenarios

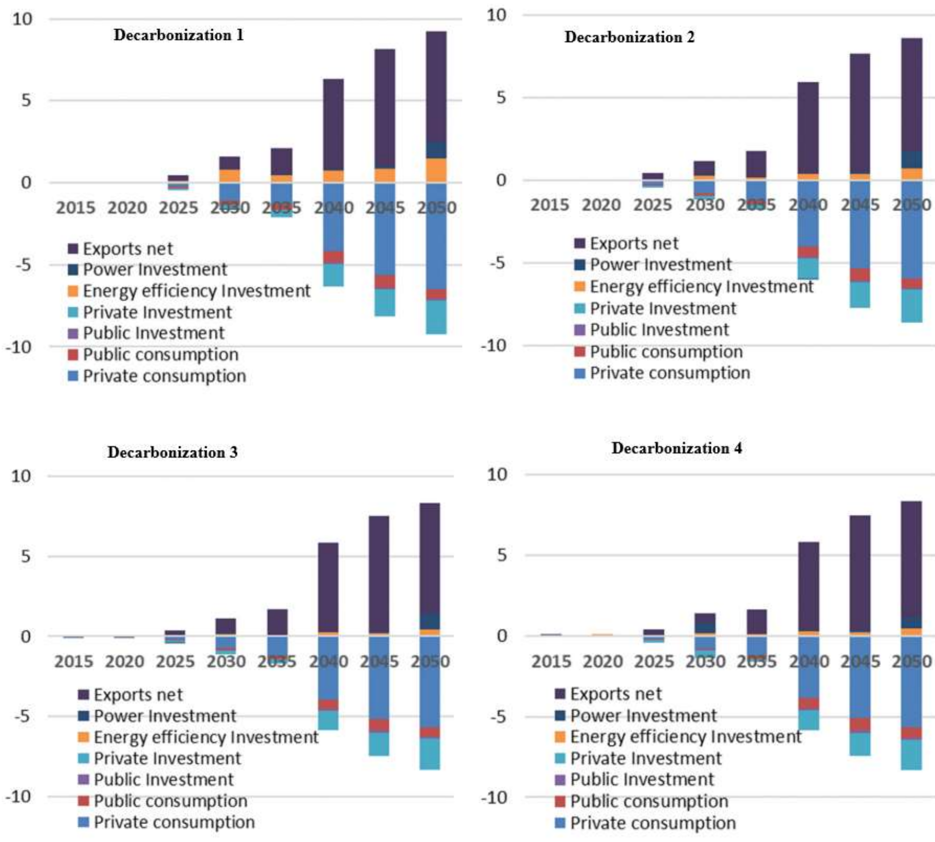


Source: Slovak-CGE model results.

Decreased demand for fossil fuels reduces Slovakia's import bill; however, the terms of trade also deteriorate. The worsened terms of trade imply that – from the macroeconomic perspective – more factor resources need to be used for export activities to trade for a given amount of imported goods. Consequently, imports drop further, while exports increase. The increase in net exports, related to terms of trade deterioration, "consumes" the GDP gain, stemming from productivity (energy efficiency) improvement and contributes to the drop in private consumption.

There can be some crowding out of non-energy investment, as Slovakia focuses on investing in decarbonization. Energy efficiency and power sector investments are significant – from 0.3 to over 2.0 per cent of GDP across scenarios and years. The increase in prices as firms recoup the cost of investing in energy efficiency reduces Slovakia's competitiveness and impacts the firm's profitability. In addition, the fall in household consumption reduces demand, also creating a drag on profitability. The reduction in profitability discourages foreign investors from investing in the Slovak economy. Similarly, investment in electricity generation crowds out some non-energy investments.

Figure 9. Expenditure shares in GDP, by policy scenario, 2015-2050, in % change from reference scenario, Net export shares are boosted over the long-term, more than compensating for reduced consumption



Source: Slovak-CGE model results

Changes in industry outputs are affected by the shift in the structure of aggregate demand. The drop in consumption lowers the demand for market services (including both personal services and trade services) and transport services. Market services' share of value-added is lower by 1.8 to 2.2 percentage points in the decarbonization scenarios compared to the reference scenario in 2050. Decarbonization does lead to a reduced importance of some heavy manufactures such as chemicals, rubber and plastic sector and iron & steel. Iron & steel experiences high extra investment cost, leading to significant price increases, and petroleum refining faces lower demand for oil fuels. On the other hand, in some other cases – notably the non-ferrous metals sector – the energy system cost actually drops as a result of decarbonization policies, leading to price decreases and output expansion. Moreover, the increased cost of energy efficiency investment for heavy manufactures is mitigated by lower labor costs, related to lower wages, or – more generally – real depreciation that the Slovak economy experiences as a result of decarbonization policies. Motor vehicle manufacturing maintains its importance in the Slovak economy across all four scenarios. The implicit assumption is that the Slovak motor vehicle manufacturing industry would shift towards the production of electric vehicles in line with demand. Households and the transportation sector purchase electric motor vehicles rather than traditional motor vehicles; hence the industry's share of value added is stable across reference and policy scenarios. The results for industries supplying investment goods are rather mixed. In the decarbonization scenario which involves substantial investment in building renovation, the construction sector expands. Construction is boosted by the renovation of buildings, both by households and businesses. However, in the remaining scenarios, the crowding out of private investment outweighs the boost from the decarbonization-related investment (Table 3).

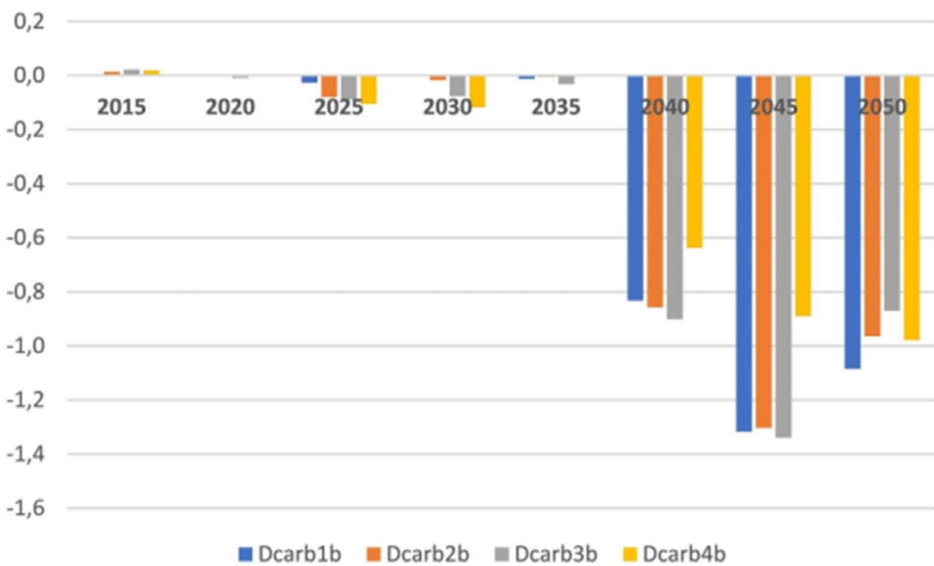
Table 3. Value added shares in GDP, by sector and policy scenario, 2030 and 2050, in % change from reference scenario Industry responds to the altered structure of GDP

Change in share of value added (in percentage points) by policy scenario	2030				2050			
	Decarb1	Decarb2	Decarb3	Decarb4	Decarb1	Decarb2	Decarb3	Decarb4
Agriculture	0,01	0,06	0,07	0,03	0,08	0,11	0,11	0,08
Energy	-0,06	0,17	0,26	0,61	0,97	1,02	1,04	1,06
Other manufacturing	-0,03	-0,04	-0,05	-0,08	0,75	0,78	0,80	0,84
Chemical, rubber, plastic	0,08	0,04	0,02	0,10	-0,24	-0,23	-0,22	-0,23
Non-metallic minerals	0,01	0,01	0,01	0,01	0,10	0,11	0,11	0,11
Iron and steel	0,03	0,01	0,00	0,04	-0,18	-0,16	-0,14	-0,15
Non-ferrous metals	0,02	0,02	0,01	0,01	0,15	0,15	0,15	0,14
Motor vehicles	-0,07	-0,05	-0,04	-0,11	0,25	0,22	0,22	0,24
Equipment	0,00	0,02	0,04	-0,05	0,17	0,17	0,17	0,17
Construction	0,38	0,08	0,01	0,06	0,62	0,22	0,06	0,01
Transport	-0,01	-0,01	-0,01	-0,05	-0,41	-0,39	-0,39	-0,39
Non-market services	-0,03	-0,03	-0,03	-0,05	-0,03	-0,02	-0,01	-0,04
Market services	-0,33	-0,28	-0,30	-0,52	-2,22	-1,98	-1,90	-1,83

Source: Slovak-CGE model results

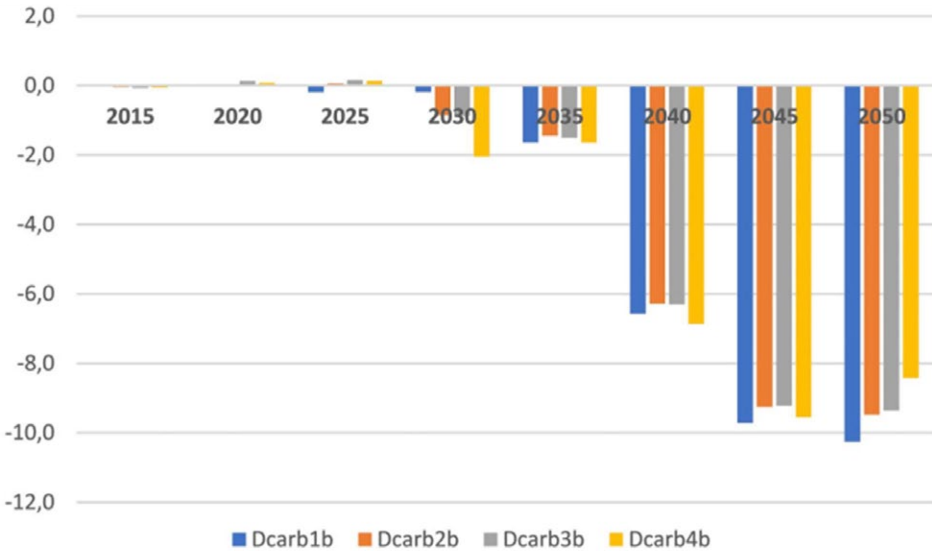
The changes in the industry structure of the economy lead to a reallocation of labour across industries. As can be expected, sectors that expand (mainly export-oriented industries and industries supplying investment goods) attract additional labour, whilst those that contract (mainly industries producing consumption goods) release labour. However, not all workers who are made redundant from contracting sectors can find work in expanding sectors, leading to an increase in unemployment. Overall, structural change in the economy in response to decarbonization policies seems to be negative for aggregate labour demand. In the short run (due to lagged wage adjustment), decreased labour demand translates mostly to lower employment. In the long run, by comparison, this translates mainly to decreased wages. The latter effects are substantial and dominate, especially towards the end of the projection period (Figure 10, Figure 11).

Figure 10. Total employment, by policy scenario, 2015-2050, in % change from reference scenario, Labor is reallocated towards expanding sectors, but unemployment rises



Source: Slovak-CGE model results.

Figure 11. Real wages, by policy scenario, 2015-2050, in % change from reference scenario, Wages fall over the long-term as the labor market adjusts



Source: Slovak-CGE model results.

A LOW CARBON GROWTH PATH: RECOMMENDATIONS

A GROWTH PATH TO 2050 WHILE LOWERING EMISSIONS

The scenarios generated by the CPS and Slovak-CGE models show Slovakia achieving its mitigation targets rather easily. The large use of hydro resources and biomass is behind the easy achievement of the renewables target, whereas gross energy consumption grows very moderately in Slovakia due to the energy efficiency progress achieved in parallel, manifested by an improvement of the energy intensity of GDP. Despite the lack of additional policies supporting the use of renewables, the renewables share follows an ascending trend over time due to the rising EU ETS carbon prices. The ETS carbon prices affect the power sector, as well as the energy-intensive industries and constitute the main driver for carbon emission reduction.

The reference scenario projects energy-related CO2 emissions to decrease. Energy emissions fall by 1 percent and 11 percent in 2030 and 2050, correspondingly, compared to the 2015 levels. This is mainly achieved by the CO2 emission reduction of the ETS sectors, the power sector and the energy-intensive industries. The power sector, being subject to ETS, decarbonizes significantly mainly due to the commissioning of new nuclear reactors and the moderate development of renewables. Thus, power sector emissions are 19 percent lower in 2050 compared to 2015 levels. The industrial sectors also decarbonize, reducing emissions by 24 per cent in 2050 compared to 2015, due to efficiency improvements and changes in the fuel mix in energy-intensive industries.

In the reference scenario, non-ETS sectors, by comparison, do not face a carbon price, and no energy efficiency and other policies beyond 2020 are assumed. Nonetheless, the long-lasting effects of energy efficiency policies focusing on 2020, the eco-design and car standards, and the market-driven energy productivity improvements sustain a downward trend in carbon emissions in the non-ETS sectors over the medium term, mainly until 2035. In the longer term, the absence of additional policies in the reference scenario and sustained economic growth pace outrun the technical efficiency progress of new equipment, causing CO2 emissions to trend up from 2040 onwards in the non-ETS sectors.

Looking across the policy scenarios, all exhibit the same effort towards reducing CO2 emissions over time. The CO2 emissions in Slovakia decreased by 65 percent in 2050, compared to 2015 levels, whereas in the reference scenario, the emissions decreased by only 11 percent. By 2030, CO2 emissions decrease by 18 percent compared to 2015. The variation is small across the policy scenarios, by assumption. A less ambitious RES target combines with a more ambitious efficiency target, and vice versa in the definitions of the policy scenarios.

The EU ETS price trajectory drives the emissions reduction in the ETS sectors, which represent the largest part of total CO2 emissions. The introduction of a new nuclear reactor and the deployment of renewables enable the decarbonization of the power sector, which plays a significant role in the ETS emission reduction. In the non-ETS sectors, the main drivers of the emission reduction are the energy efficiency policies, the technology standards and additional policies related to the transport sector (vehicle standards). The efficiency policies from a national perspective will have to focus mainly on facilitating the renovation of buildings over the entire projection period. The promotion of heat pumps and new uses of electricity drive accelerated electrification, which is more intense in the long-term due to electrification of road transport. The increase of the ambition of the policy scenarios regarding renewables implies varied penetration of renewables in the power sector and in the heating sector but do not vary in the transport sector.

The policy scenarios were designed to provide a contrasting mix of targets, to assess the impacts of setting different ambitions for the renewable and energy efficiency targets. Setting renewables (RES) and energy efficiency (EE) targets is at the discretion of national policy. The suggested range for the RES share in 2030 is 16.5 to 22 per cent. The baseline scenario projects 14 percent for the RES share in 2030. The suggested range for the energy efficiency target in 2030 is -30 to -29 per cent. The reference scenario projects -25 per cent for the energy efficiency target in 2030. From these numbers alone, it would be presumed that Slovakia needs considerable effort to achieve both RES and EE targets in 2030, above the business-as-usual trends reflected in the reference scenario projection.

The range of possibilities is larger for the RES target than for the EE target. For the latter, the most important policy focus must regard the renovation of buildings, which constitute the most important source of possible energy savings until 2030. The potential for savings in industry and transport, which are very significant, can only be deployed in the longer term. For renewables, there exists a trade-off between developing biomass or variable RES in the power sector. However, both are needed to develop significantly if the RES-share target is ambitious. Achieving energy efficiency targets by 2030 requires significant effort in the renovation of buildings.

The main outcomes in the scenarios can be summarized:

(i) Decarbonization of electricity generation is achieved through additional investment in nuclear generation and renewables.

(ii) More stringent efficiency policies drive down final energy demand in all demand sectors, except transport

(iii) The industry and transport sectors are the most significant among the demand sectors in terms of total energy savings, representing 60-80 per cent of total energy savings across policy scenarios

(iv) For the transport sector, the additional policies introduced across the policy scenarios are the same; thus, transport demand is similar across policy scenarios. Emissions standards for cars and vans and efficiency standards for trucks, along with the electrification of transport and the increased use of biofuels, enable a significant reduction of energy demand in the transport sector. However, any decarbonization scenario for Slovakia requires electrification of the transport sector in the long term.

(v) In the industrial sector, the reduction in energy demand increases as more ambitious efficiency policies are implemented, with rising energy efficiency during 2025-2035. After 2035, the energy savings of industry are not significantly different across scenarios, indicating that it is the rising EU ETS price that is the main driver of investment in more efficient technologies.

(vi) Funding these investments will lead to a reduction in household consumption but create opportunities in industries supplying investment goods such as construction.

STRATEGIC CONCLUSIONS FOR POLICYMAKERS

The analysis undertaken via modelling of the macroeconomy and the energy sector as well as other investigations identified possible low carbon growth paths for Slovakia but also identified issues that merit strategic consideration by policymakers. These issues are likely to include gaps in data and knowledge, uncertainties such as the speed of technological change and future global and regional developments, and a variety of tradeoffs related to the costs of mitigation actions, implementation difficulty, timing, and many others. The energy and macroeconomic models should serve as valuable tools for the ongoing assessment of mitigation options for Slovakia.

The newly adopted EU targets of 32 percent for renewables and 32.5 percent for energy efficiency in 2030 are higher than assumed in this analysis. After the completion of this analysis, the European Union finally adopted targets of 32 percent and 32.5 percent for RES and EE respectively. These are higher than the targets assumed in the Slovakian policy scenarios explored in this study. Most likely, the new EU targets imply that Slovakia will be obliged to adopt ambitious targets for both RES and EE, for example, 22 percent for RES and 30 percent for energy efficiency. The findings of the analysis presented here suggest that both biomass and variable renewables will have to develop, accompanied by the strongest possible policy promoting the renovation of buildings to the horizon of 2030.

A scenario approach is used to assess alternative settings of targets related to Slovakia's national strategy for climate mitigation. The choice of the mix of targets is not simplistically the result of cost minimization since the best choice also depends on non-economic criteria. Security of energy supply, implementation feasibility, political constraints, social acceptance, and economic affordability for more vulnerable economic classes are among the criteria to consider in addition to system cost minimization. The modelling is able to quantify performance on some of these criteria in addition to costs, such as energy dependence on imports, system reliability, and consumer tariffs. The modelling is able to include implementation difficulties, social acceptance, and other restrictions on the cost-potential curves of resources, such as nuclear siting or renewable resource availability. A full accounting of performance against multiple criteria can be handled practically by quantifying alternative policy scenarios (which contain alternative targets).

The policy scenarios were designed as contrasting and stylized mixes of targets, to assess the impacts of setting different ambitions for Slovakia's renewable energy (RES) and energy efficiency (EE) targets. Setting renewable and energy efficiency targets is at the discretion of the national policy. For a national plan to be acceptable to the EU, low ambition on one target must be compensated by high ambition on the other target. The modelling considers synergies between the targets, since energy efficiency (e.g., heat pumps) may also enable higher renewables and vice versa. In addition, high performance in energy efficiency reduces energy consumption, which reduces the denominator of the RES shares, facilitating the achievement of higher RES targets. Despite the complementarities considered in the modelling, the two targets require very different policy frameworks, and in this way, the targets conflict with each other from a policy implementation perspective. Some of the efficiency-enabling policies, such as car standards and eco-design regulations, are not at the discretion of the national government and instead result from Europe-wide decision-making. Nevertheless, policies supporting efficiency in buildings, some transport policies, and support schemes for RES, heat pumps and other technologies and fuels, including biomass, are subject to national jurisdiction. The ETS carbon price is determined at a pan European level, and Slovakia is a price-taker from this market. National performance in the non-ETS sectors, which is subject to a national target difference for each EU member, derives from the choice of targets for energy efficiency and renewable and the ambition of non-CO2 GHG emissions reduction.

Four policy scenarios are assessed and compared against a reference scenario (with no new policies). The policy scenarios can be simplified as: (i) a low energy efficiency and high-RES scenario; (ii) a high target for energy efficiency and low RES scenario; (iii) a middle case scenario; and, (iv) a scenario with very ambitious RES (mainly renewables in electricity generation) and less energy efficiency (Table 8).

Table 4. Decarbonization scenarios by renewables and energy efficiency target intensity, A simplified view of the decarbonization scenarios

Scenario Name	Renewables target	Energy efficiency target
Decarbonization 1	Basic	Ambitious
Decarbonization 2	Median	Median
Decarbonization 3	Ambitious	Basic
Decarbonization 4	Very ambitious (for electricity)	Basic

Source: E3-Modelling, CPS Technical Report

Several policies defined at the EU level are needed to achieve the EU's 2030 targets and are assumed as part of the scenarios analyzed here. The main policies are:

(i) ETS: Increase in the ETS carbon prices enabled by the Market Stability Reserve, assumed to apply without exemptions, except the leakage regulations for industry. It is exogenous in all policy scenarios, taken from the EUCO scenarios.

(ii) Renewables: Renewables support policies in various sectors expressed by raising the shadow value of RES in the electric model, in the heating sector and transport regarding biofuels. The RES value is the shadow value of an implicit minimum contribution of renewables per sector, which influences the decision-making of agents as a marginal benefit of using renewables (per unit of energy). The scenarios assume different RES values per sector to represent different policy priorities of renewables development in the sectors.

(iii) Energy efficiency: Emphasis on policies supporting faster renovation of old buildings compared to historic trends and deep energy insulations in the renovated buildings. The model represents such policies by raising the energy efficiency value, which stands for the shadow value of a virtual constraint on energy savings in the heating of buildings, and acts in the model as a marginal benefit per unit of energy consumed due to energy savings. The energy efficiency policies also include strict building codes for new constructions, the promotion of heat recovery and the best available techniques in the industry, infrastructure and soft measures enabling higher efficiency in the transport sector and the EU-wide measures that include car standards and eco-design regulations.

(iv) Transport policies: The main policy measures are not at the discretion of national policies, such as the CO2 car standards (70-75 gCO2/km in 2030, 25 in 2050) and for Vans (120 in 230, 60 in 2050), the efficiency standards (1.5% increase per year) for trucks. However, infrastructure and other transport policies improving the efficiency of transportation in cities and the logistics are at the discretion of national policies.

(v) Enabling conditions: The scenarios assume a reduction of uncertainty and consequently a decrease in received costs for new technologies and efficient appliances, accompanied by a removal of barriers to investment in house renovation and other similar actions in various sectors, which influence decision-making as hidden costs. The removal of barriers also implies a reduction of discount rates used in the decision of capital-intensive energy-efficient equipment and investment. Finally, the scenarios involve new infrastructure facilitating the charging of electric vehicles, smart systems, grids facilitating the development of renewables, higher learning rates of new and advanced technologies (that take place at a pan–European level), and positive anticipation of the rising ETS prices in the future.

Complementary national policies will also be needed for the policy scenarios. In addition to the national policies included in the Slovak reference scenario, the policy scenarios include the following national policies:

(i) Earlier decommissioning of solid-fired utility power plants: Vojany and Novaky power plants are assumed to decommission in 2025 and 2023 respectively.

(ii) RES support scheme in power generation: Eligible RES technologies are Solar PV, wind onshore turbines and biomass. The scenarios assume a support to 50MW in the period 2021-2025, followed by the support of another 500MW based on auctions.

(iii) Further development of nuclear energy is possible based on economic optimality

(iv) Carbon capture and storage is excluded.

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Sustainable Transport: Dilemma or Revolution?

Theoretical introduction

Sustainable transportation

Environmental pollution effects have been observed for many decades. In response to these effects, more sustainable and smart cities (smart cities) have been developed. People are increasingly migrating from rural areas to cities, which positively influences urban and economic development but also contributes to the growth of transportation. This, in turn, can lead to increased emissions and a higher number of road accidents. The reasons for the rise in road accidents include a lack of consistent traffic regulations, poor road infrastructure quality, insufficient financial resources allocated to transportation development, lack of driving skills among drivers, traffic congestion (including pedestrian and bicycle traffic), and adverse weather conditions [3, 7, 14].

Smart cities, aligned with the 2030 Agenda for Sustainable Development, aim to use information and communication systems alongside other technologies to tackle challenges faced by urban areas, offering sustainable and efficient solutions. These cities address citizens' needs to improve the quality of services provided. One major challenge for smart and sustainable cities is improving mobility, particularly through the implementation of smart urban mobility that utilizes communication technologies. These technologies aim to provide affordable, efficient, attractive, and sustainable

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services for residents who are passengers. Key objectives include increased mobility efficiency, enhanced safety, and reduced pollution and energy consumption.

Smart mobility encompasses various modes of transportation such as public transport, vehicle sharing, private vehicles, and ride-hailing. Each of these solutions has been modified to reduce drawbacks and align with sustainable goals. Public transport faces challenges such as overcrowding during peak hours and frequent delays. Private vehicles generate significant congestion, reducing road traffic flow. Limited access to shared or rental vehicles previously hindered connectivity and reduced interest among passengers. A revolution in sustainable transportation came with the introduction of information systems and mobile applications, enabling better user coordination and broader reach [1, 7, 8].

Urban areas have been adapted to encourage cycling and walking, aimed at combating the decline in physical activity. To this end, numerous cycling and walking paths, trails, bike parking areas, and other infrastructure elements have been developed in many cities. Active and dynamic sustainable transportation methods are widely discussed in scientific publications, often accompanied by analyses of cyclist and pedestrian safety.

The development of sustainable urban mobility is promoted in many countries through campaigns, community meetings, advertisements, promotional activities, and demonstrations of applications or systems. The most effective form of promoting urban mobility has proven to be local authorities and organizations engaging in dialogue with city residents [2]. Information systems and mobile applications should ensure equality among users in terms of age, gender, income, and health [6].

Road transport contributes to 24% of CO2 emissions (2020 IEA study) and generates noise and air pollution (including chemicals like PAHs, PCBs, particulate matter, and suspended particles) [8, 9]. Sustainable transportation and development are based on three pillars: social, economic, and environmental. Related topics include social exclusion, improved governance, climate change, biofuels, and vehicle sharing.

Social goals of sustainable transportation include ensuring basic accessibility, meeting safety and health needs, and improving equality, affordability, and transport options. Sustainable social development in transport systems has a profound impact on societal and economic factors, including employment, health, education access, and overall well-being [4, 13].

MaaS (Mobility as a Service) is a concept aimed at combining various forms and types of transportation to meet travel needs. MaaS research is relatively new and continues to evolve, focusing on platforms that allow users to plan journeys, purchase integrated tickets, and use convenient payment methods. Recent studies (2019–2021) indicate that integrating passenger and freight transportation could improve efficiency and sustainability. A variation of this concept, eMaaS, involves using electric vehicles or electric scooters [8].

Urban transport systems have a significant impact on sustainability. Achieving sustainable development goals requires substantial changes, including:

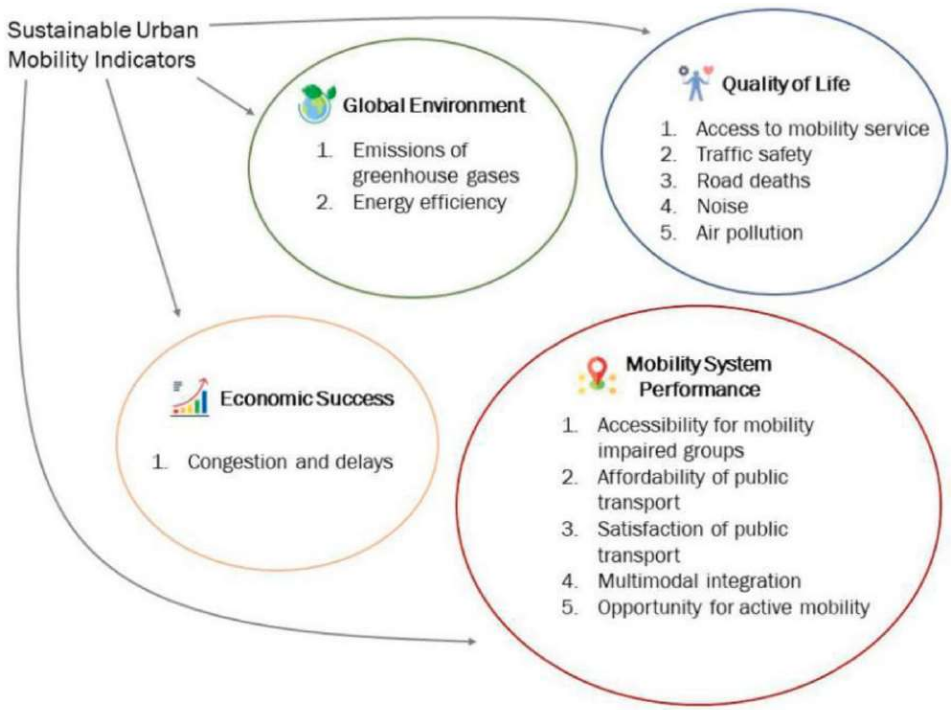
- Implementation of modern emission standards.
- Mandatory use of sensors and regular compliance monitoring.
- A shift in public transport approaches, emphasizing its importance and status.
- Development of environmentally friendly public transport modes, such as trams.

These measures will make cities more environmentally friendly and convenient for all residents, solving issues related to motorization, urban congestion, and promoting greener, more sustainable urban areas [11].

An important element of sustainable development is achieving goals through task implementation and indicator evaluation. There are four groups of Sustainable Urban Mobility Indicators (SUIMI) [12] (Fig.1):

- Global Environment: greenhouse gas emissions, energy efficiency.
- Quality of Life: access to mobility services, road safety, traffic accidents, noise, air pollution.
- Economic Success: congestion and delays.
- Mobility System Efficiency: accessibility for individuals with specific needs, affordability and availability of public transport, satisfaction with public transport, multimodal integration, opportunities for active mobility.

Figure 1. Sustainable Urban Mobility Indicators



Carbon Footprint

What exactly is a "carbon footprint"? It seems there is no clear definition of this term, and ambiguities remain. It refers to a specific amount of greenhouse gas emissions resulting from human activities, whether through production or consumption. In most cases, "carbon footprint" is used as a general synonym for carbon dioxide emissions or greenhouse gases expressed in CO2 equivalents [14].

Air pollution caused by transportation is particularly problematic in large metropolitan areas and other urban centers. The transport sector emits pollutants such as particulate matter, nitrogen dioxide (NO2), and polycyclic aromatic hydrocarbons (PAHs), which interact with other compounds to form harmful smog. Numerous studies confirm a strong correlation between the presence of air pollutants and the occurrence of specific diseases and phenomena, such as reduced life expectancy and high mortality rates. This issue is particularly significant for Poland, which ranks high among the most polluted countries in the EU.

Progress and Challenges in Reducing Pollution

In recent years, air pollution caused by transportation has decreased due to the use of less polluting technologies and the implementation of appropriate fuel quality and emission standards for vehicles. However, it remains concerning that permissible air pollution concentration standards are still high. All movement of people or goods consumes energy, and the most environmentally harmful energy is derived from burning fossil fuels. Therefore, the least energy-intensive forms of travel, such as walking or cycling, should be prioritized, followed by public transport. The most harmful modes are individual car and air travel. Road freight transport (trucks) produces the highest CO2 emissions – about three times greater than shipping and nine times higher than rail transport. Air transport, due to its high emissions, is rarely used for mass transportation. This underscores the need to invest in rail infrastructure and develop this mode of transport [14, 15].

Electric Vehicles and Carbon Emissions

Electric vehicles (EVs) have the greatest potential to reduce emissions, enabling a threefold reduction in carbon dioxide emissions. For EV adoption to increase, incentive systems encouraging their purchase are necessary. In Poland, the "Energy for the Future" policy, adopted in 2017, supports the development of electromobility. Besides environmental benefits, economic advantages, reduced travel times, and increased safety are provided by ecodriving – a smooth and deliberate driving style that is becoming increasingly popular in Poland. Ecodriving can reduce fuel consumption by 8–25%.

Packaging in Transport

Transport packaging also indirectly impacts the environment. A common issue is the significant presence of air (up to 25% of total volume) in shipments. Transporting "unnecessary" air contributes approximately 122 million tons of CO2 emissions annually [14].

Global Efforts Toward Carbon Neutrality

In 2019, the global "Net Zero Carbon" environmental program was launched, aiming to reduce carbon footprints across all services provided by participating enterprises. Key objectives include:

1. Achieving full carbon neutrality for direct impacts starting in 2020 (GHG Protocol – Scopes 1 and 2).
2. Achieving carbon neutrality for suppliers and customers by 2030 (GHG Protocol – Scope 3).

Electric Vehicles (EVs)

A growing wave of interest in electromobility has been observed, defined as a road transport system powered by electric energy. Achieving electromobility depends on solving significant technological challenges and societal shifts. EVs, including battery electric vehicles (BEVs), plug-in hybrid vehicles (PHEVs), and range-extended electric vehicles (REEVs), emit less CO2 compared to internal combustion engine vehicles (ICEVs), particularly when charged using renewable energy. EVs are also advantageous in terms of energy efficiency, energy security, lower operating costs, reduced noise, and decreased local air pollution. However, the overall impact on CO2 emissions depends on the energy grid used for charging.

Considering that 80% of the CO2 emissions increase over the past 45 years originated from road transport, the global adoption of electromobility is a critical strategy to reduce greenhouse gas emissions in the transport sector.

EV Market Growth

The demand for EVs is rapidly increasing, particularly in China and Europe. The transport sector accounts for over 20% of global greenhouse gas emissions, making it a key focus for climate change mitigation. In the EU, only 3.3% of energy consumption in transport is renewable. Therefore, replacing conventional vehicles with EVs is an essential strategy for sustainable transportation systems.

Barriers to EV Adoption

Despite their benefits, potential EV users express concerns related to:

1. Range Anxiety: Fear of insufficient battery range to reach destinations.
2. Charging Time: Long charging durations compared to the quick refueling of ICEVs.
3. High Initial Cost: The relatively high price of EVs.

EV Statistics and Future Outlook

As of 2019, the global EV market included over 10 million vehicles. Key developments:

- EV sales accounted for 50% of the market in Norway, 5% in China, and 2% in the US.
- In 2019, global EV sales reached 2.17 million, with China leading in absolute numbers.
- Preliminary data for 2020 indicated a 43% increase in global EV sales despite the COVID-19 pandemic.

While challenges remain, such as limited charging infrastructure and range anxiety, advancing battery technologies and supportive government policies will accelerate EV adoption. This transition is essential for reducing emissions and creating sustainable urban transport systems.

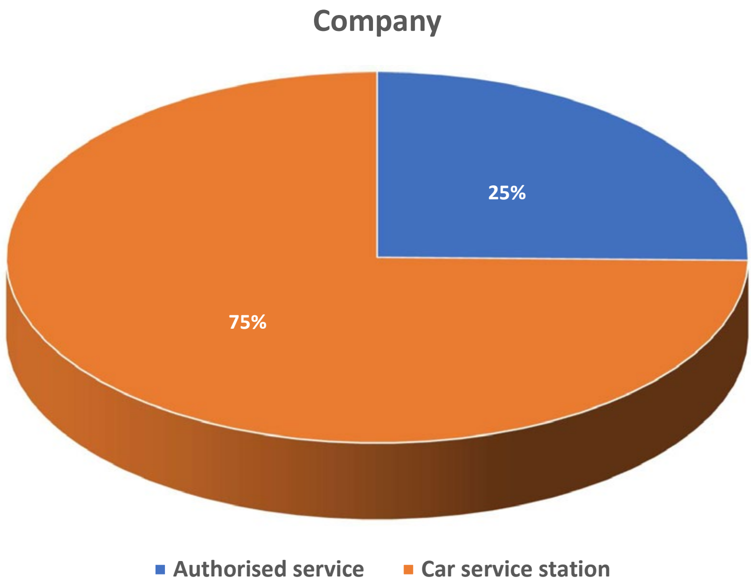
Methodology

The economic study of the repair and maintenance of electric, hybrid, and combustion vehicles was conducted using an online survey method. The survey was carried out in 200 workshops, authorized service centers, and companies with fleets of electric vehicles in the largest cities in Poland.

Results

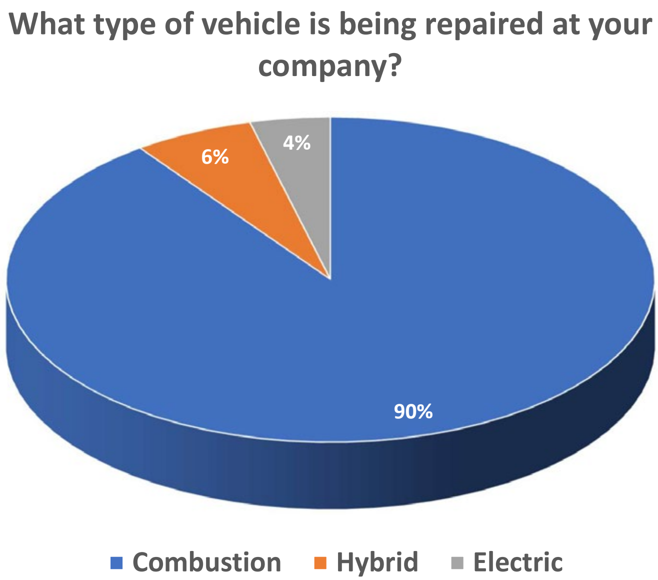
The chart indicates that **75% of services are performed by car service stations**, while only **25% are conducted by authorized services**. This suggests that car service stations dominate the market for vehicle repairs and maintenance, likely due to lower costs or easier accessibility. Authorized services, despite their smaller market share, may be preferred for specialized repairs or warranty-related work. This distribution highlights the importance of understanding customer preferences and competitive pricing in the automotive service sector.

Figure 2. Type of workshop or service



Based on the Figure 3, it is evident that the majority of repair companies focus on servicing combustion engine vehicles, which account for 90% of the vehicles repaired. Hybrid and electric vehicles constitute a smaller share – 6% and 4%, respectively. This indicates the dominant position of traditional combustion vehicles in repair services. However, the low proportion of electric and hybrid vehicles highlights the need to develop expertise and technical facilities for servicing modern technologies. The conducted survey revealed that combustion engine vehicles still dominate the activities of repair companies, accounting for 90% of all repaired vehicles. Hybrid and electric vehicles hold a significantly smaller share, which may be due to their lower market presence or limited servicing capabilities in this area. These results suggest that repair shops should focus more on developing services targeted at owners of electric and hybrid vehicles, especially given the growing interest in more environmentally friendly forms of transportation.

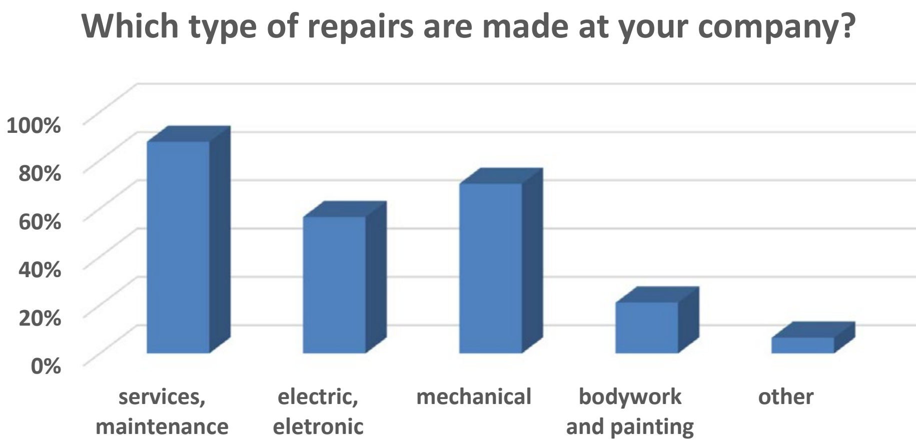
Figure 3. Type of repaired vehicle



Based on the chart (Figure 4), the most common type of repairs conducted by the surveyed companies is services and maintenance, representing nearly 100% of their operations. Mechanical repairs follow, with a significant share close to 70%, indicating a strong demand for traditional vehicle repair services. Electrical and electronic repairs are also common, constituting around 60% of the total. On the other hand, bodywork and painting services are less frequently offered, accounting for about 30%, while other types of repairs make up a marginal share of less than 10%.

This distribution highlights that companies primarily focus on general maintenance and mechanical repairs, reflecting the core needs of vehicle owners. However, the relatively lower emphasis on bodywork, painting, and other specialized repairs suggests that such services may be niche or offered by dedicated specialists rather than general repair shops.

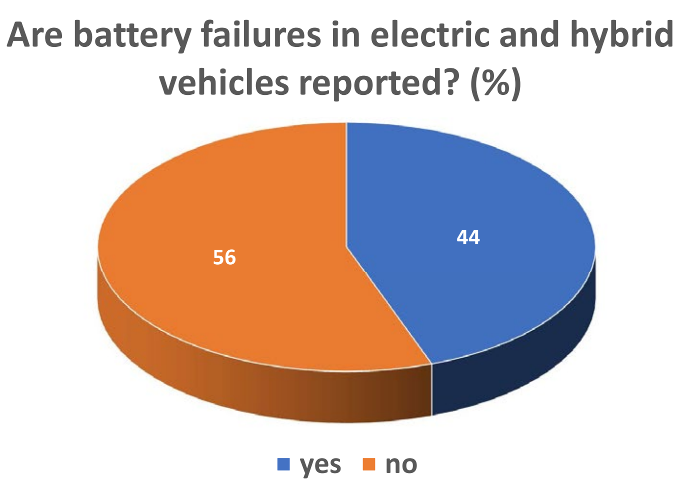
Figure 4. Type of repairs



Based on the Figure 5, 44% of respondents reported battery failures in electric and hybrid vehicles, while 56% did not experience such issues. This indicates that battery failures are a significant concern for nearly half of the surveyed population, highlighting the need for further investigation into battery durability and reliability in electric and hybrid vehicles.

The fact that more than half of the respondents did not report battery failures suggests that advancements in battery technology and maintenance practices might be effective in preventing issues. However, the relatively high proportion of reported failures emphasizes the importance of continued focus on improving battery performance and addressing potential weaknesses in electric and hybrid vehicle systems.

Figure 5. Battery failures in electric and hybrid vehicles



Tab. 1. Types of battery failures in electric and hybrid vehicles

Type of battery failure in electric and hybrid vehicles	Repair
faulty battery cell	exchange for new or reconditioned ones
	high-mileage exchange
	remote software update
lack of battery capacity	exchange for new
no contact/connection between the battery and other parts of the vehicle	
battery overload	

The table 1 outlines common types of battery failures in electric and hybrid vehicles, along with their corresponding repair solutions. Key observations are as follows:

1. Faulty battery cells are addressed through replacements, either with new or reconditioned batteries. For vehicles with high mileage, exchanges are specifically recommended, suggesting that wear and tear is a contributing factor to these issues.
2. Lack of battery capacity often leads to the need for remote software updates, indicating that such issues may sometimes be addressed through recalibration or optimization rather than hardware changes.
3. No contact or connection between the battery and other parts of the vehicle necessitates the replacement of the battery with a new one, implying a hardware failure that cannot be resolved through repairs.
4. Battery overload is similarly resolved by replacing the battery with a new one, pointing to severe damage that renders the existing battery irreparable.

These findings suggest that battery issues in electric and hybrid vehicles frequently require either replacement or software intervention. The focus on replacements highlights the importance of ensuring battery quality and durability during production, while the role of software updates indicates the need for advanced diagnostic and optimization tools to prevent or mitigate failures.

Tab. 2. Inspection/review requirements for electric/hybrid vehicles

What are the inspection/review requirements for electric/hybrid vehicles?	Hybrid vehicles	Electric vehicles
How often are reviews carried out?	Once a year / depends on needs, repairs	
How long does it take to complete the review?	Max 1 day	
What does the duration of the review depend on?	Depending on: – fault/failure – availability of parts, – make and model of vehicle – condition of the vehicle – location of the service	
After what mileage should the inspection be carried out?	As recommended by the manufacturer, usually after 12,000 km	As recommended by the manufacturer, usually after 2,000–30,000 km

Both hybrid and electric vehicles require inspections at least once a year. However, the frequency may vary based on needs or necessary repairs, reflecting the flexibility of maintenance schedules depending on vehicle condition and usage. The review process for both vehicle types takes a maximum of one day, ensuring minimal downtime for owners. This indicates an efficient inspection process that prioritizes quick turnarounds. The duration of inspections depends on several factors, including:

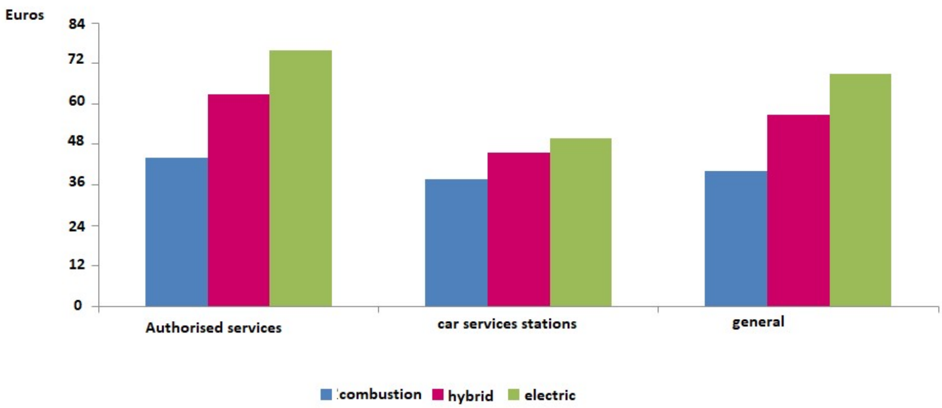
- The type and severity of faults or failures.
- Availability of replacement parts.
- The vehicle's make, model, and condition.
- The location of the service center.

This highlights the importance of well-equipped service centers and accessible supply chains to reduce repair times.

For hybrid vehicles, inspections are generally recommended after every 12,000 km, based on manufacturer guidelines. For electric vehicles, the mileage varies significantly, with inspections recommended between 2,000 and 30,000 km. This range may reflect variations in vehicle usage patterns or differences in manufacturers' designs and specifications.

Overall, the inspection and review process for hybrid and electric vehicles is structured to ensure regular maintenance, but specific requirements vary depending on the vehicle type, usage, and manufacturer recommendations. Ensuring the availability of skilled personnel and parts will be critical to maintaining efficient service operations.

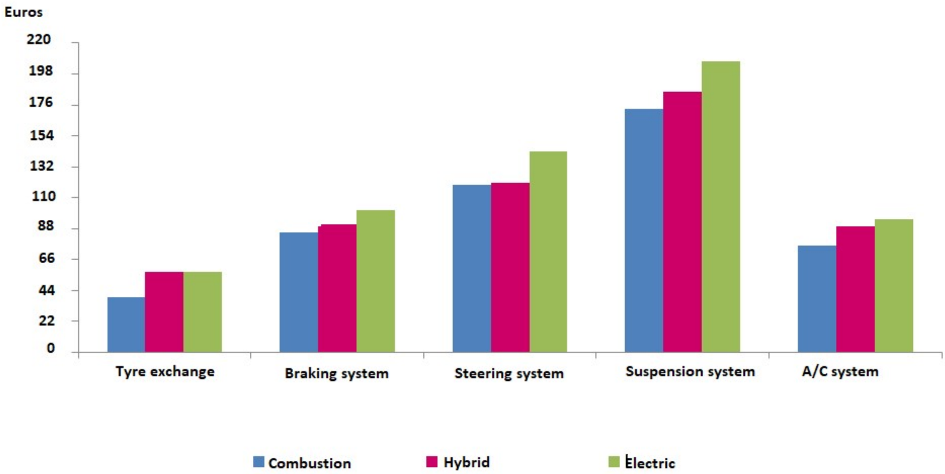
Figure 6. Average hourly repair prices for individual cars



For authorized services, the maintenance and repair costs for electric vehicles are the highest compared to other vehicle types, exceeding 70 Euros. Hybrid vehicles follow with slightly lower costs, while combustion vehicles have the lowest costs among the three categories (Figure 6). In general car service stations, the cost for electric vehicles remains the highest, followed closely by hybrid vehicles. Combustion vehicles still incur the lowest costs, indicating that traditional vehicle repairs are generally less expensive in non-authorized service centers. Across all types of services, electric vehicles consistently show the highest repair and maintenance costs, while combustion vehicles are the most cost-effective. This trend highlights the higher costs associated with newer technologies and specialized parts required for electric and hybrid vehicles. The cost of repairs for hybrid vehicles is higher than for combustion vehicles in all service categories but lower than electric vehicles. This suggests that hybrid technology, while less complex than electric, still demands more resources than traditional combustion vehicles.

These results underline the financial implications of owning electric or hybrid vehicles, especially in terms of maintenance and repair costs, which may act as a barrier to adoption for some consumers. As technology advances and becomes more widespread, these costs are expected to decrease over time.

Figure 7. Average prices for repairing individual vehicle components



The costs for tyre exchange are similar for hybrid and electric vehicles, and both are higher than for combustion vehicles. This indicates that tyre replacement for newer vehicle types may involve additional costs, possibly due to differences in vehicle weight or specialized components (Figure 7). Repairs or maintenance costs for the braking system are slightly higher for electric vehicles, followed by hybrid vehicles, with combustion vehicles having the lowest costs. This trend suggests that advanced braking technologies, such as regenerative braking in electric and hybrid vehicles, may lead to higher maintenance expenses. The costs for the steering system are highest for electric vehicles, followed by hybrid vehicles, while combustion vehicles have the lowest costs. This reflects the increased complexity or additional technology in steering systems for electric and hybrid vehicles. The suspension system shows the highest repair and maintenance costs for electric vehicles, followed closely by hybrid vehicles, with combustion vehicles incurring the lowest costs. This could be due to the additional weight of batteries in electric and hybrid vehicles, which places greater stress on suspension components. The costs for maintaining the A/C system are higher for electric vehicles, slightly lower for hybrid vehicles, and lowest for combustion vehicles. This suggests that advanced climate control technologies in electric and hybrid vehicles may be more expensive to maintain.

Overall, electric vehicles have the highest repair and maintenance costs across all systems analyzed, while combustion vehicles are the most cost-effective to maintain. This emphasizes the need for cost optimization in maintaining advanced systems in electric and hybrid vehicles to enhance their affordability and adoption.

Conclusion

Electric vehicles consistently incur the highest costs across various service categories, including authorized services, general car service stations, and specific system repairs (e.g., braking, suspension, and A/C systems).

Hybrid vehicles rank second in terms of maintenance and repair costs, while combustion vehicles remain the most cost-effective to maintain. The higher costs for electric and hybrid vehicles can be attributed to advanced technology, specialized parts, and additional labor associated with these systems.

Both hybrid and electric vehicles require annual inspections, but the mileage intervals vary significantly. Hybrid vehicles typically require inspections after 12,000 km, while electric vehicles have a broader range of 2,000 to 30,000 km, depending on manufacturer recommendations. The duration of inspections and reviews depends on several factors, such as fault severity, availability of parts, and service location.

For electric and hybrid vehicles, battery-related issues such as faulty cells, lack of capacity, or connection problems are common. Repairs often involve replacing batteries or software updates, indicating the need for continued advancements in battery technology.

Advanced systems like regenerative braking and complex steering mechanisms contribute to higher maintenance costs for electric and hybrid vehicles compared to traditional combustion vehicles. Suspension systems in electric vehicles incur the highest costs among all analyzed systems, likely due to the increased weight from battery packs. Tyre exchange and A/C system maintenance are also more expensive for electric and hybrid vehicles, reflecting the higher technical requirements of these vehicles.

The findings highlight the need for repair shops and service stations to adapt to the growing market of electric and hybrid vehicles by investing in specialized tools, training, and diagnostic equipment. Manufacturers should focus on reducing the costs of spare parts and improving the reliability of key components, particularly batteries, to make electric and hybrid vehicles more affordable to maintain.

While electric and hybrid vehicles currently face higher maintenance costs, technological advancements, economies of scale, and improved servicing practices are expected to reduce these costs over time. Repair shops should prepare for an increasing share of electric and hybrid vehicles in their service portfolios as the global shift toward sustainable and eco-friendly transportation continues.

In summary, although electric and hybrid vehicles present higher costs and unique challenges in maintenance and repair, these issues can be mitigated with technological improvements and greater expertise within the service industry.

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András Márton[1]

The role of electric cars in reducing greenhouse gas emissions in the V4 countries – Hungary's contribution

Introduction

The aim of the study on transport habits, preferences and incentives is to promote the uptake of sustainable and environmentally friendly transport, in line with the EU's plans for carbon-neutral electrification. In the European Union, including the V4 countries, the motorisation rate, i.e. the number of cars per thousand inhabitants, is steadily increasing (Eurostat, 2025). Economic analyses generally consider the increase in motorisation rates as a sign of growing prosperity, but pollutant and greenhouse gas emissions are rising accordingly, calling for action at national and international level. According to EU statistics, passenger cars are responsible for 14.39% of greenhouse gas emissions in the EU (EEA, 2025), so there is significant room for improvement in this area to achieve environmental sustainability and the EU's 'green' targets.

There is no consensus among media professionals and the public on the environmental benefits of electric cars, with some accepting and others rejecting the mitigation potential of the new technology. However, it is important to note that the literature on environmental sustainability and life-cycle environmental pollution considers e-cars to be "greener" (more environmentally friendly) than conventional

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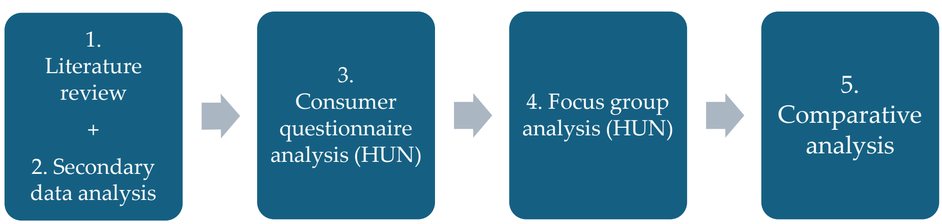
cars with internal combustion engines. In addition, a growing number of car manufacturers are committing themselves to producing more or only electric cars (e.g., Bentley, General Motors, Honda, Jaguar, Mercedes-Benz, Volvo, Volkswagen,[2] Ford, Fiat, Hyundai),[3] encouraged by EU environmental measures.

As a result, the spread of electric cars can be identified as an ongoing or even accelerating trend (particularly in China and Europe) with significant implications for the automotive industry, the industries concerned (suppliers, distributors) and other related industries such as insurance, finance, logistics, road and transport development, oil refining and trading, electricity generation and grid development. Both top-down and bottom-up factors play a role in driving this trend, such as environmental targets and regulations on the public side, evolving electric car technology and wider supply on the manufacturers' side, and changing car use preferences on the consumers' side. In this research we focus mainly on the corporate and consumer sides.

The aim of the research is twofold: to show (1) the environmental (GHG) significance of the electrification of passenger cars in the V4 countries and (2) what motivational factors may push consumers towards the purchase of electric cars (BEV and PHEV).[4]

To answer the research questions, a complex research design was developed, and a fitting methodology was chosen. A literature review and secondary data analysis were conducted to identify the current market situation and trends, showing the potential in the V4 region. To gain a targeted insight into individual consumer attitudes, a large sample survey was conducted in Hungary in 2021, and as a third step, focus group interviews were organised, during which Hungarian consumers further specified their needs, energy and future energy-related ideas. This shows that the results on motivating factors reflect the views of Hungarian consumers, but can also be extended to some extent to the other V4 countries.

Figure 1. Flowchart of the research



Source: Author

2 https://www.forbes.com/wheels/news/automaker-ev-plans/, accessed: 15.01.2025.

3 https://www.abc.net.au/news/2021-11-10/which-cars-going-all-electric-and-when/100529330, accessed: 15.01.2025.

4 The PHEV category includes passenger cars that can be charged from the mains and can cover a distance of around 20-50 km in pure electric mode, but are also equipped with an internal combustion engine.

1. Literature review

Academic publications on transport are diverse, both globally and regionally. The search has filtered out other areas of electromobility (e-scooters, e-bikes, electric buses) as well as the wider transport sector – except for passenger cars with internal combustion engines, which have been compared to e-cars. The technology of e-cars is evolving rapidly, so that publications from a decade ago can already be considered partly outdated. In our research, we have tried to use the most recent scientific results possible, but we have not automatically excluded studies published before 2015. Among the publications, we gave preference to articles on the uptake, usage patterns, charging preferences or economic aspects of e-cars, but also included some technology-type analyses in the literature collected.

The passenger car market is at a relatively early stage of the electrification process, with the overall world market share of e-cars currently at around 1.76% (IEA, 2023) and an average of 0.53% in the V4 region (European Alternative Fuels Observatory, 2025).

Table 1. Transport sector emissions in the EU27 and V4

Sector Name	Country	Emissions	Emissions per capita	Emissions per GDP (1000 EUR)	% of Transport	% of Total
		t CO2 equivalent	*t CO2 equivalent*	*t CO2 equivalent*		
1.A.3 – Transport	EU-27	803,284,009	1794.01	61.23	100.00%	25.60%
	Czechia	19,390,688	1816.93	97.21	100.00%	16.02%
	Hungary	15,075,423	1563.22	107.51	100.00%	28.59%
	Poland	69,332,714	1863.67	125.92	100.00%	20.10%
	Slovakia	7,778,848	1432. 07	86.90	100.00%	26.08%
1.A.3.a – Domestic Aviation	EU-27	13,105,055	29.27	1.00	1.63%	0.42%
	Czechia	12,493	1.17	0.06	0.06%	0.01%
	Hungary	15,461	1.60	0.11	0.10%	0.03%
	Poland	129,380	3.48	0.23	0.19%	0.04%
	Slovakia	1,493	0.27	0.02	0.02%	0.01%
1.A.3.b – Road Transportation	EU-27	763,725,753	1705.66	58.21	95.08%	24.34%
	Czechia	19,115,902	1791.18	95.84	98.58%	15.79%
	Hungary	14,875,898	1542.53	106.09	98.68%	28.21%

Sector Name	Country	Emissions	Emissions per capita	Emissions per GDP (1000 EUR)	% of Transport	% of Total
	Poland	68,685,087	1846.26	124.75	99.07%	19.92%
	Slovakia	7,664,391	1411.00	85.62	98.53%	25.70%
1.A.3.b.i – Cars	EU-27	451,486,083	1008.32	34.41	56.21%	14.39%
	Czechia	11,189,963	1048.51	56.10	57.71%	9.24%
	Hungary	8,382,935	869.25	59.78	55.61%	15.90%
	Poland	34,944,068	939.30	63.47	50.40%	10.13%
	Slovakia	4,579,248	843.03	51.15	58.87%	15.35%
1.A.3.b.ii – Light duty trucks	EU-27	92,236,314	206.00	7.03	11.48%	2.94%
	Czechia	2,404,596	225.31	12.06	12.40%	1.99%
	Hungary	2,218,120	230.00	15.82	14.71%	4.21%
	Poland	7,741,470	208.09	14.06	11.17%	2.24%
	Slovakia	860,934	158.50	9.62	11.07%	2.89%
1.A.3.b.iii – Heavy duty trucks and buses	EU-27	210,461,760	470.03	16.04	26.20%	6.71%
	Czechia	5,418,561	507.72	27.17	27.94%	4.48%
	Hungary	4,163,722	431.75	29.69	27.62%	7.90%
	Poland	25,751,856	692.21	46.77	37.14%	7.47%
	Slovakia	2,202,113	405.41	24.60	28.31%	7.38%
1.A.3.b.iv – Motor-cycles	EU-27	9,416,779	21.03	0.72	1.17%	0.30%
	Czechia	102,782	9.63	0.52	0.53%	0.08%
	Hungary	111,121	11.52	0.79	0.74%	0.21%
	Poland	247,693	6.66	0.45	0.36%	0.07%
	Slovakia	22,096	4.07	0.25	0.28%	0.07%
1.A.3.c – Railways	EU-27	3,477,164	7.77	0.27	0.43%	0.11%
	Czechia	230,262	21.58	1.15	1.19%	0.19%
	Hungary	119,014	12.34	0.85	0.79%	0.23%
	Poland	309,000	8.31	0.56	0.45%	0.09%
	Slovakia	91,481	16.84	1.02	1.18%	0.31%

Sector Name	Country	Emissions	Emissions per capita	Emissions per GDP (1000 EUR)	% of Transport	% of Total
1.A.3.d – Domestic Navigation	EU-27	17,913,698	40.01	13.65	2.23%	0.57%
	Czechia	9,692	0.91	0.49	0.05%	0.01%
	Hungary	12,790	1.33	0.91	0.08%	0.02%
	Poland	28,901	0.78	0.52	0.04%	0.01%
	Slovakia	5,345	0.98	0.60	0.07%	0.02%
1.A.3.e – Other Transportation	EU-27	5,062,339	11.31	0.39	0.63%	0.16%
	Czechia	22,340	2.09	0.11	0.12%	0.02%
	Hungary	52,260	5.42	0.37	0.35%	0.10%
	Poland	180,347	4.85	0.33	0.26%	0.05%
	Slovakia	16,138	2.97	0.18	0.21%	0.05%
Total net emis-sions (UNFCCC)	EU-27	3,138,341,494	7009.00	239.22		
	Czechia	121,066,043	11344.00	606.96		
	Hungary	52,732,464	5468.00	376.07		
	Poland	344,864,785	9270.00	626.35		
	Slovakia	29,826,471	5491.00	333.19		

Source: Author based on EEA (2025)

The statistical database of the European Energy Agency (EEA) (Table 1) shows that road transport is indeed the most polluting transport sector, accounting for 25.60% of total EU GHG emissions, 95.08% of transport sector emissions and 24.34% of total emissions. Within this, the environmental impact of passenger cars is also prominent: cars are responsible for 56.21% of transport emissions (i.e. more than light trucks, lorries and buses, motorcycles and other road vehicles combined), which is also a significant share of total EU GHG emissions (14.39%). Clearly, the V4 region and the individual countries show similar trends. According to the IEA (2023) report, in 2022 the world's total e-cars will have reduced GHG emissions by 80 Mt, which means that transport and passenger car emissions have a significant environmental potential and justify the EU's intensive policy, regulatory and financing practices to promote and support the uptake of electric cars.

The main environmental benefit of e-cars compared to classic cars is lower GHG emissions, but the issue is complex in terms of their whole life cycle. There are three main approaches used in the literature to determine the life-cycle efficiency of e-cars (Kukreja, 2018):

1. the well-to-wheel efficiency (WTW), which consists of the extraction, processing, transport and conversion of the fuel into energy in the engine;
2. product life cycle (technology) efficiency (cradle-to-grave efficiency, or CTG), which consists of the extraction of raw materials for the vehicle, the manufacture of components, the use of the vehicle and its treatment as waste;
3. complete life cycle efficiency, which is the combination of the previous two.

Albatayneh et al. (2020) investigated the WTW efficiency of e-cars and found that the type of resource from which the electricity is generated is of crucial importance. Based on measurement and manufacturer data, they made the following estimates of efficiency:

Table 2. WTW efficiency of vehicles with different powertrains

Technology	Petrol	Diesel	Natural gas	Electric (source of electricity)				
				coal	natural gas	diesel	PV/wind	HMKE
Efficiency	11–27%	25–37%	12–22%	13–27%	13–31%	12–25%	39–67%	42–72%

Source: Author based on Albatayneh et al. (2020)

Messagie's (2017) research highlights the large variance and inconsistencies in efficiency estimates reported in the literature, which are sensitive to different input data: the composition of the energy mix, differences between manufacturer and real (measured) emissions data, vehicle lifetime (in km), and battery lifetime and technology (charge cycles, discharge depth, energy density). The energy mix is also a key factor according to Messagie (2017), but it also draws attention to the mode of use: in urban and suburban transport, the emissions advantage of electric and plug-in hybrid cars is considerable, while for use on the motorway this advantage is significantly smaller. Taking the EU energy mix in 2015 as a reference, an e-car emits on average 55% less GHG than a diesel car, which is of course even better in countries with below EU average GHG emissions per capita (Sweden, Romania, Hungary, Slovakia) and worse in countries with above average emissions (Iceland, Luxembourg, Czech Republic, Poland). Messagie (2017) also highlights the negative impact of toxic substances potentially hazardous to humans, which is higher for two battery technologies (LFP and NCM)[5] and lower or negligible for the others.

Product Life Cycle Efficiency (CTG) was investigated in a study by Kukreja (2018) using conventional and e-cars of the same category in the Vancouver municipal car fleet. Although e-car production is significantly (one and a half times) more environmentally damaging in terms of raw material extraction and somewhat more

5 LFP (Lithium Iron Phosphate) and NCM (Lithium Nickel Cobalt Manganese) are two relatively common battery technologies.

environmentally damaging in some other steps, the 150th study (2018) found that the production of e-cars is more environmentally damaging than the production of conventional cars. The results are confirmed by another similar study (Poovana – Davis, 2018), which came to even more convincing conclusions: e-cars can achieve GHG emissions up to 2/3 lower over their lifetime.

Based on his research on whole life cycle efficiency, Bieker (2021) highlights that the ambitious Paris and EU climate targets can only be met by electric and hydrogen-cell cars, but even with the current energy mix, and of course with the expansion of renewables, e-cars can do even better. In terms of whole life cycle efficiency, e-cars are significantly better than gasoline cars in the European and US energy mix, with GHG emissions 66-69% lower than gasoline cars, but hydrogen cell cars are also 26-40% better (Bieker, 2021).[6] The uptake of all-electric cars and plug-in hybrids in Europe is a step in the right direction, with the former increasing from 2% to 6% and the latter from 1% to 5% of the EU population in 2019-2020 (Mock et al, However, passenger cars powered by internal combustion engines will have to be phased out in any case, as Bieker (2021) concludes that neither biofuels nor e-fuels (e-diesel, synthetic diesel, synthetic petrol) will meet climate targets.

The extent to which the deployment of each technology could reduce GHG emissions compared to internal combustion engines is shown in Table 3.

Table 3. Environmental benefits of each technology compared to conventional cars based on whole life cycle efficiency

Powertrain	Emission reduction compared to internal combustion engines		
	Current EU energy mix	2030 EU energy mix	Fully renewable energy
fully electric	63-69%	71-77%	78-81%
hidrogen cell	21-26%	–	76-79%
plug-in hybrid	25-31%	34-40%	–
hybrid	20%	–	–
gas	11-19%	11-19%	–
biofuel	-2%	0%	–
e-fuel	–	2%	–

Source: Author based on Bieker (2021)

6 Hydrogen for hydrogen cell vehicles is currently produced from natural gas (methane) and therefore has less environmental benefit than electric cars.

The literature therefore suggests that the efficiency of e-cars – by any dimension (WTW, CTG or total) – is significantly higher than that of conventional cars. Their efficiency can be further improved by further penetration of renewable resources, development of new battery technologies, production of lighter vehicles and better waste management (e.g., better harmonisation of EU directives on vehicle and battery waste) (Messagie, 2017).

Beyond the environmental and technological aspects, electric cars also have wider economic dimensions. The availability and share of renewable resources in the energy mix has a significant impact on the price of electricity, and therefore there is a wide variation in the mix and electricity prices across European countries. Norway is well placed to use renewable resources and is therefore a leader in e-car penetration (Figenbaum et al., 2015). The study by Figenbaum et al. (2015) identifies four important steps that could help increase the share of electric cars in other countries: supportive climate policies, economic subsidies and incentives (e.g., VAT waivers for e-cars) to increase competitiveness, increasing the share of renewable resources, effective communication and information. In the latter case, the authors (Figenbaum et al., 2015), citing several other local studies, find that in Norway it is typically young, highly educated, high-income consumers and opinion leaders from an academic community who have/can have a strong influence on other consumers in the uptake of new technologies.

Geronikolos and Potoglou (2021) review the most commonly used economic incentives in Europe, e.g.: direct car purchase subsidies (varying from €1000 to €9000 in each country), registration tax reductions, VAT reductions, customs duty reductions, car tax waivers. Interviews with stakeholders and experts in Greece highlighted by the authors suggest that, in addition to economic incentives, it would be important to assess the needs of potential customer groups, tailor subsidies, improve the charging network, increase coverage and adopt new business models that have been successfully applied in other countries (Geronikolos – Potoglou, 2021).

The importance of state involvement and subsidies is also highlighted by Joller and Varblane (2016), but they also suggest a thorough economic and political preparation for the future phasing out of subsidies. Eco-innovation programmes to promote the uptake of e-cars need to be implemented in a systematic way to avoid being stalled by the contradictions of different political regimes, and new business models – such as promoting or rethinking the rental contract – may also be worth considering to make the new technology accessible to a wider range of consumers (Joller – Varblane, 2016).

Looking at the potential of e-mobility from a broader automotive perspective, Auvinen et al. (2016) highlighted in their study that, in addition to ongoing green policy measures ($_{CO2}$ emission restrictions, tightening of conventional car traffic) and the development of charging infrastructure, the competitiveness of e-cars can be enhanced through strategic alliances of industry players. Without these, and according to scenarios based on previous EU policies (circa 2009), even if the share of e-cars increases to 5% in 2027 and 8% in 2030, e-car penetration will not be able to exceed a marginal level and climate targets will not be met.

Charging electric cars is a high-profile issue both among consumers and in the literature. Straka and Buzna (2019) conducted a statistical analysis based on four years of data collection at more than 1,700 charging stations in the Netherlands, with the aim of forming typical consumer groups (clusters) along charging habits and times. The results of the analysis are summarised below (Straka – Buzna, 2019):

- Cluster 1 (21% of the observations) of consumers charging at work: medium charging/connection rate, low number of charging units, early start and late end times;
- Cluster 2 (16.5%) is charging in shopping centres: medium charging/connection rate, high number of charging units, midday start and (late) afternoon end of charging;
- Cluster 3 (23.5%) covers residential night charging: low charging/connection rate, low number of charging units, late charging start and (late) morning charging end;
- Cluster 4 (39%) users of other charging stations: short charging, charging start around noon and end in the afternoon, high charging/connection rate, low number of charging units.

The results show that more than half of e-charging does not take place at the more confined night-time or workplace charging points, which, especially with the proliferation of e-cars, may create problems in terms of predictability and stability of energy supply. Fernández's (2021) research in Spain has led to the conclusion that the electricity grid must be upgraded to meet the additional demand from e-mobility. The adaptation of e-mobility can be accelerated by manufacturers (with larger battery cars, competitive pricing), the state (subsidies, installation of fast chargers) and external actors (technological development, increasing production intensity), but the most appropriate solution in terms of load distribution on the grid is charging at the workplace, which eliminates the need for fast charging and thus does not place an increased burden on the grid (Fernández, 2021).

Differentiated electricity pricing also offers the possibility of better regulation of e-charging, according to a study by Wangsness et al. (2021). Wangsness et al. (2021) found that under separate peak and off-peak pricing, both the BAU and the enhanced CO_2 reduction scenarios result in approximately 33-37% lower aggregate welfare costs than under uniform pricing. It should be noted that differential pricing can also work with high reliability and transparency in Norway (the target country of the research) because since 2019 it is mandatory for all households to be equipped with a smart meter (Wangsness et al., 2021).

The charging of e-cars is also a much-researched topic from a technological point of view, as it has a significant impact on battery life and thus on the life cycle efficiency of e-cars. It is well known among e-car users that high-current (fast or rapid) charging accelerates battery ageing (Gou et al., 2021). In their article, Keil and Jossen

(2015) explain that in practice, the more extensive use of regenerative (energy-recharging) braking helps to keep battery degradation as low as possible (on average about 10% per 100,000 km), while long charging times are the most damaging for the battery. From a technological point of view, therefore, long charging at work or at home at night is not optimal, and the right driving style, i.e. consumer behaviour, is also important.

Several researchers agree (e.g., Holden et al., 2020; Fernández, 2021) that our current driving habits and driving style are not sustainable or not well compatible with certain features of e-cars. According to Holden et al. (2020), sustainable mobility includes an increasing supply of e-cars, public subsidies, increasing consumer awareness, recognition of the convenience of e-cars, further improvements in e-car efficiency, and adaptation to specific e-car driving needs (safety, range, charging) (Holden et al, The development of electromobility alone is therefore not sufficient to achieve sustainable transport, which requires other factors as well as the development of public transport and the reduction of vehicle traffic in cities (Holden et al., 2020).

In their research, Higueras-Castillo and colleagues (2019) investigated which factors are more likely to motivate Spanish consumers to adopt (attitude) and purchase (action) e-cars. The results of the research show that the greatest influence is trust in e-car ownership and technology, followed by the level of subsidies, with environmental awareness contributing to a much lesser extent and lack of knowledge negatively influencing attitudes. These results, with the exception of environmental awareness,[7] are in line with Haugneland's (2012) findings on the main arguments in favour of e-car ownership according to owners:

- Environmental considerations (38%);
- Economic considerations (29%);
- practical considerations[8] (28%);
- other reasons (5%).

Appropriate communication, increasing consumer awareness and the extent to which consumers feel empowered to achieve environmental sustainability can be important tools to increase the popularity of e-mobility (see Figenbaum et al., 2015; Higueras-Castillo et al., 2019).

Active e-car users also have the opportunity to use their vehicle more efficiently or in a more environmentally friendly way, which can be mainly reflected in the choice of the right route and charging habits. In their research, Kacperski and Kutzner (2020) highlighted that not only financial incentives (differential pricing), as described earlier, but also symbolic incentives (e.g., gaming applications, awareness of the environmental impact of consumption, visualisation of energy savings,

7 It should be noted that trust in green technology can also be interpreted as a form of environmental awareness.

8 E.g., free parking, bus lane passes, other e-car discounts.

normative information, emotional tools) can help consumers to charge their e-cars at the optimal time for the electricity system or to choose a better route.

As far as the V4 countries are concerned, a lot of overlap can be seen in the challenges related to the electrification of passenger cars.

The Czech society is sceptic about the shift to electromobility. According to Jaderná & Přikrylová's (2023) study, a European survey indicated that 50% of Czechs prefer fuel engines, and rather businesses are interested in electric vehicles to enhance their sustainability image. A majority (60%) of respondents would consider purchasing an electric vehicle only if it had a reasonable price, while 24% prefer fuel engine vehicles, and only 16% would consider an electric vehicle even at a higher price than regular cars. MHEVs (mild hybrids) are viewed as the most appealing option, whereas BEVs rank lowest in attractiveness. Nevertheless, younger generations show a greater inclination towards purchasing EVs compared to older generations (Jaderná & Přikrylová, 2023).

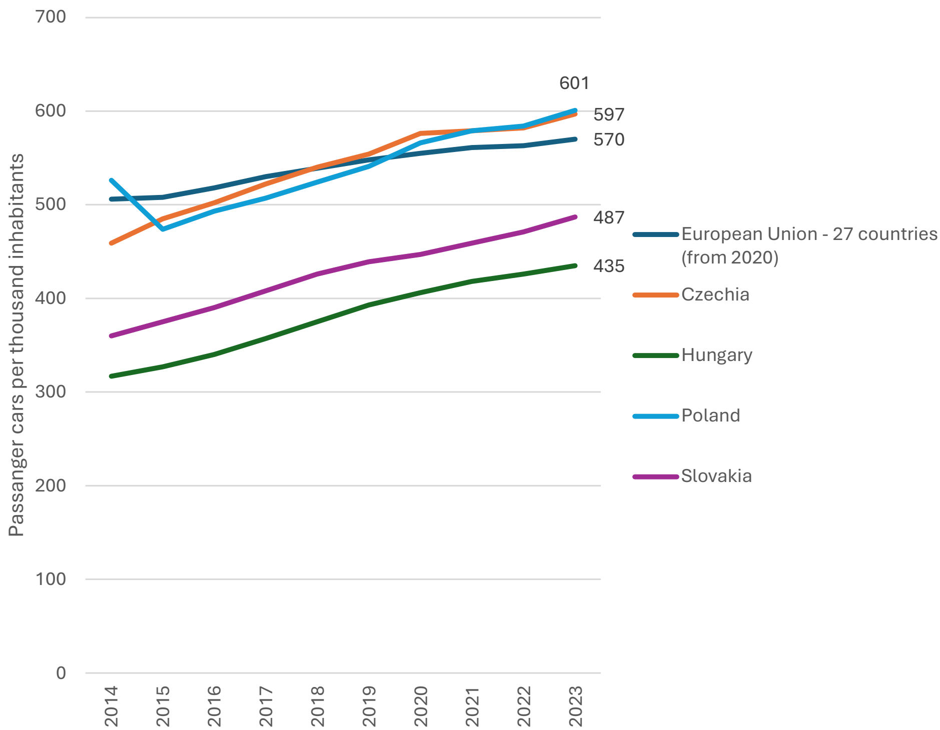
In Poland, the reliance on non-renewable energy sources in electricity generation is a notable constraint for electromobility, too (Łuszczyk et al., 2021). The dominance of fossil fuels and rigorous climate policies have led to a significant rise in electricity costs. Consequently, the competitiveness of eco-friendly transportation is diminishing (Sulich, 2021). The effective realization of a pro-greening program necessitates extensive and costly measures for green energy transition and the establishment of incentives for electric vehicle purchasers. Statistical analyses indicate that infrastructure development is essential for electromobility (Łuszczyk et al., 2021). Łuszczyk and colleagues (2021) emphasize the importance of enhancing charging infrastructure and increasing renewable energy contributions to the energy mix. In nations with average per capita income, including Poland, the focus should be on subsidizing electric vehicle purchases (Łuszczyk et al., 2021), because profitability is a critical factor influencing electric car purchasing decisions in Poland and countries with similar economic status like the V4 countries.

In a Slovakian research, respondents prioritized possible fuel cost reductions over the reduction of greenhouse gas emissions (Zábojník et al., 2022). However, the most discerning consumers regarding electric vehicles consist of younger, educated, and environmentally conscious individuals who primarily engage in urban travel and charge their vehicles at home (Hackbarth – Madlener, 2013). The adoption of electromobility in the Slovak Republic is strengthened by four fundamental conceptual documents, outlining the present and future restructuring of the vehicle fleet with specific objectives: (1) Action Plan for the Development of Electromobility in the Slovak Republic (2019), (2) Strategy for the Development of Electromobility in the Slovak Republic and its Impact on the National Economy of the Slovak Republic (2015) and related transposition documents, (3) National Policy for Deploying Infrastructure for Alternative Fuels in the Slovak Republic (2016), and (4) National Policy Framework for the Development of the Alternative Fuel Market (2016). This means Slovakia is committed to accelerate the transition of passenger transportation using a top-down approach, even though the share of BEVs and PHEVs is still below EU average (see Table 4).

2. Analysis of secondary data, with a focus on Hungary

According to the Eurostat time series, the motorisation rate of the population in both European and V4 countries has been steadily increasing over the last 10 years, although the average for the Visegrad countries (53%) is slightly lower than the EU average (57%). Hungary has the lowest motorisation rate of all the countries surveyed (43.5%).

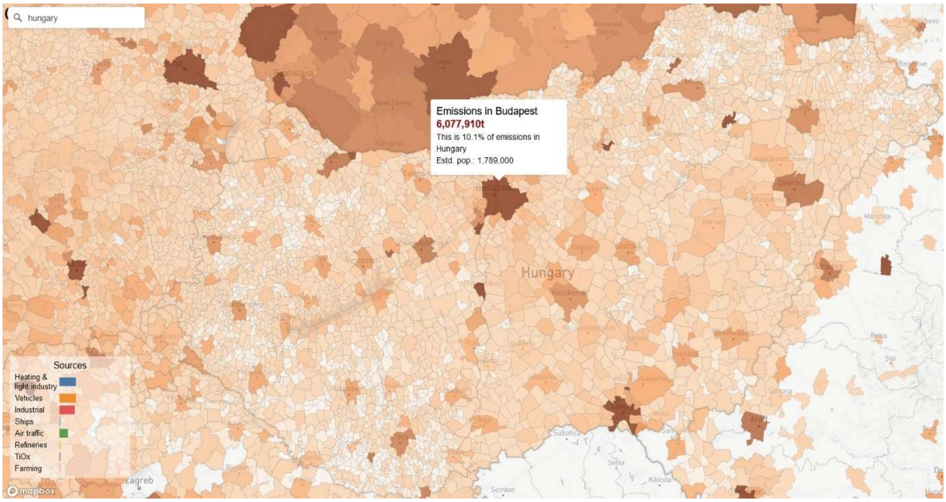
Figure 2. Motorization rate in the EU27 and the V4 countries



Source: Author based on Eurostat (2025)

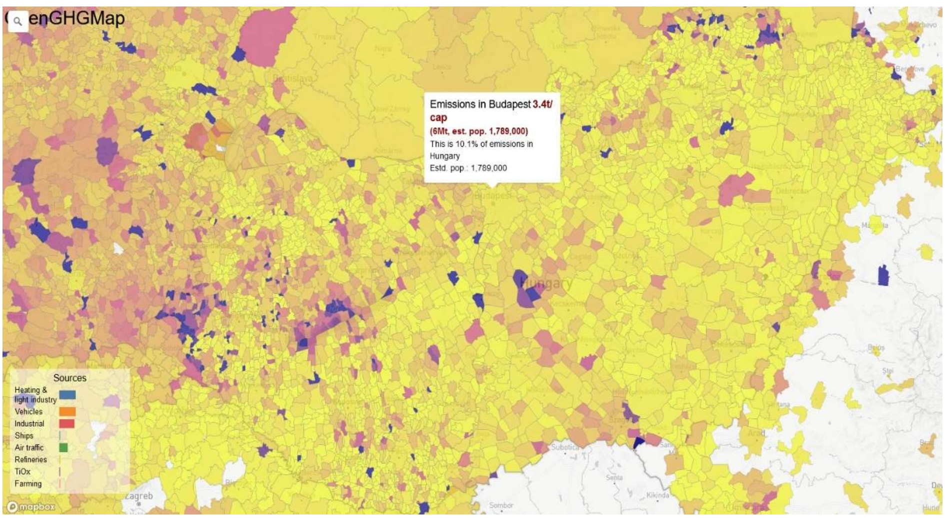
17.36% of cars are registered in the Hungarian capital, Budapest, and almost as many in Pest County, so one third (32.46%) of passenger cars are concentrated in the capital region (KSH, Information Database).This contributes significantly to the fact that 10% of carbon dioxide emissions are also attributable to the capital, although it is not the most polluting area in the country in terms of per capita emissions (see Figures 3 and 4).

Figure 3. CO_2 emissions in Hungary, 2018



Source: OpenGHGMap (2025)

Figure 4. CO_2 emissions per capita in Hungary, 2018



Source: OpenGHGMap (2025)

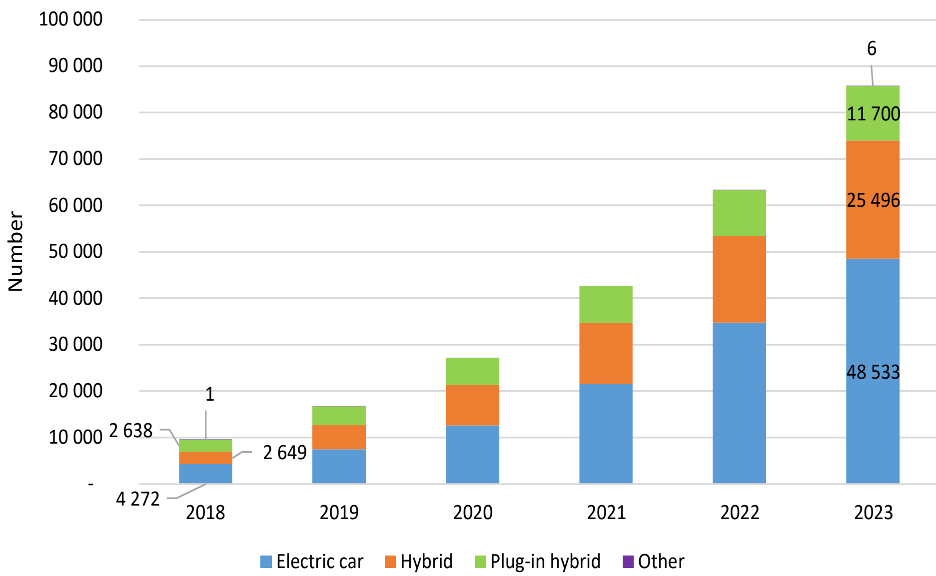
However, the Hungarian vehicle fleet is gradually ageing: while the average age of the 3 million vehicles in 2008 was only 10.4 years, the average age of the 4 million vehicles in 2022 will be 15.4 years (KSH, Information database, 2025).

The Ministry of the Interior keeps a detailed inventory of the electric car fleet in Hungary along the following categories (Magyar Közlöny, 2015):

- pure electric vehicles (5E),
- externally charged hybrid electric car (plug-in hybrid with an electric range of at least 25 km) (5P),
- extended range hybrid electric vehicle (plug-in electric vehicle with an electric range of at least 50 km) (5N),
- zero emission vehicle (other, non-electric) (5Z).

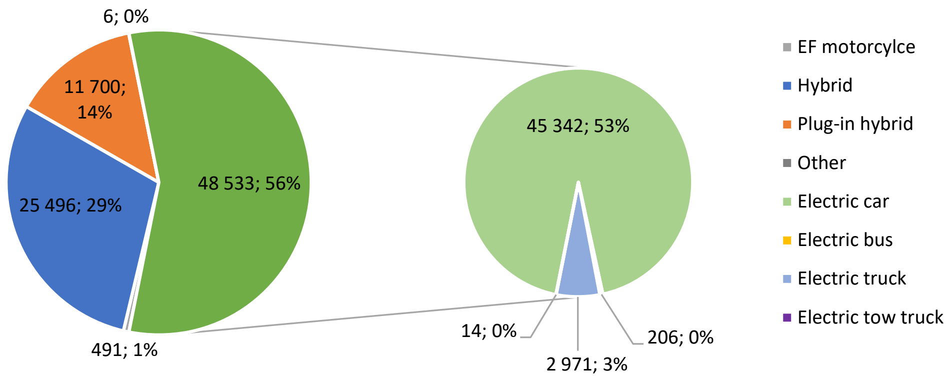
In Hungary, low emission vehicles are marked with a green number plate. According to the Ministry of the Interior (Monitoring data, 2024), 1609 vehicles had received green plates by the end of 2016 and 4434 by the end of 2017. However, the spread of e-cars has not stopped: compared to an average increase of 5-600 cars per month in 2018-19, the number of e-cars has been well over 1000 cars per month in recent years. More than 56% of vehicles with green plates by 31 December 2023 were pure electric, the extended range category (5N) has stagnated at around 30% and the share of plug-in hybrids (5P) has shrunk significantly (from 24% to 14%) (Department of the Interior, Green plate applications data, 2024). The trend and distribution of the number of cars with green plates are illustrated in Figures 5 and 6. (Note: the discrepancy between the data reported above and the aggregate data in the figures is explained by the "Other/Error Items" reported in the original database.)

Figure 5. Growth of alternative fuelled vehicles in Hungary between 2018-2023



Source: Author based on Ministry of Internal Affairs (2024) data

Figure 6. Distribution of alternative fuelled vehicles in Hungary [units; %]



Source: Source: Author based on Ministry of Internal Affairs (2024) data

Although the number of hybrid and e-cars has been growing dynamically in the V4 countries, including Hungary, in recent years, they still do not represent a significant share of the total car fleet, which is significantly inflated by the used car market. The share of low-emission passenger cars is not at the EU average level in any of the V4 countries (see Table 4).

Table 4. Share of fuel types in alternative fuels

Alternative fuel types	Czechia	Hungary	Poland	Slovakia	EU27
BEV	17,31%	56,46%	1,91%	13,61%	30,28%
PHEV	10,88%	21,52%	1,67%	11,18%	20,76%
H2	0,01%	0,00%	0,00%	0,00%	0,02%
LPG	57,41%	19,15%	96,24%	69,68%	42,01%
CNG	14,39%	2,87%	0,17%	5,52%	6,92%
Share of alternatives in total passenger cars	2,46%	1,95%	12,47%	2,41%	7,97%
Share of BEVs in total passenger cars	0,43%	1,10%	0,24%	0,33%	2,41%

Source: European Alternative Fuels Observatory (2025)

It is also worth mentioning the charging network, as both literature research and consumer surveys show that charging infrastructure is key. Although there is considerable variation in the distribution of charging points across countries, with the majority generally located in larger cities and along busier roads, on a per area basis the Czech Republic has the highest number of charging points (72 per thousand km^2) and Poland the lowest (29 per thousand km^2) among the V4, but none of the countries is close to the EU average (205 per thousand km^2).

Table 5. Number of EV charging stations, 2024

Charging stations	AC	DC	Total	Stations/1000 km²
Czechia	3964	1682	5646	72
Hungary	3167	848	4015	43
Poland	6481	2918	9399	29
Slovakia	2040	889	2929	60
EU27	696,082	125,691	821,773	205

Source: European Alternative Fuels Observatory (2025)

3. Results of the consumer attitudes questionnaire

We conducted a market survey to identify the factors that help and hinder the uptake of electric cars in Hungary, with data collected in 2022. The Russian-Ukrainian war and its aftermath – apart from a short period of extreme fuel price increases and then a correction – did not significantly affect the Hungarian market for cars and e-cars, as confirmed in the previous chapter, so the consumer attitudes survey can be considered time-tested and no new survey has been conducted on this topic since the end of our data collection.

Representativeness was not a criterion in the design of the random sample of 620 respondents, as we sought consumers who were open to answering these questions and who were expected to provide relevant responses. The sample was selected from those who met the following criteria: residents of the capital (Budapest) and county towns (85% of the sample) or their surrounding areas, who have a relatively high income, drive a car and consider vehicle emissions to be a problem (87% of the sample, of which 29% identified vehicle emissions as a significant problem).

The sample was 60-40% male to female. More than two thirds of respondents were aged 45 and over. (The under-30 age group – otherwise very open and receptive to innovative and environmentally friendly technologies – is not included due to their very limited financial means.) Almost half of respondents have a tertiary education. In terms of employment, 88% of respondents are active earners, of whom 68% are employed and 85% of respondents have an income perception of "living on their income but with little to save".

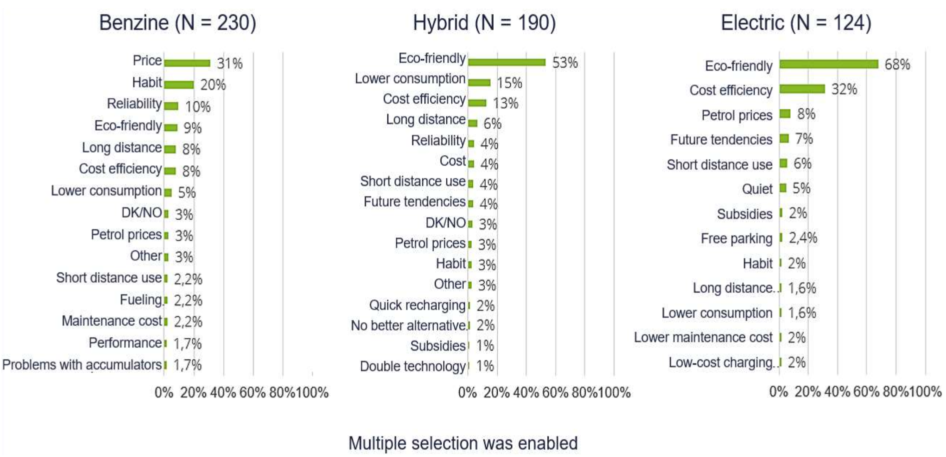
91% of the households in the sample have 1 or 2 cars, but the proportion is slightly higher for self-employed people by occupation (1.9 cars compared to an average of 1.6 for other occupations). Cars are predominantly conventional, with 78% of respondents owning a petrol car and 41% a diesel car. In order of prevalence, these types were followed by hybrid (3%) and electric (1%), while none of the respondents had a plug-in hybrid.

Around two thirds of the sample of 620 respondents are not against buying or renting a new car in the next few years, but buying is much more popular (91%, including 64% used cars), leasing and renting for at least 1 year less so. A higher proportion of those with tertiary education and entrepreneurs plan to buy a car.

In terms of the mode of car to buy, petrol cars are the most popular in the total sample and among the confident car buyers (37% and 42% respectively), with hybrid cars second (31% and 26%). However, the share of those preferring electric cars in the total population is also relatively high at 20%, a technology that is mostly popular among women and university graduates (in line with the results of Vereckei-Poór – Törőcsik, 2022), but more so in the longer term.

Among the respondents, the relatively lower price, familiarity and reliability are arguments in favour of petrol cars when choosing the next car, while sustainability and cost-effectiveness are arguments in favour of environmentally friendly technologies (hybrid and electric) (Figure 7).

Figure 7. Criteria for choosing next car

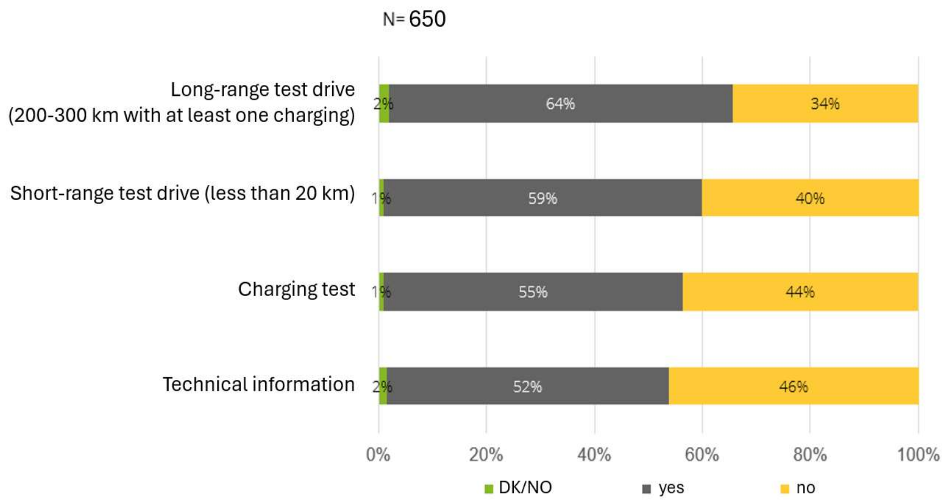


Source: Author

More than half of respondents (54%) think they will definitely or probably buy an electric car in the future, mainly women, people under 55, people with higher education, people living in larger cities and entrepreneurs. The most frequently cited arguments in favour of e-cars are that they are environmentally friendly (74%), cheap to run (32%) and quiet (22%). The most common arguments against buying an electric car are that the range is too short (46%), the price is too high (37%), the charging infrastructure is inadequate (35%) and the battery is polluting (17%). The survey confirmed that a significant level of subsidy (around 42%) would increase the pool of potential buyers by nearly 30%, a level not reached in practice by any of the previous tenders, and the intensity of the company e-car subsidy announced in early 2024 is at most 25%.

28% of those surveyed have driven an electric car, almost twice as many men (34%) as women, but three quarters have not yet charged (and of those who have, only a third have tried paid public charging). This suggests that they have only ever driven an electric car for car-sharing, or perhaps for a test drive or trial, and that their experience is not complete. 64% of the total sample said that they would also try an e-car on a long test drive that included at least one charging session, which would broaden the audience (Figure 8).

Figure 8. Preferences for learning about e-cars



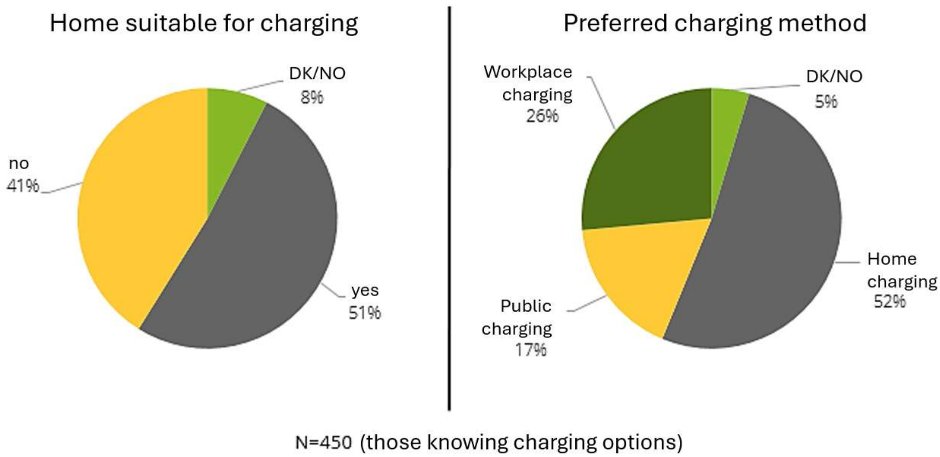
Source: Author

Advantageously for the uptake of e-cars, 72% of those with experience of e-cars had rather positive or even very positive impressions: quiet operation (61%), good acceleration (41%), ease of use (26%) and comfort (15%) were the most frequently mentioned, but more people also mentioned dynamic driving experience, cheap operation and environmental aspects.

The possibility of using an e-car for private purposes provided by the employer is also very popular, with 83% of non-employers respondents saying they would use it. However, far fewer would pay a rental fee, at 46% of employees open to this option.

Regarding charging, nearly three quarters of respondents (73%) said they were aware of the charging options for e-cars. However, our survey also strongly suggests that respondents overestimate the true breadth and depth of their charging knowledge. Half of those who are aware of charging options believe that their home is suitable for home charging, and in line with this, 52% would prefer this charging method, followed in popularity by charging at work (26%) and in public (17%) (Figure 9).

Figure 9. Home charging and the preferred charging method



Source: Author

4. The focus group interview

Of those interviewed for the questionnaire research, 8 people were able to participate in the focus groups, and additional groups were organised with additional participants on a random sample basis. The analysis below summarises the results of 4 focus groups with a total of 20 participants, mainly from the capital and large rural cities, mostly with higher education, family backgrounds and middle-aged participants. Most of them had no experience with electric cars.

The transport habits of the focus group participants follow the pattern of the previous (questionnaire) survey: 1-3 cars are available in the household, used daily or weekly for commuting to work and errands, depending on the proportion of work at home, typically for a daily distance of up to 20 km. On weekends, they occasionally travel 30-40 or even 150-160 km. The car is by far the most important means of daily transport for respondents in Budapest and urban areas with county status, public transport is not common (for reasons of practicality and convenience), while walking and cycling are more common in smaller rural settlements.

Car use was associated with established habits, so although there was some openness towards e-cars, most expect further innovation and development in e-car use and are at most thinking about replacing traditional vehicles in the long term. More people would be willing to replace (at least partially) private car use by alternative means of transport (bicycles, e-scooters, e-bikes, scooters, car-sharing services), but slowness, more cumbersome handling, dangerous traffic in larger cities, inadequate road infrastructure and, in particular, weather dependency are important barriers.

The majority of participants agreed with the environmental benefits of e-cars in urban transport but were sceptical about the lifetime environmental benefits. They are aware of the accelerating uptake of e-cars, but a majority of respondents are also sceptical about this, for two main reasons: (1) charging a large number of e-cars at the same time would be problematic, and (2) the current price of e-cars is significantly higher than that of classic cars with similar characteristics. Some of the participants could see it more as a second car, mainly for urban use.

Based on the discussion, the most important car purchase criteria are the planned budget, value for money, appropriate (sufficiently large) size, maintenance costs (consumption, servicing) and reliability. The relatively high price discourages even interested respondents from buying an e-car, and leads many respondents to the used car market, where the supply of electric cars is still significantly lower and interested respondents would prefer to keep their old (classic) car for longer journeys. Conversely, respondents who have tried or are actively using an electric car will tend to buy an electric car for their next purchase.

Reducing the purchase price of e-cars as a priority, together with preferential loans and subsidies or a combination of these, would be the most likely to boost sales. Several participants considered it important that the subsidies should not be reflected in the repayment instalments but in the purchase price itself (clarity), and that they should be available to the widest possible social group, without being "visible" beneficiaries (e.g., taxi companies). Support for purchase is also an important aspect, as participants felt that car ownership is the main driver of car ownership in Hungary, with no culture of renting.

Ease and accessibility of charging was the second most important dimension. Consumers would be more open to e-cars if fast (faster) charging could be provided and if electricity could be accessed at relatively good prices. The technical need to increase the performance and lifetime of batteries was also raised, but it was acknowledged that there is a lack of information on charging technologies and costs (even compared to conventional cars). Some mentioned that a complete replacement of the battery pack could speed up the use of e-cars, but this is not yet widespread and a range of at least 1000 km would be desirable.

Other barriers mentioned by several participants were the lack of a service network for electric cars (despite the fact that they were aware that e-cars also require less servicing) and a narrower product range. The possibility to test drive an e-car is generally considered a motivating factor only once one has made a commitment to buy an e-car. As regards the environmental message, some respondents explained that, in addition to industrial pollution, the electrification of car transport – and thus the individual – can do little to slow down climate change, but that sufficiently broad communication (on environmental benefits, battery use and recycling, etc.) can go a long way to ensuring that e-cars are accepted as green by consumers in a truly visible and "credible" way.

5. Comparative analysis and evaluation of results

The following section compares research results from different sources (literature, questionnaire survey, focus group interview). The comparative analysis avoids repeating the results. It will highlight similarities and differences and identify key areas that could determine the further development and uptake of e-cars.

In many respects, the direction of influence on the advantages and disadvantages of electric cars is similar across the different data sources. Not all aspects have been explored in the same depth in each research step, and it is worth bearing in mind that the results have been generated from different methodologies and with different geographical focus.

A summary of the research results is presented in Table 6.

Points of convergence

The different research sources led to the same or similar results in several aspects. For example, within the economic category, both the literature and the questionnaire and focus group interviews identified the relatively high price as a major disadvantage of e-cars. This disadvantage was identified as a particularly big problem by Hungarian respondents in the domestic survey and also in the literature for the V4 countries, while it is less pronounced in higher income countries.

The second, economic type factor is the importance of subsidies, which is also linked to the price issue. As e-cars are sold on the world market at a higher price (due to higher costs) irrespective of the region under study, the local (domestic) market price can be reduced by public intervention, which encourages purchases. Both the literature review and the questionnaire survey have shown that the wider the scope and the higher the rate/volume of support, the higher the propensity to buy e-cars.

In all the technological type aspects, we found that e-cars are at a disadvantage compared to classic cars: their range is shorter, charging times are longer and charging networks have less coverage. However, two points should be noted from the literature: firstly, charging times are not necessarily (much) longer, as some rapid chargers can charge a discharged battery to 80% in 20-30 minutes, and secondly, the coverage (density) of the charging network varies (i.e. is not evenly distributed) from region to region and even within countries, so this statement cannot be generalised in full.

Table 6. Summary of the results of the research on electric cars

Aspect (relative)	Literature	Questionnaire	Focus group
Economic			
Total life cycle cost	+	n.d.	?/–
Price	–	– –	– –
Importance of support	+	+	+
Cost-effective maintenance	?	++	?
Price of fuel	n.d.	+	n.d.
Technological			
Range	–	– –	–
Time of charging	?	–	–
Charger infrastructure	?	– –	–
Environmental			
Environmental friendly	+	++/?	?
GHG emissions	++	+	+
Noise emissions	++/–	+	n.d.
Other			
Habits	n.d.	– –	–
Short range vehicle	n.d.	+	n.d.

+ e-cars are better than conventional cars
– e-cars are worser than conventional cars
? the advantage of e-cars over conventional cars is not clear
n.d. no data

Source: Author based on the literature and results

The findings from different sources were consistent with the favourable (zero or near-zero) emissions of electric cars. 87% of the respondents to the questionnaire consider emissions from cars to be a relatively or very big problem, but few are likely to know in absolute terms or even in terms of ratios how much emission reduction could be achieved by electrification of cars. Therefore, this advantage was less emphasised than in the literature, which draws conclusions by looking at precise figures.

Finally, from a social point of view, it is important to mention the role of habits and practices. The literature we have reviewed did not address this issue, but both the focus group and the questionnaire highlighted as an argument for using and buying conventional cars that their accessibility, use, refuelling and other features are familiar and convenient, which gives them an advantage over e-cars. In our view, this opinion is a general phenomenon and stems from a lack of confidence (insecurity) in new technology. However, as with many other new technologies, the younger generation, higher educated and higher income groups are the social groups that are more open to e-car use in all V4 countries and of course in the Western countries.

Points of divergence

The life cycle efficiency of electric cars is reported in the literature to be significantly higher than that of classic cars. However, lay users have expressed doubts as to whether they are really more efficient when taking into account electricity generation, battery raw material extraction or end-of-life recycling. As a result of this lack of information, there was also a perception in the focus groups that e-cars produce even more emissions over their entire life cycle than conventional cars. This discrepancy and lack of knowledge could be reduced with proper information and awareness.

There was a lack of consistency between economic type factors in terms of maintenance costs. While respondents to the questionnaire rated the relative cheapness of running an e-car as a strong positive, participants in the focus groups gave a more nuanced picture of the service costs, battery degradation, and the continuous reduction or withdrawal of e-car discounts. The importance of subsidies and discounts has been highlighted in the literature and is therefore currently perceived as an advantage for e-cars, but in the longer term it is likely that the benefits will diminish as significantly more e-cars are introduced.

The cost of fuel was also identified as a separate factor in the questionnaire, where the advantage of electric cars is clear. Specifically, this dimension was not discussed during the focus group interviews, nor was a literature analysis carried out. Based on recent trends (see energy price explosion in Western Europe), it is clear that the cost of refuelling e-cars can be as volatile as the price of petrol, and therefore the future energy mix, energy independence and pricing of electricity will be of great importance.

In the environmental category, we observed two contrasting results. The first, which is also related to total life cycle costs, is that while some of the literature and consumers who filled in the questionnaire clearly consider electric cars to be more environmentally friendly than conventional cars, others, as well as many of the focus group participants, question the advantage of e-cars in terms of overall environmental impact. Lay participants are most sceptical about the production and treatment of batteries as waste. It is worth noting that few have precise information on the secondary and recycling potential of batteries, but expert participants also agree that the environmental benefits of e-cars may become clearer as battery technology continues to develop significantly.

Not mentioned by the focus group participants, but consistently mentioned in the questionnaire and in the literature, the benefits of e-cars include low noise pollution. However, silent operation can also be a disadvantage: a small proportion of (Hungarian) consumers considered the “silence” of e-cars as a disadvantage, partly for safety reasons and partly out of habit. Although media bias[9] and a lack of accurate knowledge about noise pollution may play a role, there are also findings in the literature that mention this type of safety risk. E-cars can be heard at a distance of only about 5 metres when driving at low speeds, while internal-combustion cars can be heard from up to 50 metres, which may explain why the rate of hit-and-run accidents involving electric cars in the US is higher (0.9%) than that of conventional cars (0.6%) (Misdariis – Pardo, 2017).

6. Conclusions

From the literature review and the analysis of the statistics, it can be concluded that electric cars are indeed technologically and environmentally superior to conventional cars when considering their whole life cycle efficiency. In addition, other external factors can also enhance the environmental benefits of e-cars, the most important of which is the energy mix from which electricity is produced. Using the estimations from the literature (Bieker, 2021), a GHG reduction by 66% has already caused roughly 59,000 tons of GHG emission savings in the Czech Republic, 134,000 tons in Hungary, 115,000 tons in Poland, and 17,900 tons in Slovakia per year, while a full electrification of passenger cars would further decrease the yearly GHG emissions by nearly 40 M tons of CO_2 equivalent in the V4 countries.

From an economic point of view, there are a number of challenges to the rapid uptake of electric cars in the V4 region. The most important is the relatively high price of e-cars, which is holding back sales even in higher-income countries, despite significant government subsidies and economic incentives. Other important considerations are the charging time and the availability of charging networks, which are both a technological issue and may require users to reorganise daily activities or routes, which may entail additional costs. In addition, the energy mix and the external energy dependency of the country or the consumer can have a significant impact on the charging tariff through the price of electricity, which can also be generalised to the V4 countries.

The results of the Hungarian consumer survey were in many respects consistent with the secondary data. The environmental benefits of e-cars and the economics of operation are recognised by consumers, but the high price and time needed for

9 The small number or isolated cases presented in the media may also appear to be widely accepted as a general phenomenon in the eyes of consumers.

charging are seen as a serious barrier. Most people still plan to buy a conventionally powered car, including mainly second-hand vehicles, but feedback suggests that the share of hybrid and fully electric cars in the transport sector will increase. If the high-cost price could be substantially reduced through significant public support, this would be a major boost to consumer openness to electric cars.

Electric cars have only been on the market for a relatively short time and there is still a considerable lack of knowledge or a lot of misinformation among consumers about e-cars. However, climate change and increasingly obvious environmental problems call for more sustainable technologies, both from a regulatory and strategic perspective and from a societal perspective. Governments are also motivating the market and consumers to use newer, more efficient devices through subsidies and regulations, but through responsible behaviour and environmental sensitivity, business and consumers themselves are increasingly willing to do more to promote sustainable development. The technological development of electric cars will not stop, and as competition increases and the market becomes saturated (including with second-hand e-cars), e-car use will become more economical and affordable for consumers. This also requires the development of charging networks and the adaptation of driving habits (culture). The electrification of passenger cars can achieve significant GHG savings and thus play an important role in the climate mitigation of the V4 countries.

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